NAVIGATION IN SPACE, TIME AND TOPIC

Interdependencies of Spatial, Temporal and Thematic Navigation in 2D Interactive Maps

By Example of a European Map of Cultural Heritage

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Abstract

As GISystems become more mature and spatial research questions more complex, time is regarded as a crucial component to GIS data models. Cartographic visualization can be one useful method of presenting dynamic spatial data and visualizing changes over time, hence assisting the study of spatio-temporal patterns and phenomena. The rise of interactive mapping applications, together with the growing demand to incorporate time in GIS, however, fuel the need for efficient navigation tools in space, time and topic. This paper summarizes the current results of an ongoing PhD work that contributes in the following areas: Study of the effects that changes in one of the dimensions should trigger on the navigation and visualization of the dependent dimensions, compilation of a taxonomy of spatiotemporal and thematic questions, in order to understand how navigation tools can assist in answering these questions and development of a sophisticated user interface for thematic navigation in space and time by creating a prototype of a european map of cultural heritage.

Introduction

Motivation

Already the early GIS pioneers discovered that "theme", "location" and "time" are major cornerstones around which one should design a data model: *»It can be argued that any observation that does not record explicitly or implicitly all three of the above attributes is not useful information. Equally important, a report of information or data which does not specify all of these attributes will be deficient in its information content and therefore should not be part of a geographic information system«* [Sinton1978].

Today, more than 25 years later, time is still not an integral part of GISystems and incorporating time in standard GISoftware, no matter if it concerns data modeling, visualization or navigation, is still a very complicated task. While considerable research dealt with incorporating time in GIS data models and visualization of dynamic data, graphical user interfaces for temporal navigation are still in their infancy. Furthermore, little is known about the relationships between space, time and topic, especially in the context of navigation. New interactive media require sophisticated navigation controls in order to facilitate the study of spatio-temporal patterns in the context of various related topics.

Current State of Research

While time was always an important topic in geography, geography was defined as a "science of space" after the quantitative revolution in the 1960s geography, which considerably influenced the first operational GISystems. Geographers are therefore at least partially responsible for the fact that GIS technology neglected the temporal component for a long time. [Harrower1999] partially explains the primacy of space over time with the close relationship between cartography and geography. *"Perhaps if cartography had allied with history, time would be treated with equal or greater import than space."* Another reason is, that many GIS projects are simply at an earlier stage, where multi-temporal datasets and spatio-temporal analysis is not yet a priority. ([Langran1992], p. 5) distinguishes several stages of GIS capabilities: The first stage includes initial data capturing, none to few analysis and primarily static output. The second stage introduces centralized data management and exchange, simple analysis and static modeling, and first interactive graphics. The third stage, at which most projects have not arrived yet, features incremental updates, multi-state analysis and dynamic modelling with animated and fully interactive maps as output. Finally, and probably the most likely cause for the unubiquitousness of spatio-temporal GIS functions, the limited toolset available for spatio-temporal analysis and modelling severely hinders a broad introduction of spatio-temporal methods within GIS. It is quite obvious that time deserves more attention and needs better solutions than just adding it as an additional conventional attribute to spatial datasets.

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Geographers in the 60s and 70s mainly studied the change of the society over time. Through his studies on innovation waves [Hägerstrand1952] and human migration[Hägerstrand1970], Hägerstrand can be regarded as one of the fathers of time geography. He was one of the first geographers who declared time as an essential component in his spatio-temporal model. As part of this model, he introduced the space-time pathes of individuals where the map was two-dimensional and the third dimension was time. Stationary people are represented as vertical lines, a location is represented as a vertical tube. If people move, their movement is drawn with a sloped line. The slower the movement, the steeper the line will be. Additionally, a space-time prism can indicate the locations that can be reached in a particular time interval, which obviously depends on the maximum travel speed the individual can accomplish. In the pre-computer graphics time, it was time consuming and expensive to produce such space-time cube illustrations. However, with the rise of new visualization technology and interactivity, researchers revisited this concept for the visualization of lifelines and movements of individuals ([Kraak2003] and [MooreEtAl2003]).

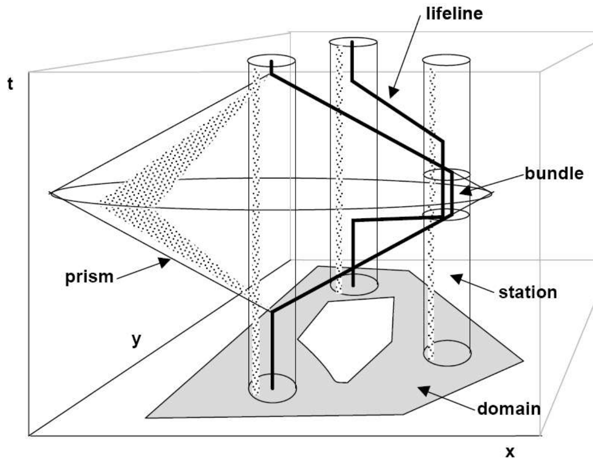

Figure 1: Illustration of the space-time cube with explanations of the individual components, Source: [MooreEtAl2003]

[HaggettEtAl1977] uses a three-dimensional matrix to represent relationships of times, locations and activities (attributes). [Sinton1978], as already mentioned in the motivation, is even clearer: he not only states that all three dimensions need to be present in GIS data models, but also distinguishes between fixed, controlled and measured ways to aquire data. He mentions that in most cases, GIS specialists fix the time component and control and measure the space or attribute dimension. Both Sinton and [Langran1992] give examples for classifying different common data sets into the three formats mentioned before. ([Langran1992], p. 12).

With the establishment of GIScience as an independent scientific discipline [Goodchild1990] at the end of the 80s/beginning of the 90s, spatio-temporal modelling, visualization and analysis became central research questions. Prominent researchers in the space and time domain are [Langran1992], who primarily approached this topic from a conceptual and technical perspective (modelling and implementation), and [Peuquet2002] who additionally added a more theoretical and interdisciplinary aspect to the topic. Peuquet also dealt with perceptual and cognitive issues and included a broader view on the topic integrating also aspects from philosophy, psychology, linguistics, anthropology, neuroscience and artificial intelligence. [OTT/SWIACZNY2001] provide a good overview over the current research on time in GISystems and GIScience. They discuss topics such as conceptualizing entities in spatio-temporal GIS, integrating and implementing time in GIS, analysis and visualization. They also provide a comprehensive research bibliography.

One of the more recent and promising projects dealing with spatio-temporal maps and temporal navigation is the TimeMap project by the University of Sydney, an open source Java based web application [Johnson2004]. Additional research can be found at the homepage of the ICA commission on visualization and virtual environments [MacEachren/Kraak2005] and the Geovista homepage of the Department of Geography, Penn State University [GeoVista2005].

Today, modelling and visualizing time and spatio-temporal navigation in GIS is a truly interdisciplinary research topic, including domains such as geography, social and life sciences, psychology, philosophy, GIScience, GIS, cartography, computer science, information visualization, multimedia design, mathematics, statistics, etc. Substantial input is currently contributed from information visualization, a discipline that deals a lot with interactive graphics, visualizing large datasets and data mining issues ([CardEtAl1999]).

Terms and Definitions

Following are definitions of the most relevant terms and concepts as used in this article:

Space is the basic organization concept in geography. In spatial data, elements or entities have a location or series of locations associated with them. These locations are either zero, one, two or three dimensional. In the further discussion and the prototype implemented during this PhD project, it is almost exclusively dealt with two dimensional spatial data and representations. Locations are usually expressed implicitly or explicitly in a coordinate system. As to [Yattaw1999] space can either be measured metrically or temporally with clocks (e.g. "drive time"). This shows already how tightly interlaced the spatial and temporal dimensions usually are. Spatial data is usually modeled as discrete elements (e.g. point features, linear features, polygon features) where the spatial and temporal extents are attached as attributes directly to these entities, or as a continuum (surface data, e.g. grids, TINs or isolines) where the basis of the representation is space and/or time. Individual objects are specified as attributes attached to a given location in the space and/or time continuum. ([Peuquet2002], p. 270). It is beyond the aim of this article to discuss spatial data structures in detail.

*"**Time** quantifies or measures the interval between events, or the duration of events. Time has long been perceived as a dimension in which each event has a definite (but not necessarily unique) position in a linear sequence, but as differing from spatial dimensions in that "motion" through time appears restricted to having only a forward direction"* [WikipediaTime2005]. Time is often considered as the fourth cartographic or geographic dimension. Different domains and philosophical schools view, perceive and describe time in different ways ([WikipediaTime2005] and [Peuquet2002]). "*In our culture, time is commonly viewed as a line without endpoints that stretches infinitely into the past and the future"* ([Langran1992], p. 27), but other, alternative topologies exist as well, such as multiple parallel lines, tree structures, circularity, discreteness and non-existence. According to ([Yattaw1999], p. 88), time cannot be measured tangibly like space but is perceived by its effects (change). From a conceptional point of view one can distinguish between "continuous" or "mechanical" time and "discrete" or "body" time. Mechanical time is defined through the natural rhythms of the earth revolving around the sun (measured or defined through clocks, calendars with days, seasons or years as units). Body time is more related to human activity (e.g. hours, decades and generations). Both, discrete and continuous time concepts, are useful for modeling and visualizing spatio-temporal phenomena and may lead to different discovery patterns and understandings.

If **attributes** are added (in this article also refered to as **thema** or **topic**) we end up in a triadic model, as propagated by ([Peuquet2002], p 203; see figure 2). Peuquet suggests in her generalized diagram on how knowledge is cognitively arranged, that our cognitive storage comprises of three subsystems for "what", "where" and "when". Each subsystem works cognitively distinct, but highly interrelated and in parallel, and has its own distinct category hierarchies, based on objects, places and processes. The "what system" is based on recognition, comparing observed evidence with a gradually accumulating store of known objects. In contrast, the "where system" builds on direct perception of scenes in the environment, picking out relevant, invariant bits from the rich flow of sensory information. The "when system" operates through the detection of change over time in both stored object and place knowledge, as well as sensory information.

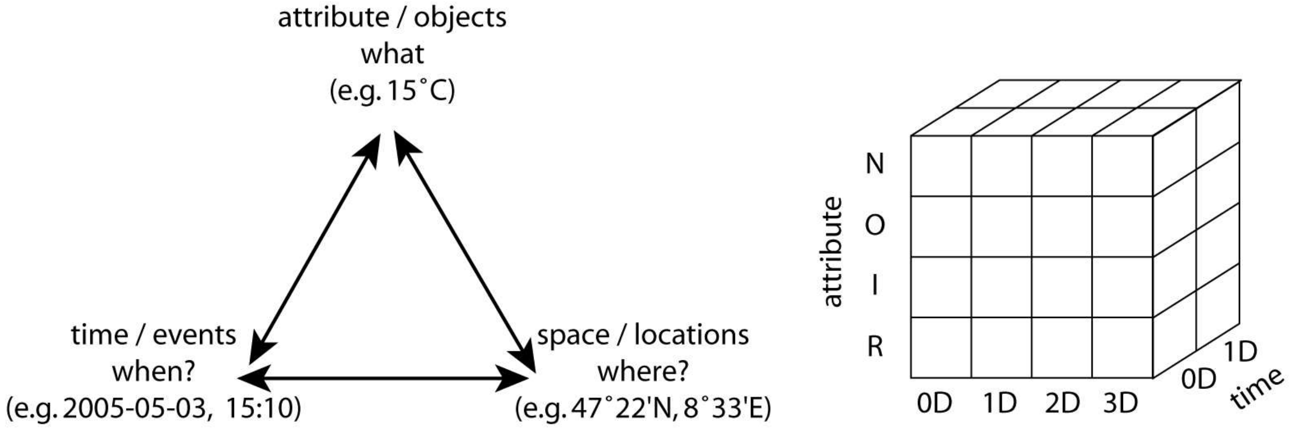

Figure 2: a) Peuquets diagram of how knowledge is cognitively arranged in memory ([Peuquet2002], p. 203);
b) Multidimensional cube of space, time and attribute with potential number of dimensions ([OTT/SWIACZNY2001], p. 4)

In an entirely different classification scheme, based on dimensions, ([OTT/SWIACZNY2001], p. 4) extend Harrowers multidimensional cube of space, time and attribute. Within this cube they visualize the potential number of dimensions. The attribute dimension is categorized into nominal, ordinal, interval and ratio scale. In order to characterize change and movements, all three dimensions are relevant.

The **relationship between space and time** is usually a very close one. The quotation *"Nothing in the world is purely spatial or purely temporal; everything is process"* [Blaut1961] clearly emphasizes this fact. In physics, after Einsteins discoveries, the term "spacetime" indicates, that time and three-dimensional space together form a single four-dimensional object ([WikipediaSpacetime2005]). A "point" in spacetime is denoted as an event (e.g. the explosion of a star) and must be defined in all four dimensions. In geography or cartography, however, the simpler Newtonian concept of noninteracting space and time is often used. "*While it may well be that a geographer's spatial and temporal dimensions do interact, spatiotemporal data are more generally useful when space and time are recorded separately.*" ([Langran1992], p. 29).

Navigation, in this context, can be described as the task of determining position within the information space and finding the course to the envisaged information and other relevant related information. Navigation helps explore information spaces that are too large to be coveniently displayed in a single windows. The information space consists of spatial, temporal and thematic dimensions. Therefore, one distinguishes between spatial, temporal and thematic navigation. These three modes build on different methodologies and tools, but are closely interrelated. Good navigation tools provide answers to questions, such as "Where am I?", "Where can I go?", "How will I get there?", or "How can I get back to where I once was?". Navigation tools, together with spatio-temporal visualization, help to solve spatio-temporal tasks more efficiently and provide both overview and detail. The several navigation modi, available tools, navigation metaphers and the advantages or disadvantages of specific navigation methods are discussed later in this article.

Conceptualizing and Modeling Time

Depending on the accuracy of time oberservations and measurement one can differentiate between ordinal scale (e.g. more or less accurately defined geologic eras) and interval scale where the level of accuracy and precision is defined by its granularity, the smallest chronon used (e.g. second, hour, day, year) in measuring time. Scale, like in space, is also in issue here, as granularity may well depend on the topic to be modeled. In geology a granularity of 1000 years may sufficient, where as data needs to be captured every minute or hour in meteorology. ([Frank1998], p. 45) furthermore distinguishes between linear and cyclic time in his taxonomic model of time. Cyclic time is used in case of reoccurring events and needs to be brought into relation with an absolute, linear time scale for accurate calculation against an origin. A further distinction needs to be made between world time (also called event or valid time) and database time (also called transaction time). Langran adds a third facet, the "display" time. The database time always lacks a bit behind the world time. Both are relevant and should be stored in the data model. "Realtime" GISystems try to update the database immediately after an event occurred, they have a better synchronicity.

([Langran1992], p. 28) introduced the notion of "cartographic time", which "*distills the characteristics of time that are essential for representing spatiotemporality in the most pragmatic and generic fashion"* in contrast to treating time strictly as a continuum with all minor, often irrelevant details. Conceptually, she distinguishes four different models of spatiotemporality ([Langran1992], p. 37ff): The **space-time cube**, as propagated by [Hägerstrand1970] and others, is the first concept. Langran, in 1992, however mentions that from a technical point of view, building GIS on top of this concept is beyond the current hard- and software capabilities. This statement, however, should be revised today, in the light of better hardware, visualization and interactivity techniques. This concept can be very useful to model and visualize spatio-temporal phenomena ([Kraak2003]), but is limited to two-dimensional spatial representations.

The second model is a **snapshot sequence of time slices**. Depending on the granularity and frequency, this concept is similar to "slow motion" video. This concept is very poor, when it comes to model and visualize change. Snapshots, usually taken at regular intervals, represent "states" but are usually not coincident with the events, which trigger change from one state to another. Also, this model does not describe versions of elements and creates highly redundant data structures – unchanged data in different snapshots is stored as duplicates. Langran describes this model as the temporal equivalent of the spatial "spaghetti structure". However, this is still the most common and often the only possible way to model and visualize time in todays GISystems.

The third concept is called "**base state with amendments**" where a base state first stores an initial state and only the differences are stored to describe the next snapshot. Changes need only be stored if there is actually a change in the spatial or attribute domain, which also leads to an adaptive, irregular data sampling interval, triggered by change and/or events. This concept matches conceptually well with the object-based philosophy of the vector GIS school. Because this model represents changes of boundaries both in the spatial and temporal dimension, this data structure is substantially better than the snapshot spaghetti data model, since it is easier to derive both spatial and temporal neighbours.

The fourth model mentioned by Langran is the **space-time composite**. This composite is constructed by flattening the space-time cube into a two-dimensional data structure. Differences in the time dimension show up as new objects in two-dimensional space. Like in the third model, there needs to be a starting point at which the initial geometry and topology is aquired, from which the changes are introduced. As in the third model, changes are only introduced when changes actually occur. Each singular, discrete object has its own history, derived also from the parent entities. The more changes are introduced, the more fragmented the composite will be. To construct a single time slice from the composite, one has to walk the history list of each polygon to locate the attribute set that was curent at the desired time. Adjacent polygons that share the same attributes at a current time slice need to be merged. Model 3 and 4 require GIS overlay functions to create the new geometries or the differences. Langran recommends these two models as viable for use in spatio-temporal GIS at the time of her writing, but mentions the potential problems inherent in these models: decomposition (fragmentation) and retroactive changes to identifiers. Both models facilitate error detection through their implicit topological structures in space and time. However, both models will be inferior in performance, compared to the second model, since time slices need to be generated by walking the history and by extensive use of overlay functions.

In reality there won't be an ideal data model that suits all requirements. The data model should be chosen in the context of the envisaged data type, the update frequency, database size, visualization type and interactive environment and technical framework. *"It is important to note, however, that there should be no expectation that a single, all-encompassing computer database representation can be derived, nor that all representations can be reduced to a few common, atomistic elements."* ([Peuquet2002], p. 8)

A closer look on Spatial, Temporal and Thematic Navigation Tools

Why Navigation?

The "Where am I?" questions is one of the most basic questions. Disorientation makes people feel insecure. "Lost in Hyperspace" is a common problem of internet surfers and multimedia users, especially for inexperienced ones. In hyperspace we have fewer sensories at hand to find our way. We can't rely on touch, balance and smell. The use of audio is limited and our viewing angle is often narrow. Moving through hyperspace or multimedia products can be compared to moving around in the real world with diving goggles.

Good navigation tools guide the user through the information space of a product or webpage, helping explore the content and functionalities of a project. Navigation enables the exploration of information spaces that are too large to be conveniently displayed in a single window. Efficient navigation tools provide both overview and detail. Ideally, multiple user profiles are supported: beginners, intermediates and experts. Experts need more precise and efficient navigation tools and a more direct access to the information offered. Good navigation tools are intuitive and don't force the user to first study extensive manuals or help documents. They are consistent throughout the whole product. This includes the appearance (e.g. colors and fonts), the placement and the functionality of the tools. Navigation tools should not be dominant in the screen layout of a product. A history function allows the user to go back to previous views.

There is no single best, one-size-fits-all navigation method available. The suitability of navigation tools depends on the audience, the user's experience and motivation, the task to solve and the type and size of the information space. A rough rule of thumb is that the larger and more complex the information space is, the more sophisticated and efficient the visualization and navigation tools should be. Good visualization systems provide multiple methods for solving the envisaged tasks, supporting different preferences and capabilities of their audience.

When introducing new methods for user interfaces and navigation tools, [HarrowerSheesley2005] mention an interesting fact: people aquire interface skills primarily through exposure and repetition. Navigation methods that were present in early days of emerging technologies and commonly used, not necessarily represent the best possible implementation. It is not easy to introduce new and potentially better navigation tools and make them appealing to the user. Harrower suggests that design decisions made in early days of emerging technologies should be critically questioned before introducing them. The past has shown that often technical limits or the lazyness of developers have driven these decisions, rather than trying to really understand the users' needs.

Spatial Navigation

Spatial navigation in two dimensional maps consists primarily of zooming and panning. Zooming enlarges or reduces a map to see it more clearly or to get a better overview. Alternatively, we can say that the user is changing the map scale if he is zooming. Panning describes the process of repositioning or re-centering the map. The term "panning" is derived from "panorama", from *"machines that unrolled or unfolded a long horizontal painting to give the impression the scene was passing by"* [WikipediaPanning2005]. For zooming, we distinguish between physical and semantic or logical zooming. Whereas physical zooming is a mere geometric magnification, semantic zooming also changes the shape of geographic objects and adds more detail through more fine grained selections. Semantic zooming usually requires a LOD concept and is closely related to automatic generalization. [HarrowerSheesley2005] differentiate between "precise" and "fuzzy" spatial navigation tools. Precise zoom and pan tools are usually used in scenarios where users know exactly the position either through exact coordinates or geographic names. They are often non-visual tools. Among the graphical spatial navigation tools there are also various levels of precision. Zooming and panning by dragging and drawing a zoom box directly in the map is substantially more precise than having to zoom and pan with predefined zoom steps and discrete panning. Finally, one can distinguish continuous versus discrete or non-sequential versus sequential panning and zooming. Panning and zooming with fixed steps are discrete and sequential, whereas zoom sliders or scrollbars would be continuous.

Zoom Options	*Pan/Scroll Options*	*Spatial Reference/Context*
plus/minus zoom buttons (discrete steps, sequential)	pan hand (continuous, non-sequential)	linked reference map indicates map extent in context/overview map
zoom slider (continuous)	recentering with mouse click	coordinate display on mousemove
fullview or predefined zoom step buttons with scale cues (e.g. street, city, province, country level)	pan buttons at map edges/corners or somewhere in the navigation interface (discrete steps, sequential)	"rocket functionality" lets one quickly zoom out and back in to see larger map context
zooming by resizing a rectangle in linked reference map	panning by repositioning a rectangle in linked reference map	grid lines
zooming and by entering a scale value in text input box	panning with smart scrollbars	scale bar
zoom to selected objects	panning with arrow keys (keyboard)	scale cues (e.g. street level, city level)
zooming and panning by dragging and drawing a zoom box		
zooming and panning by searching for geographic names (gazeteer) – non visual		
zooming and panning by explicitly entering coordinates in text input boxes – non visual		
zoom and pan history lets one step forward and backwards between previously extents		

Table 1: Zooming and Panning Options, Spatial Reference Options

Measuring the efficiency and functionality of spatial navigation tools is not an easy task. [HarrowerSheesley2005] suggest four functionality and two efficiency criteria. The functionality critera are sequential vs. non-sequential map browsing (fixed steps vs. continuous zooming an panning), precision, local-global orientation cues, live-linked manipulation. The efficiency criteria are the interface workload and the information-to-interface ratio. The workload can mainly be determined in a qualitative way. The NASA TLX worksheet and the GOMS model are two possible qualitative methods to determine the workload. The TLX worksheet includes six workload sources: mental demand, physical demand, temporal demand, performance, effort and frustration level. Each criteria should be rated on a 5 point Likert scale. The information-to-interface ratio is derived from Edward Tufte's concept of the data-ink ratio. Navigation tools should not dominate the user interface. Everything not relevant to the information and important for the functionality should be omited. [HarrowerSheesley2005] detected two superior spatial navigation tools: the linked reference map and smart scrollbars where the scroller length indicates the position and percentage of the current sector in the context of the whole map.

Temporal Navigation

As discussed above in the section on "conceptualizing and modeling time", time cannot be seen and visualized directly, but only through the changes in the spatial and thematic dimensions. It is only natural, therefore, that temporal controls are usually tied to visualization, serving both navigation and visualization purposes. Depending on the topology, range and granularity of the time, linear, circular or tree representations and controls are more suitable. Following is a table of possible time controls and representations:

Linear controls and visualization	*Circular controls and visualization*	*Other*
interactive timelines / lifelines	knobs	day / night buttons
temporal slider	watches	calendar widgets
smart scrollbars	wheels of months or seasons	text input
small multiples along timeline	cogwheels	selection lists (e.g. list of months)

Table 2: Temporal Navigation - Linear, Circular and Other Controls and Visualization

Interactive timelines are particularly useful since they can serve both visualization and navigation. Timelines can be used to show events, processes and the distribution of attribute values along time. Processes or uncertainty can be visualized using gradients. Timelines can be combined with sliders and scrollbars. Small multiples are a series of small pictures representing the same topic over time. These can be ordered along a timeline. They are propagated by [Tufte1990] and [Monmonier1992]. An interesting option is to use cogwheels for controlling time. A series of cogwheels with different sizes and ordered by granularity can intertwine with each other and allow the user to navigate through time at various speeds. Finally, the space-time cube could be an interesting navigation tool to enable combined spatio-temporal navigation and visualization. Slicing planes could be moved within the cube to cut out space or time clippings of the whole space-time cube.

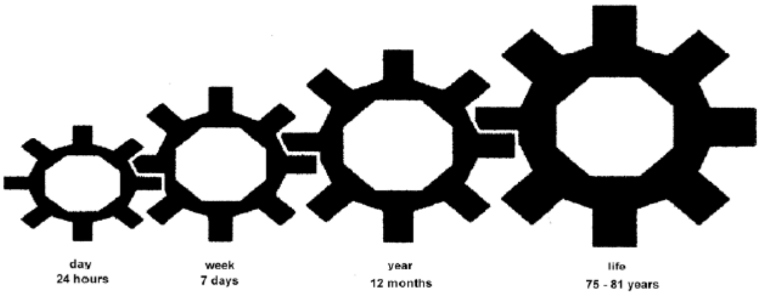

Figure 3: Cogwheels for Navigation in and Representation of Time, Source: [Drewe2005]

Thematic Navigation

The optimal technique for navigation in a topic depends very much on the nature and data type, as well as the size of the information space to be visualized. Disciplines dealing with the visualization and navigation within topics are "information visualization", "document visualization" and the "semantic web" community. Basically, one can distinguish between **hierarchic** data structures and **graphs** or **network** data structures. Hierarchic data structures are often visualized using interactive trees where one interactively opens and collapses sub-hierarchies. A typical example for such a tree structure is the file-browser, present in any modern GUI to operating systems. A special form of a hierarchic tree is the **hyperbolic browser** developed and propagated by Inxight, where items can be interactively moved to the center of the visualization. Linked branches can be opened or collapsed or automatically appear as they move closer to the center of the visualization. Objects farther away from the visualization center are perspectively scaled down and later hidden. A nice demonstration utilizing this technology for interactive grocery shopping can be explored at [Inxight2005]. **Treemaps** are alternative tree representations, originally introduced by [JohnsonShneiderman1991]. Within the treemap, one starts with a large root rectangle, filling the entire canvas. Within that rectangle are smaller rectangles, one for each subordinate node of the node just considered. This procedure is repeated until all nodes are represented. There is no limit on the depth of the tree. Color and text labels can be used to represent different attributes.

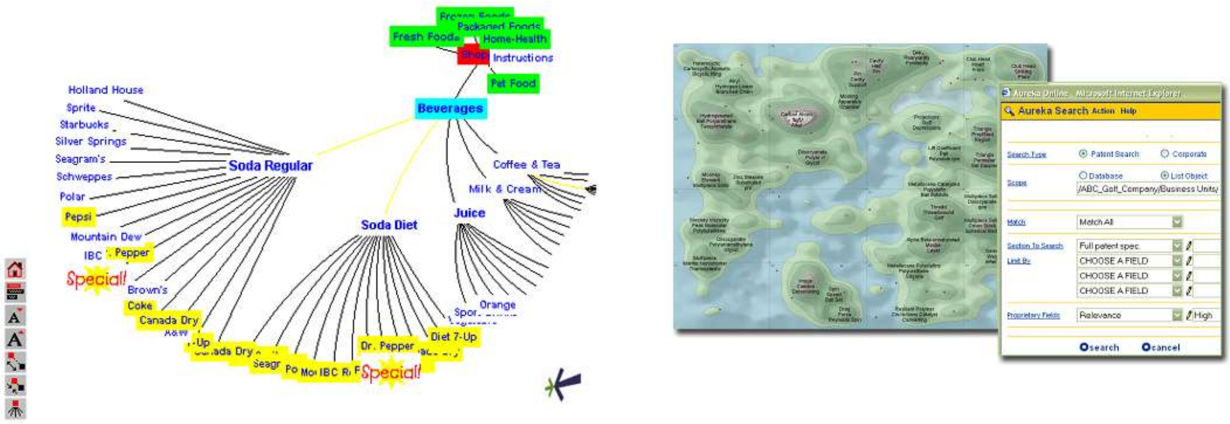

Figure 4: Hyperbolic Tree and Themescape, Sources: http://www.inxight.com/ and http://www.micropatent.com/

Increasingly, interactive maps are used to display a topic in two or three dimensions. The information space is defined by two or three attributes. Objects that are closer to others, according to the attribute space, appear closer in the map. Links to other objects can be visualized using linear or network structures and arrows indicating directions. When using a LOD concept, important objects appear first, less important ones only after zooming into the information space. Objects that are close to eachother are often grouped in "**galaxies**", in which the user can dig into deeper, gradually revealing more details. Exponents of this technology are e.g. **graphical front-ends to search engines**, such as [Grokker2005] or [Kartoo2005]. Another form of information landscapes is the "themescape". A **themescape** is a thematic terrain where the elevation indicates theme strength. Peaks indicate where concentrations of closely related objects appear. An example application for such themescapes is available as part of the "Aureka" product, a patent browser of a company called Micropatent (http://www.micropatent.com/). Using the map metaphor, one can use spatial navigation and analysis tools to explore the themescape. This includes zooming, panning, LOD or perspective views.

Depending on the data type and scale of the topic, statistical analysis, charts and diagrams might be useful for visualization and navigation. Examples include scatterplots, histograms or parallel coordinate plots. It has proven useful to provide several visualization and navigation options and link them together using brushing and linking techniques.

Taxonomy of Spatio-Temporal Tasks, with Special Consideration of Navigation Tasks

In order to design efficient navigation tools, it is important to have the tasks in mind that the user is trying to solve with the interactive mapping application. As navigation tools are usually among the key interactivity and analysis tools, it is useful to analyse the individual tasks in spatio-temporal analysis where navigation is directly involved. A task analysis includes a task taxonomy, where tasks are classified on a high level. During this step it is formalized what will and will not be analyzed. Later, in the course of a task decomposition, these high level tasks are broken down into sub-tasks. These sub-tasks are arranged in a hierarchy und structured, describing relationships, dependence and inheritance. During task allocation, tasks and sub-tasks are divided up between humans and machines. Various implementation options are evaluated and the most (cost)-effective option chosen. A detailed verbal description of the tasks is done in the task description, including a title, stimulus, required equipment, response, feedback, output and performance. The author is currently working on a general task analysis for spatio-temporal tasks and navigation tasks, and a more in depth task analysis for the prototype mapping application discussed below.

Interdependencies of Spatial, Temporal and Thematic Navigation

A study of the interdependencies in spatial, temporal and thematic navigation includes questions, such as: What effects should changes in one of the three dimensions (space, time or topic) trigger in the two remaining dimensions? How should the user interface adapt to the new constraints? What do changes in either dimension mean for the cartographic visualization within the map? A systematic reflection of these dependencies leads to the following table:

<table>
<tr><th>Fixed (Given) dimension
(changed by user)</th><th>First, Variable dimension</th><th>Second, dependent dimension</th><th>Effects on Space
(Map Design, Map Content)</th><th>Effects on Time
(Timeline visualization a. tools)</th><th>Effects on Thematic
(Thematic choice, depiction and tools)</th></tr>
<tr><td rowspan="2">Space</td><td>Time</td><td>Topic</td><td rowspan="2">• Adapt map content according to map extent (generalization)
• Display objects according to relevance in topic
• Resymbolize map in relation to map extent
• Choose different scale for base maps.</td><td rowspan="2">• System should display in timeline only objects relevant for the given space
• Other elements could be hidden or dimmed</td><td rowspan="2">• System should only give thematic choice available in the area selected by the user</td></tr>
<tr><td>Topic</td><td>Time</td></tr>
<tr><td rowspan="2">Time (Span)</td><td>Space</td><td>Topic</td><td rowspan="2">• Display objects according to relevance in time span
• Adjust global relevant bounding box according to new time span</td><td rowspan="2">• Adapt to new global time scale
• adjust granularity in global timeline and clockspeed in animation
• display objects according to relevance</td><td rowspan="2">• System should only give thematic choice available in the time-span selected by the user</td></tr>
<tr><td>Topic</td><td>Space</td></tr>
<tr><td rowspan="2">Topic</td><td>Space</td><td>Time</td><td rowspan="2">• Adjust global relevant bounding box according to new topic selected by the user
• Display different topic in map according to rules in data model</td><td rowspan="2">• Show in timeline view new relevant time spans according to new topic</td><td rowspan="2">• Highlight new active topic in timeline view
• Possibly reorder neighbour topics in timeline view</td></tr>
<tr><td>Time</td><td>Space</td></tr>
</table>

Table 3: Interdependencies of Spatial, Temporal and Thematic Navigation

Prototype implementation of an interactive 2D map of european cultural heritage

A prototype is currently being implemented to demonstrate the feasibility of the proposed navigation tools, as well as their close interrelationships. The topic of the prototype is a map of european artists that displays where the artists worked and lived. The prototype allows the user to navigate in time and topic. Topics include the navigation in various art styles (e.g. painters, sculptors, architects, poets, etc.). Furthermore, the user can display network diagrams that show links from selected artists to related artists, e.g. friends, collaborators, apprentices, teachers. Links to Google and Wikipedia are provided for artists and events. Temporal navigation and visualization is implemented using timelines. They show the life span of artists as well as important events in their life. If data is available, travelling of artists is visualized in the map. To put the artist's life into context, important events, such as wars, political events, inventions, etc. are visualized in a separate timeline. Timelines are linked to the map and vice versa. Highlighting emphasizes the corresponding elements in the temporal and spatial visualization. If there is a corresponding network diagram available, it is linked as well. Figure 5 below shows a screenshot of the prototype. As this is work in progress, the screen layout and available navigation tools are subject to change. The current version of the tool can be found at [Neumann2005].

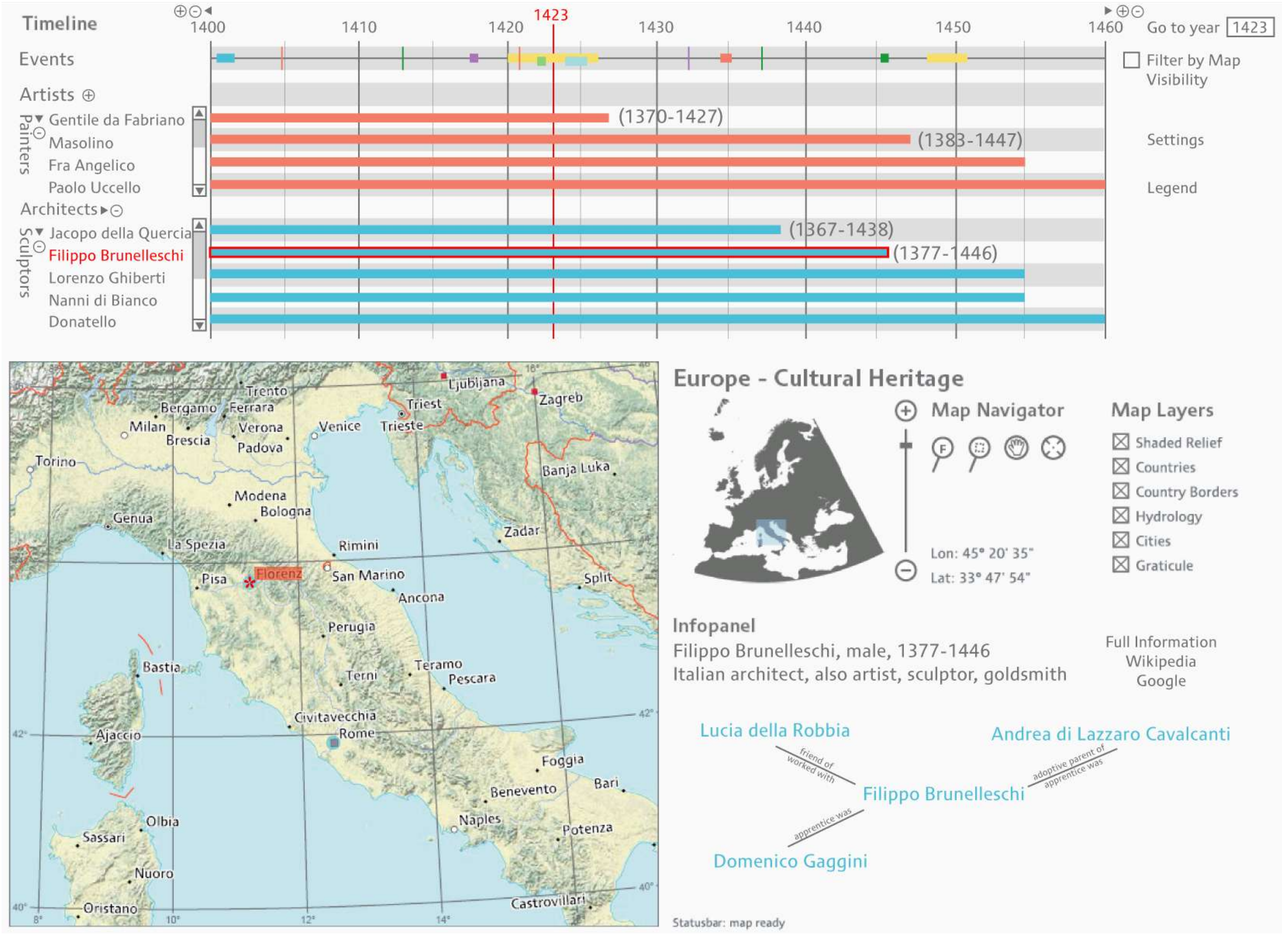

Figure 5: Screenshot of the current, preliminary version of the prototype "European Map on Cultural Heritage", Source: [Neumann2005]

The project was inspired from the Twistory software [Boer2003], a Macintosh freeware history browser that displays lifetimes and travels of historic figures. The project implements similar features than the twistory project, but with higher emphasis on cartographical quality, navigation and interactivity. Furthermore, the prototype utilizes advantages from the fact that it is web-based. Resources are linked to search engines and online encyclopedias, such as Wikipedia. The prototype is technologically based on SVG (Scalable Vector Graphics) and ECMAScript on the client, with a PostgreSQL/Postgis spatial database backend that collaborates with Apache and PHP on the server. Postgis is an OGC compliant spatial extension to PostgreSQL that features spatial queries, reprojection of data, geometric processing (such as overlay and buffering) and output in SVG format (among other formats) [Postgis2005]. The application follows the client-server approach where only portions of the whole dataset are loaded on demand. Spatial data is filtered and generalized to deliver the user scale-adequate map data. Basic topographic geometry data was obtained from the WDBII freeware datasets and corrected and enhanced in ESRI ArcGIS. A shaded relief with natural colors was provided by Tom Patterson ([Patterson2005]). Thematic Data (database of artists) was obtained from the Paul Getty Research Institute ([Getty2005]).

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Biography

Andreas Neumann got a masters degree in Geography/Cartography from Vienna University, in 2001. In 1999 he joined the Cartographic Institute of the Swiss Federal Institute of Technology, first as a system administrator and later as a teaching and research assistant. At the same institute he advised several thesis and student projects in the webmapping domain. Currently he is working on a PhD with the title “Navigation in Space, Time and Topic - Interdependencies of Spatial, Temporal and Thematic Navigation in Two Dimensional Interactive Maps”. Besides university he occasionaly does consulting work in the domain of SVG for Webmapping and Online GIS. He also worked for two years as a GIS specialist and cartographer at a geology consulting company located in Zurich. He was one of the initiators of the SVG.Open 2002 conference in Zurich, the first international SVG developers conference, co-organized by the W3C consortium.