

Alexander Salveson Nossun

**EXPLORING NEW VISUALIZATION
METHODS FOR MULTI-STOREY
INDOOR ENVIRONMENTS AND
DYNAMIC SPATIAL PHENOMENA**

Thesis for the degree of Philosophiae Doctor

Trondheim, May 2013

Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
Department of Civil and Transport Engineering



NTNU – Trondheim
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Table of contents

| | |
|--|-----------|
| PREFACE | v |
| ACKNOWLEDGEMENTS | vii |
| INTRODUCTION | 9 |
| MOTIVATION | 9 |
| STRUCTURE OF THE THESIS | 10 |
| PRESENTATION OF RESEARCH PAPERS | 12 |
| Paper I | 12 |
| Paper II | 12 |
| Paper III | 12 |
| Paper IV | 13 |
| Paper V | 14 |
| Paper VI | 14 |
| Paper VII | 15 |
| Paper VIII | 15 |
| Papers not included in the thesis | 16 |
| SCOPE OF THE THESIS | 16 |
| BACKGROUND | 17 |
| INFORMATION VISUALIZATION | 17 |
| DYNAMIC AND ANIMATED VISUALIZATION | 26 |
| RESULTS | 29 |
| SEMISTATIC ANIMATIONS | 29 |
| GLIMPSES OF THINGS TO COME: A GUIDED TOUR OF MULTI-STOREY INDOOR ENVIRONMENTS IN THE NEAR FUTURE | 39 |
| CONCLUDING REMARKS | 53 |
| REFERENCES | 55 |
| PAPERS | 61 |
| PAPER I | 63 |
| PAPER II | 77 |
| PAPER III | 91 |
| PAPER IV | 109 |
| PAPER V | 125 |
| PAPER VI | 147 |

| | |
|--|------------|
| PAPER VII | 159 |
| PAPER VIII | 177 |
| APPENDIX | 193 |
| A1. HIGH RESOLUTION OF INDOORTUBE GASTROENTERET | 195 |

Preface

In recent years, computer users have come to expect dynamic, interactive, distributed, and highly connected user interfaces as a matter of course. Hand-held devices with significant computing power, internet, GPS, and audiovisual communication are commonplace. Software for navigation with streetmaps and topographic maps is readily available both on stationary and mobile platforms. Advances in visualization, cartography and geospatial technology have been a prerequisite for this technological revolution.

Even so, along with increased implementation of dynamic and interactive maps, significant challenges still remain. For example, how best to address fundamental problems like change blindness and inattention blindness is a topic of debate in the research literature. In the work reported here, I have shown that *Semistatic Animations*, a novel visual symbol design for cartographic animations, limits the effect of change and inattention blindness. A case study using weather map animations demonstrated the superiority of semistatic animations over regular weather map animations. The concept lends itself to dynamic interfaces such as real-time maps.

Analyses of eye-movements were used to evaluate the concept of semistatic animations. The analyses showed that traditional analysis methods of eye-movements are sub-optimal for many tasks involving animated stimuli. A new visual analysis method, relying on dynamic and interactive two-dimensional projections of a space-time-cube, demonstrates the potential of novel analysis methods. The proposed method is better suited to the analysis of eye-movements captured using animated stimuli than traditional ones.

The current increase in the amount of measurements made of the world is so rapid as to amount to a veritable data explosion. This also holds true for data about indoor spaces, and multi-storey buildings in particular. Still, the exploration of indoor environments has only recently attracted the interest of industry leaders and the scientific community. I have investigated the capabilities of indoor positioning technology by carrying out a practical evaluation of a commercial WiFi positioning system. This technology provides an accuracy far inferior to the widely available satellite based positioning outdoors. Despite the low precision of current indoor positioning systems, both scientific results and commercial trends indicate increased use of this technology in the future.

Indoor environments pose several interesting research problems which are fundamentally different from those of outdoor environments. In multi-storey buildings, with ever more spatially referenced data available, information can be massively overlapped in the vertical dimension. So far, there is very little consensus in the scientific community about how best to design dynamic and interactive interfaces for visualizing multi-storey indoor environments.

The *Vertical Color Map* is a design principle for multi-storey maps which I have proposed and investigated. It introduces a simple, yet powerful way of visualizing relevant information about the inside of a multi-storey building, without relying on detailed knowledge of the spatial interior of the building. For instance, the whereabouts of one's friends could be displayed using their icons or avatars at the appropriate places within the building. Applying knowledge of visual variables together with regular outdoor maps enables the user of the vertical color map to traverse the vertical dimension without the requirement of interacting with the map. Results from an empirical evaluation confirms that the proposed vertical color map performs as well in many scenarios as a regular floor plan map, while not being hampered by having to access spatial databases of the interior of the building.

Measurements of interior environments generating structured spatial databases are of great interest to the scientific and industrial communities. Given access to spatially referenced data about the interior of multi-storey buildings, like hospitals, airports and similar, the potential for innovative applications is great. Floor plans of different designs seem to be the favored implementations for many applications. Adequate handling of the vertical dimension using floor plans can be tricky. Each floor requires its own floor plan map. Many applications can benefit from an alternative to floor plan maps.

The *IndoorTube* is another novel map design principle resulting from this project. It generalizes the concepts of Beck's tube map design, widely known from transportation maps worldwide, to multi-storey interior building data. By exploiting the similarities between multi-storey buildings and transportation networks, the IndoorTube design permits visualizing several overlapping floors, hallways, rooms and entities, like equipment and persons, *simultaneously* in one map. During the preparation of the concept, several refinements have been made and discussed. In an evaluation of the IndoorTube's capabilities of providing wayfinding guidance in a hospital building, an IndoorTube map was found to perform as well as the floor plan map currently used at that hospital. At the same time, no statistically significant difference was found between not using a map at all and using either of the maps. As a result, other use cases are recommended for the IndoorTube map, such as; monitoring systems, dynamic real-time maps and socio-spatial awareness applications.

In dealing with multi-storey indoor environments, the technological possibilities are as enticing as the scientific challenges are daunting. The research I am reporting here revolves around the three above-mentioned design principles which I have proposed and put to the test: *Semistatic Animations*, *Vertical Color Maps*, and *IndoorTubes*. The results of my research are written up in a series of peer-reviewed research papers which are described below. Further research on the topics of this thesis is desirable and, I hope, inevitable given the current technological trends.

Acknowledgements

I am thankful to the research group in Geomatics at the NTNU for the opportunity to work on the project leading to this PhD thesis. Special thanks are given to my supervisor Terje Midtbø together with the rest of the staff at NTNU Geomatics. I would also like to express a special thanks to Letizia Jaccheri, Tomasz Opach, John Krogstie, Trond Arve Haakonsen, An Mai Nguyen, and the COSTT project. The students at Geomatics have also been inspiring and a source of motivation throughout the project period.

I am also grateful for the opportunity to visit the University of Maine during the academic year 2010/11, and in particular for many fruitful discussions with Mike Worboys, Nicholas Giudice, Hengshan Li, Balaji Venkatesan and Shreyans Jain. My colleagues in the GeoForum interest group are an inexhaustible source of enjoyable conversation and stimulating challenges. Their steady focus on real world applications is truly appreciated.

Finally, I am indebted to my parents and my friends for their unfailing support, and most of all to my dear companion Marit for all her encouragement and love.

Introduction

Motivation

Advances in technology have made the world more closely connected than ever before. Mobile technology is one of the prime examples of how we are interconnected all the time; sensing the environment, interacting with, and consuming information at a rapid pace. Computational and storage capacities are increasing rapidly. Spatial visualization has gained a tremendous popularity the last decades. Maps are today widely available, free of charge, on a range of platforms provided by such industry leaders as Google (Google Maps 2011) and Microsoft (Bing Maps 2011). The industry is constantly developing new map interfaces, distribution methods and interaction techniques. The result is more interactive, more dynamic, better animated and more responsive spatial visualizations. Coverage is not limited to the traditional topographic map. The world is now measured more thoroughly, more accurately and by more advanced methods than ever before. High resolution satellite images, street level photo realism, high resolution aerial photogrammetry, high resolution 3D laser scanning, bathymetry, and ground penetrating radars are all used to survey the surface of the Earth in order to better understand the world, to build more accurate data warehouses, and to provide customers and consumers with new attractive solutions.

As spatially referenced data about the world becomes ever more readily available, indoor environments have recently become an area of interest for industry leaders and the scientific community (Giudice *et al.* 2010, Bing Mall Maps 2011, Google Maps for Android 2012, OpenStreetMap 2012). What is special about indoor environments? The first obstacle is the scarcity of mapping methods applicable to indoor environments. Conventional methods, like aerial photogrammetry, do not, for obvious reasons, work inside buildings. Even more peculiar to indoor environments is their information density, which is usually higher than for most outdoor environments. However, what really distinguishes indoor environments from outdoor environments is the vertical dimension, and in particular the ubiquity of overlapping vertical information in indoor environments.

Regular spatial visualization methods do not account for, let alone support well, vertically overlapping information. The spatial structure of outdoor environments is, generally speaking, considered as a two-dimensional surface with very limited overlapping information. Indoor environments are, on the contrary, filled with overlapping vertical information. Regular spatial visualization methods are thus sub-optimal in an indoor context.

The application of modern dynamic, interactive and animated visualizations to multi-storey indoor environments seemed to me a very intriguing terra incognita waiting to be explored. The following research questions defined the point of departure for this PhD project:

- Can contributions to the conventional animated and dynamic maps be made?
- Can our understanding of spatial visualization of multi-storey indoor environments be increased?
- What kinds of suitable applications for spatial visualizations used in multi-storey indoor environments exist?

Structure of the thesis

Figure 1 illustrates the high level structure of the thesis including the research papers that were written as part of the thesis work, and their backgrounds, such as posters and literature surveys. Two overarching themes make up the structure of the work: Dynamic and animated visualization and multi-storey indoor environments. Problems associated with dynamic and animated visualizations are presented and discussed. Contributions aimed at resolving some of these issues have been proposed. Related work to which I have contributed is also included, in order to shed light on the applications of novel dynamic and animated visualizations. Empirical investigations have been carried out, yielding statistical evidence and indications on the quality of the proposed contributions. These empirical investigations have also inspired contributions to the dynamic and animated visualizations, in particular related to the investigations on eye-movement analysis.

The second theme revolves around multi-storey indoor environments and represents the majority of the work in the thesis. The work on dynamic and animated visualizations is, however, fundamental to the applications identified within the indoor theme. Visualizations discussed in the second theme are, or could be, of an interactive, dynamic and animated kind. In the literature, too little attention has been paid to the application of dynamic and animated cartographic visualizations to the visualization of indoor environments. This thesis proposes and tests novel design principles for the combination of these two themes, while at the same time contributing to both fields individually.

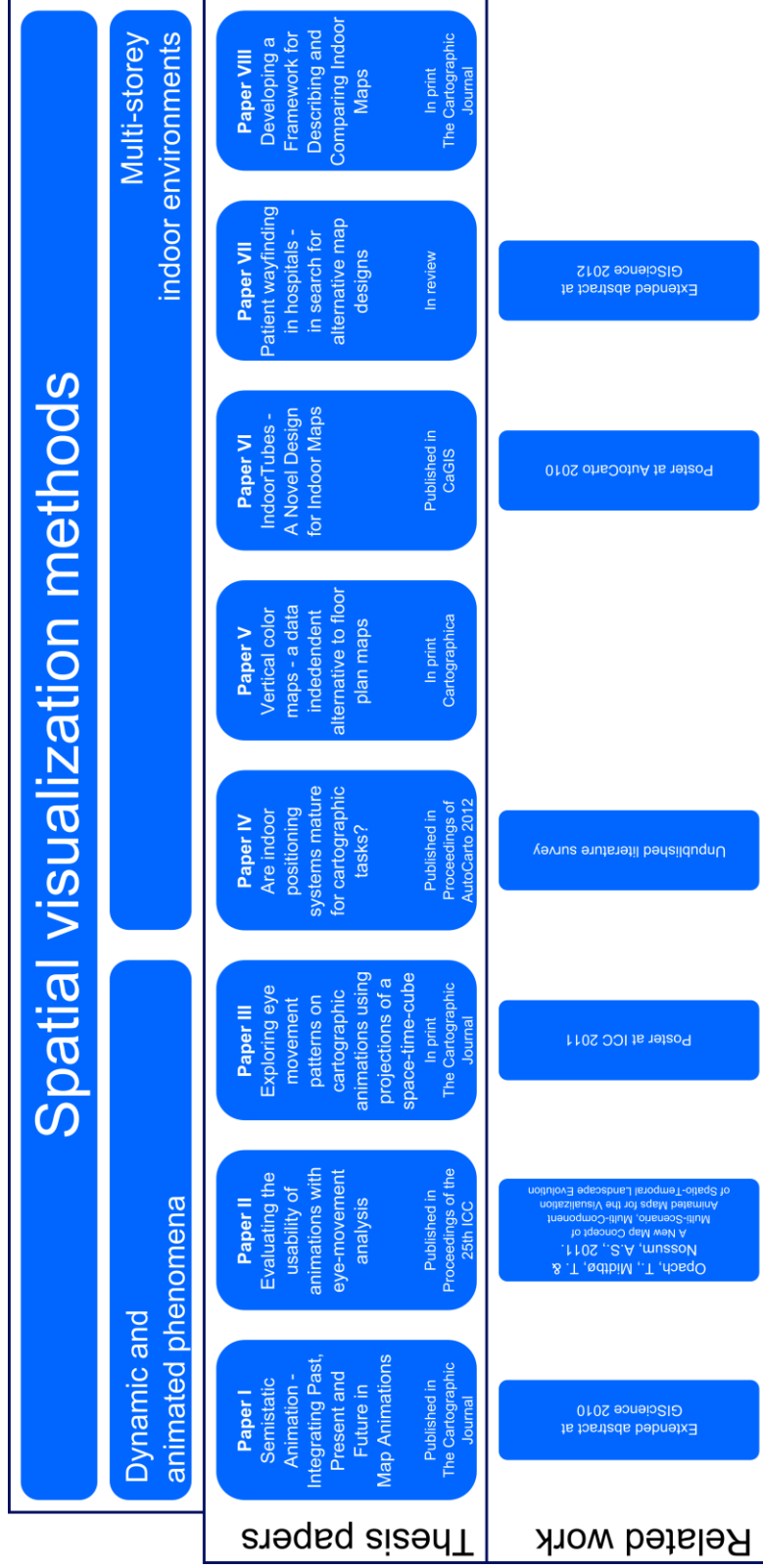


Figure 1: The overall structure of the PhD project and thesis with relevant work for papers where relevant.

Presentation of research papers

The following section presents the individual papers briefly and places them in the context of the overarching structure. The candidate's contributions will be detailed where relevant.

Paper I

Nossum, A.S., 2012. Semistatic Animation - Integrating Past, Present and Future in Map Animations. *Cartographic Journal, The*, 49(1), pp.43–54.

The first paper presents a new way of including the complete temporal information at any given time in cartographic animations. The integration is performed on a symbolic level by adding a local temporal legend to the local visualizations for each point of interest. An empirical web-distributed experiment was carried out and results analyzed. The paper is based on a peer-reviewed extended abstract presented at GIScience 2010 (Nossum 2010). All aspects of the paper, the extended abstract, and project were carried out by the candidate.

Paper II

Opach, T. & Nossum, A.S., 2011. Evaluating the usability of cartographic animations with eye-movement analysis. In A. Ruas, ed. *Proceedings of the 25th International Cartographic Conference*. Paris, France.

The paper discusses the usefulness of eye-tracking in light of the experience gained by performing two eye-tracking experiments on two different cartographic animations. The semistatic animations, presented in paper I, and a cartographic animated interface, developed by Tomasz Opach, presented in Opach et al. (2011), were used as stimulus in the experiments. The eye-tracking experiments were designed and carried out in close collaboration with Opach, each carrying half the workload. Everything related to the semistatic animations was carried out by the candidate and everything related to the animated interface was carried out by Opach. The paper was written jointly, with Opach as the corresponding and presenting author.

Paper III

Nossum, A.S., 2012. Exploring eye movement patterns on cartographic animations using projections of a space-time-cube. Accepted for publication in *The Cartographic Journal* on 8 October 2012.

Paper III expands upon the work presented at the International Cartographic Conference 2011 in a poster titled: *Innovative analysis methods for eye-tracking data from dynamic, interactive and multi-component maps and interfaces*. Nossum, A. and Opach, T. The work is motivated by the eye-tracking experiments and the challenges of dynamic and animated visualizations described in paper I and II. A space-time-cube is used to analyze eye-movement data recorded with dynamic stimulus. The space-time-cube was implemented as an interactive interface with several linked components, partially inspired by the work described in Opach et al. (2011) together with the challenges of three-dimensional visualizations. To ameliorate the problems of using a full three-dimensional space-time-cube, several fixed two-dimensional projections of the cube are included in linked and interactive components. Projections in the XT and YT dimensions are in particular emphasized and highlighted as very useful in the case study presented. The application areas of fixed and interlinked projections of three-dimensional visualization stretch beyond eye-movement analysis and can as easily serve as a method for other visualizations representing three-dimensional environments, such as multi-storey indoor environments. The work reported in the article was carried out in its entirety by the candidate, including formulating the idea for the research, designing and implementing the experiments, and writing the paper. The poster was designed in collaboration with Tomasz Opach.

Paper IV

Midtbø, T., Nossum, A. S., Haakonsen, T. A., & Nordan, R. P. V. (2012). Are indoor positioning systems mature for cartographic tasks? Evaluating the performance of a commercial indoor positioning system. Proceedings of AutoCarto 2012. Columbus, Ohio.

This full paper submission reflects on the ability of commercial indoor positioning systems to be used for cartographic tasks. An unpublished literature survey written by the candidate was used as background knowledge. A student project by Robert Nordan investigated the different properties of an implementation of Cisco's WiFi positioning system. Nordan's work was followed up by a more extensive investigation of the positioning system's performance and properties. Highly accurate positions were found within the test building using traditional surveying techniques to compare with results from the positioning system. Repeated and random measurements from the positioning system were collected during a period of time and their accuracies were calculated and compared with the high accuracy positions. Through the results and the reflection around accuracy requirements, the paper sheds important light on the current potential of commercial positioning systems and what can be expected in the future. The contribution by the candidate consisted of developing a test client able to request and store positions from the

positioning system. The test procedures were designed in collaboration with the rest of the authors. The paper was written in collaboration and the candidate was responsible for the parts relating to the application areas and reflections around use in cartographic contexts.

Paper V

Nossum, A., Giudice, N. A., Li, H. Vertical color maps – a data independent alternative to floor plan maps. Accepted for publication in the journal *Cartographica* on 26. March 2013.

Paper V discusses two problems associated with visualization of multi-storey indoor environments: 1) the scarcity of interior building data and, 2) the difficulty of visualizing the vertical dimension for social awareness applications. A solution is proposed which is independent of existing interior building data. The solution uses color to represent the vertical dimension in combination with regular outdoor maps with building outlines. Problems of massive vertical overlap in tall buildings are discussed and solutions presented. The proposed solution of vertical color maps is evaluated against a similar map using floor plan maps, both on a simulated mobile device. Results from the empirical experiment indicate that the vertical color map visualization performs equally well as the floor plan map visualization. The results are directly useful for applications which extend their indoor visualizations in buildings without access to floor plan maps or other kinds of interior building data, like social media platforms and widespread web maps. The project was performed in collaboration with Li and Giudice. Li took part in carrying out the experiment and provided helpful knowledge in the discussion during the design phase. Giudice acted as advisor throughout the project and provided helpful guidance in writing the paper.

Paper VI

Nossum, A.S., 2011. IndoorTubes, A Novel Design for Indoor Maps. *Cartography and Geographic Information Science*, 38(2), pp.192–200.

Building upon a poster paper presented at AutoCarto 2010, this journal paper presents the *IndoorTube* concept. Recognizing the conceptual similarities between multi-storey indoor environments and transportation networks, the new term; *IndoorTube* is inspired and guided by Harry Beck's tube map design (Garland 1994). The paper discusses other, potentially better, applications of the IndoorTube such as real-time information, spatial and social awareness, real-time coordination and analysis – in all of which dynamic and animated visualization is desirable, relating to the problems discussed in paper I, II, III.

Paper VII

Nossum, A.S., Ngoc, A.M.N., 2012: Patient Wayfinding in hospitals – in search for alternative map designs. In review.

One of the potential application areas of the IndoorTube, presented in paper VI, is navigation, or wayfinding, inside large, unfamiliar buildings such as hospitals. Paper VII builds upon a master project carried out by An Mai Nguyen Ngoc (Ngoc Nguyen 2012) in close collaboration with the candidate. The project reported in this article was also presented as a poster at Geomatikkdagene 2012 (in Norwegian) (Nguyen and Nossum 2012) and as an extended abstract at GIScience 2012 (Nossum and Nguyen 2012). The project implemented an IndoorTube map of a hospital building and carried out an empirical experiment evaluating the IndoorTube against the commonly used floor plan maps. Results indicate that the subjects using the IndoorTube map performed better than the subjects not using any map (control group). However, issues relating to the IndoorTube design were identified during the design and from interviewing subjects. In the project, the maps were printed and static.

Paper VIII

Nossum, A.S. Developing a framework for describing and comparing indoor maps. Accepted for publication in *The Cartographic Journal* on 13. March 2013

In light of the experience gained in the projects working with visualization of indoor environments, the need to more properly characterize, describe and compare different types of maps has been identified. The paper proposes a starting point for a framework able to fulfill this task. The framework builds upon earlier studies on similar frameworks for generic maps as well as related work by the candidate on quality of maps and conceptual models (Nossum and Krogstie 2009). A framework able to fulfill the tasks described could lead to better, more standardized visualization types, and not least, be able to compare different map types based on their different qualities.

Papers not included in the thesis

The candidate has an interest in education, collaboration and digital art. Listed below are some papers on these topics which were written during the PhD project period, but which fall outside the scope of the present thesis:

Nossum, A. S., 2011. Geomatikk i Skolen – et kart er ikke lenger bare et kart. Published in *Bedre Skole* nr. 4.

Chorianopoulos, K., Jaccheri, L. & Nossum, A.S., 2012. Creative and open software engineering practices and tools in maker community projects. Proceedings of the 4th ACM SIGCHI symposium on Engineering interactive computing systems - EICS '12, p.333.

Nossum, A.S., 2012. Understanding spatial information science at the trans-disciplinary intersection between IT and New Media Art. Unpublished.

Scope of the thesis

The goal of this PhD project and thesis was to gain a deeper insight into the problems and opportunities of visualization. Dynamic, animated and partially interactive visualizations have formed one part of the thesis. Visualization of multi-storey indoor environment has formed the other, and more significant, part of the thesis. Interesting possibilities open up at the intersection between these two themes. Several of these possibilities have not been implemented in the current work but have been identified and described. The scope of the project was to explore some of the possibilities in the two themes. An great number of possible novel map designs can be developed in the two themes alone and in particular in the intersection of dynamic, animated and interactive visualizations with multi-storey indoor environments. This thesis sheds light on some of the possibilities while at the same time pointing out directions for future research and innovations.

Background

Information visualization

Visualization is one of the best tools to facilitate human understanding of complex information, and in particular large amounts of interlinked information. The information can itself represent a phenomenon over time, statistical information or simply a collection of numbers. Visualizing information has been used throughout history for many different purposes, from cave inscriptions to modern dynamic renderings. Cartographic representations of the world have been an essential part of understanding geography and the world as such. Historical maps serve as a looking glass into our understanding of the past. When information visualization is introduced in the literature, it is often in the context of historical and novel visualizations. More often than not, the field of visualization is exemplified by using Doctor John Snow's Cholera map, Charles Minard's map of Napoleons March, Harry Beck's Tube map or Florence Nightingale's rose – all, except the latter, are visualizations of geographic information. Extracts of the visualizations are found in figure 2. Snow's cholera map helped to see the world in a different view by explicitly plotting the location and the number of ill people on a fairly basic map (Tufte 1985). It then became evident that there were more dots, and thus more ill people, in the vicinity of water pumps. This led to the understanding that cholera is waterborne. The visualization itself does not provide the answer directly, but guides the viewer to understanding the information and deducing knowledge from it. Minard's map represents another example which is distinctly different from Snow's cholera map in that it invites the viewer to understand a large set of interlinked data. The map illustrates Napoleon's march to Moscow and, in particular, emphasizes the decreasing number of soldiers during the campaign, and reasons for the decrease such as temperature (Tufte 2006). Beck's Tube map is distinctly different from the other maps in that it distorts, or even neglects, the metrical geography of London and favors schematic lines with right-angled turns, and limited overlaps. By neglecting the metrical geography, and focusing solely on the topological information of the transportation network, the map is made much easier to use for travelers and is used today in a majority of transportation networks. Florence Nightingale faced another issue related to temporal information. She improved the conditions in hospitals during a period of time and needed to present the effect this had on the patients (Cook 1914, Spence 2007). The visualization makes it immediately apparent that there is a dramatic decrease in the number of deaths from month to month.

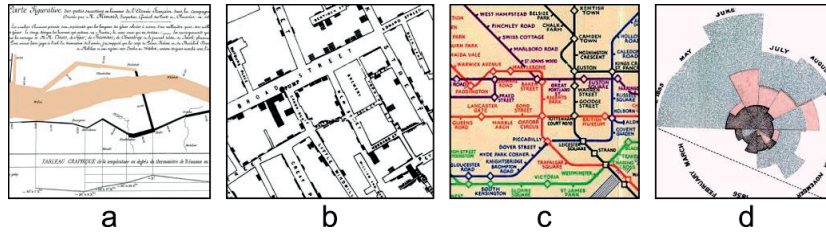


Figure 2: Extracts from: (a) Minard's map of Napoleons march, (b) John Snow's Cholera map, (c) Beck's London Tube map, and (d) Florence Nightingale's chart.

The examples given above illustrate the variety found in visual representations as well as their usefulness. Three of the four examples are focused on spatial information while the fourth is primarily focused on temporal information. However, there is a great number of different visualization methods for different purposes, different data types and even different media types. Tufte (1985, 2006), Bederson and Shneiderman (2003), Ware (2004, 2008), Spence (2007), and Heer *et al.*(2010) provide more details on the variations of generic information visualization.

Visualization techniques can be found within many different fields. Many authors distinguish between three different kinds of visualization; Information visualization, Scientific visualization and Geovisualization (Spence 2007). The areas are differentiated by what kinds of phenomena they are representing. Spence (2007) describes information visualization as representing abstract phenomena, such as stock markets, car sales, and statistics. Scientific visualization represents physical phenomena, such as laser scans of objects, and thermal imaging of buildings. Geovisualization represents spatial phenomena, either from the physical or virtual world. Both Minard's map, Beck's Tube map and Snow's cholera map are all examples of geovisualization. The different kinds of visualization are not, however, strictly distinct as applications - examples that overlap are inevitable.

Regardless of the type and area of visualization they all have a common foundation, namely the cognitive perception by human viewers. No visualization is made solely for computers to watch, rather they are made for humans to view and interpret. Understanding and categorizing the cognitive functions of humans is a goal long sought after in psychology, and the quest is by no means over. Gestalt psychology approaches human perception as a holistic system, meaning that the general form of an object is perceived before the details. A set of principles describing the different phenomena of Gestalt psychology has been developed by psychologists (Köhler 1929, Koffka 1935). Seven of the fundamental principles are described here. The principles are illustrated in figure 3 and include: Proximity,

similarity, connectedness, continuity, symmetry, closure, relative size, and the figure/ground effect.

When objects, such as points, are close to each other, they tend to be interpreted as a group. This is called the principle of **proximity** or spatial proximity. Proximity can be illustrated by drawing two sets of dots where the internal dots are close to each other with a distance between the two sets. Perceptual grouping of objects is not limited to groups of dots, but can also as easily appear in the form of lines, rows or shapes that are grouped together. Snow's cholera map, mentioned earlier, had its success primarily because of the spatial proximity principle, as this allowed the viewer to group points together and infer that their density was greater in the vicinity of the water pumps.

Humans are geared towards identifying similarities, often to such an extent that details are overlooked in favor of perceiving similarity. This is the principle of **similarity**. Perceptual grouping of similar objects can occur based on all kinds of attributes, such as color, shape, and pattern. The visual variables, discussed later, classify the attributes even more finely (Bertin 1983).

Perceptual grouping from either spatial proximity or similarity can be overtaken by the even stronger principle of connectedness (Palmer and Rock 1994). Lines or other forms of visually connected objects are more powerful than color, shape, and size. Node-link diagrams, very frequently used for visualizing graphs and trees, make extensive use of this principle.

Grouping is not the only perceptual phenomenon in the Gestalt principles. Humans also have the ability to search for, identify and perceive **continuity** between objects. Figure 3c illustrates the continuity principle by a collection of line segments. The line segments are perceived as a cross and not as a collection of line segments. The effect is also present in curved lines and even overlapping lines, where continuous objects are perceived instead of their discontinued alternatives.

Relevant to the principle of continuity and forming objects is the principle of **symmetry**. Symmetrical elements tend to provide a very powerful sense of surrounding objects, or forming a visual whole. When presented with the same elements in parallel, the perceptual interpretation is much weaker.

As with symmetry, humans tend to search for **closure** of objects. A circle broken by an overlapping rectangle is for instance perceived as a circle, rather than a curving line with two ends. The effect can also be seen with overlapping lines, where we tend to form regions and areas based on the line crossings. A Venn diagram without color is a perfect example of the closure principle where we perceive the intersecting areas as regions, but also perceive the intersecting circles as circles.

The size of objects obviously also plays its part in its perception. A collection of smaller objects tends to be perceived as one object instead of individual elements. The principle of **relative size** is used extensively in

cartography both for labeling in topographic maps and thematic maps and in particular scaled circle maps.

Effects that differentiate the depth of a graphic is also very commonly used, and sometimes misused in cartographic maps. This effect is called the **figure ground** effect. Rubin's vase (Rubin 1915) is probably the best known example of the figure ground effect. A symmetrical, black, vase with a distinctive shape on a white background can either be perceived as a vase, or as two faces looking directly at each other. This effect happens due to the balancing of figure and ground. A somewhat similar effect can often occur in maps when a blue color is used for countries and white for the ocean. Especially in unfamiliar areas, the ocean can then be perceived as land and land as ocean.

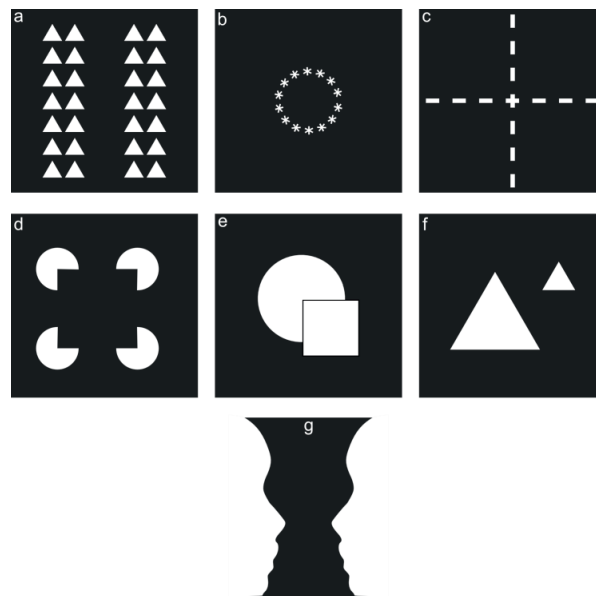


Figure 3: The seven gestalt principles illustrated: (a) the proximity of triangles creates two rows. (b) Similarity: The collection of stars is perceived as a circle. (c) Continuity: many small line segments are perceived as a cross and not even four lines meeting. (d) Symmetry: A square is perceived in the negative space – this is also partly influenced by similarity. (e) Closure: A circle is perceived behind a square, even if it the circle is actually a discontinued shape. (f) Relative size: larger objects are perceived in the foreground of smaller objects. (g) Figure/ground: Rubin's vase is perfectly balanced between figure, ground and symmetry (adapted from Wikimedia.org).

Understanding and quantifying human perception in relation to visualizations has not only been a topic for cognitive psychologists. Jacques Bertin, a French cartographer, put forward a set of graphical or visual variables describing the semiology of graphics (Bertin 1983). Graphics can, according to Bertin, be described using six distinctly different variables. According to Spence (2007), each of the variables can be evaluated in terms of four viewer tasks. Figure 4 depicts the six variables and their relationship to the four different viewer tasks.

| | Association <i>Perceived as similar</i> | Selection <i>Perceived as different</i> | Order <i>Perceived as ordered</i> | Quantity <i>Perceived as proportional</i> |
|-------------|--|--|--------------------------------------|--|
| Size | | | | |
| Value | | | | |
| Texture | | | | |
| Color | | | | |
| Orientation | | | | |
| Shape | | | | |

Figure 4: Bertin's graphical variables and their properties as suggested by Spence (2007). Figure adapted from Spence (2007).

Several scholars have challenged the visual variables of Bertin. Cleveland and McGill (Cleveland and McGill 1984) focused on the ability to describe quantitative data and the ability of accurately doing so by means of different variables. The result is a set of ordered variables, some from Bertin's original variables, which are

ordered in terms of their ability to accurately describe quantitative data. MacKinlay (Mackinlay 1986) categorized different variables, or encoding mechanisms, in relation to their ability to describe quantitative, ordinal and categorical data. The different mechanisms are ranked in relation to each other. Bjørke (2005) has a slightly different view than Spence (2007) on the viewer tasks and their relation to the visual variables depicted in figure 5. The most apparent differences from Spence's point of view (figure 4) are the added variable of location and the non-binary relation to viewer tasks, or variable properties. Bjørke also introduces *visibility* as a task in favor of *association*. The notion of visual hierarchy is discussed in light of the variables relationship to *visibility*, a notion which is not directly addressed in Spence's view on the visual variables. As illustrated by the two viewpoints of Bjørke and Spence, the different viewer tasks of the visual variables and even the relationship to the tasks have different variations throughout the literature. Both the visual variables and their qualities are sure to be open for more interpretations and variations in future studies alongside with technological and theoretical evolution.

| | Visibility | Selective | Ordering | Quantitative |
|-------------|------------|-----------|----------|--------------|
| Location | Yes | Yes | Yes | Yes |
| Size | Variable | Yes | Yes | Yes |
| Value | Variable | Yes | Yes | |
| Texture | Yes | Yes | Weak | |
| Color | Yes | Yes | | |
| Orientation | Yes | Yes | | |
| Shape | Yes | | | |

Figure 5: Bertin's graphical variables and their properties as suggested by Bjørke (2005). Figure adapted from Bjørke (2005)(Spence 2007).

Graphical variables and the understanding of human perception is the backbone of the visualizations known today and in the future. The different properties and their association with the different variables are bound to be questioned, challenged and revised, both for different contexts and from different scientific communities.

In recent decades, the era of digital technology has enabled a massive potential for data creation, gathering, processing and visualization. Visualizations that consumed hours to make can now be made within milliseconds. Reproduction and distribution is now a question of virtual connection, not of physical resources. The technological evolution has sparked many new approaches to visualization. With the increasing connectivity offered through mobile devices, social media

platforms and cloud computing, the pace at which information is generated is enormous and is rapidly increasing. Some researchers have hypothesized that a key to navigating and making use of the wealth of information lies within visualization (MacEachren and Kraak 1997, Spence 2007, Fry 2008, Virrantaus *et al.* 2009).

Large displays is an example of a technology that readily comes to mind when discussing visualization of big data due to their large footprint. Large displays can cover entire walls and easily stretch into tens of meters (Andrews *et al.* 2011). Technological limitations are no longer an issue. The economic cost is low, the scalability and computational capacity high. There are, however, issues with large displays that do not pertain to the technology but to the human user. Large size means that the user often needs to physically move around to get a better view of the display, either to see more clearly, get a better angle at the focus area or even to get more details (Andrews *et al.* 2011). The latter raises an interesting discussion about how the visualization methods need to be addressed at the level of detail visible from a range of distances, and not only from one distance, which is often the case for traditional visualizations.

Dynamic viewing distances can also be taken advantage of by the visualization to implement a natural “zoom” which can graphically reveal more details when the user is coming closer to the display, while when moving further away, the graphical similarity means the user is perceptually grouping the details into one object (Andrews *et al.* 2011). The phenomenon can be linked to the Gestalt principles mentioned earlier, and is also referred to as the micro/macro phenomenon (Tufte 1985).

Additional considerations when dealing with large displays are also primarily attributed to the constraints of the human users and not the technological capabilities. Moving from the issues of big data and large displays – mobile devices have seen a tremendous growth and has impacted the way we surround ourselves with technology. Screen size is one obvious limitation of mobile devices. The physical size is inherently limited to being of a mobile form factor. On the other hand, the pixel density and space available for visualization is increasingly higher and bigger. Moreover, mobile devices, in particular smartphones, have developed a trend in containing a wide range of different sensors, many of which are environmental sensors such as positioning, accelerometers, magnetometers, and light detectors. The array of different sensors in combination with touch sensitive screens invites the exploration of new interaction methods and visualization techniques.

Mixed reality is an example of this. Augmented, or mixed reality, overlays virtual information on top of images or video streams of the physical world (Hedley *et al.* 2002, Hedley 2011a, 2011b). Interaction with mixed reality applications are very often tied to a physical interaction such as moving a mobile device in a manner similar to a camera.

Spatial visualizations, in particular in the form of topographic maps, have seen an explosion in popularity on mobile devices in the last decade. This can be attributed to the positioning capabilities and connectivity of the devices. A similar explosive development has also been observed on the web in general. New user groups of spatial visualization have emerged, in particular in the cross-domain of computer science and art – often referred to as new media art (Rush 2005, Chorianopoulos *et al.* 2012). Nossum (2012) discusses the use of spatial components in new media art. The discussion is put into context by presenting several novel art works utilizing, and in some cases expanding upon, spatial technologies. Previous work from the new media literature has identified both conceptual and practical issues arising between the intersection of computer science and art. Moreover, the issues arising at the social level between artists, computer scientists, and other stakeholders are also identified in earlier work. Nossum (2012) expands upon the earlier work in the intersection between computer science and art by introducing spatial technologies and spatial scientists as important parts of the new media art field, for scientific purposes but primarily as a tool for artists.

The wide range of different applications and developments of visualizations have also sparked the development of the theoretical foundations of visualization. Interactive technologies open for unlimited methods of manipulating visualizations displayed to the user. In the context of interactive visualizations, the visual variables of Bertin have been expanded upon to reflect and properly describe the possibilities made available by modern technologies. Brushing and linking are two important variables which are examples of this (Ware 2004, Spence 2007, Kraak and Ormeling 2010). Brushing makes the user able to move over (for instance hover the mouse) objects to trigger an event, such as displaying similar items or more information about the object. Brushing is very frequently used in spatial visualizations and is employed in the candidate's work in paper III and V. Linking is in particular useful in a multi-component view where many individual visualizations display information using different techniques. The coupling between the visualizations can be made stronger by linking the components together such that for instance selecting, or brushing objects in one will trigger the same response in all of the different views of the information.

Understanding the way humans perceive different graphical mechanisms and exploring different interactivity methods available with modern technologies means the visualizations are, more often than not, a dynamic graphical representation. Spatial information is very often of a temporal nature, such as the case is with the number of soldiers in Napoleon's march. Minard (Friendly 2002) solved the issue of visualizing the complex spatio-temporal information in an elegant manner. However, the information at hand does not always suit such possibilities since interactivity and manipulation is often desired by the user to

explore the sets of information. The following will have a closer look at the dynamic and animated visualization in the context of the work by the candidate.

Dynamic and animated visualization

Several interesting phenomena are not only restricted to a single point in time but occurs over a period of time. Dynamic and animated visualizations are often desired to visualize this kind of spatio-temporal information. Modern digital technologies have enabled cartographers to rapidly design dynamic map animations. Early methods of designing and implementing an animation consisted of drawing each individual frame and displaying each in a sequence, such as Disney's animation of the invasion of Poland from 1940 (Peterson 1999). The principle is the same today, but technology has made the production of frames very flexible and efficient. With a rapid increase in the availability of spatial animations, the need to extend the understanding of what controls an animation equally increases. Bertin's visual variables are made and designed for static graphic representations and do not completely cover the dynamic nature of animations. DiBiase *et al.* (1992) proposed an extension to Bertin's visual variables to allow the support of dynamic animations. The extension consists of three dynamic variables: Duration, Order and Rate of change.

Duration is at the heart of an animation and describes the length in time a single scene lasts. A scene can be described as a situation in the history of time (Szegö and Miller 1987) and is for all practical purposes a state in the animation.

Order or the sequence of which the scenes are displayed greatly affects the expression of the animation. The dynamic variable is often overlooked as in the majority of situations the scenes are ordered according to the temporal reference in which they occur. However, changing the order to other attributes can greatly change the expression of the animation and lead to valuable perspectives of the information (Weber and Buttenfield 1993).

Rate of change of an animation describes to what degree the animation is changing. The variable is described by the magnitude of change between scenes and the duration of this change. A change between two scenes is often referred to as an event. The magnitude of an event can be described by the sampling interval used to generate the individual scenes and the dynamics of the phenomena represented. A small magnitude of change with a long duration can for instance lead to large rate of change, which can be perceived as less smooth and more abrupt. Blok (2005) criticized the rate of change of not being a variable of its own but an effect of other variables; nevertheless an important aspect of animations is described through the rate of change.

DiBiase's dynamic extension to the original visual variable was further extended by MacEachren (MacEachren 2004) with three more variables: Display date, Frequency and Synchronization.

Display date is an often-forgot, but very frequently used, variable that describes the moment of display that is marked by a change in the animation. In many animation applications this can be thought of as key frames, or frames that represent the change between states. The time at which these occur is the display date.

Frequency is defined as the number of identifiable changes per unit of time. If for instance there were 10 changes occurring per every other second, then the frequency would be 5 (changes/s). The frequency can be used to properly describe effects such as different blinking patterns.

Synchronizing multiple animations with regards to a common attribute can reveal patterns and similarities between them. The most apparent is to synchronize animations with respect to the temporal dimension. Temporal synchronization can be as simple as adjusting the playback of two animations to follow the same scale and speed. However, synchronization on other dimensions, such as for instance a geographic area, can have a similar effect.

Animations and dynamic visualizations have issues due to the perceptual capabilities of humans that do not occur with static visualizations. One of the strengths of animations is the dynamic ability to change the visualization and thus the information displayed to the viewer. The assumption is that the viewer perceives the changed information; this is not always the case. Perceiving changes are in many situations very difficult. The phenomenon is called *change blindness* (Rensink 2001, 2002, Simons and Rensink 2005), and is the effect that changes in stimuli is often not perceived. The degree of change blindness depends on the rate or amount of change and the position of the change. Facilitating the change with smoother transitions and change clues can limit the amount of change blindness (Rensink *et al.* 1997, Fabrikant and Goldsberry 2005, Fabrikant *et al.* 2008, Fish *et al.* 2011).

Another blindness that is observed in particular for animations is inattentive blindness. The result is equal to change blindness in that the viewer does not perceive information displayed in the animation. The reason, however, is different. The result of changing the displayed information in an animation can be that previous information is removed from the animation, and not displayed to the user. In more general terms, information displayed in an animation can be said to have a fixed time of display or lifespan with the current animation techniques. The user can seldom see beyond or in the past of the point in time the animation is at, without interacting, controlling or in other ways manipulating the animation. This effect leads to the assumption, or requirement, that the viewer is fixating at the right positions in the animation at the right time in order to perceive what is

displayed at that exact moment of time. In many situations, in particular for casual cartographic animations, such requirements are not reasonable. In practice, viewers do not fixate at all relevant positions at all relevant times. This is the essential feature of inattention blindness: The viewer does not pay sufficient attention to what is displayed and thus loses some of the displayed information (Hegarty *et al.* 2003, Hegarty 2004, Ware 2004, Spence 2007). An example of inattention blindness is an experiment where subjects are instructed to look at a video of a group of people playing ball and to pay particular attention to this group (Chabris and Simons 2011). In addition to the group of ball players, a person dressed as a gorilla also appears in the video. The subjects are not told about this in advance and are as such unaware of it. The interesting phenomenon is that subjects are paying so much attention to the ball players that they do not see the gorilla. Some subjects even believe they saw a different video! In the experiment, the subjects were clearly so blinded by their attention to a limited amount of the information displayed that they lost a significant amount of the rest of the information.

Results

Semistatic animations

Inattentional blindness and change blindness are cognitive effects often stimulated by animations. The effects can be attributed to the design of animations. The displayed information in spatial animations, such as temperature, is very often displayed as symbols that change throughout the duration of the animation. As an effect, the symbols have a fixed lifespan in the animation. Change and inattentional blindness can easily occur under these circumstances. Imagine a user looking on the TV at a weekly, non-interactive, weather map animation of Europe. If the user is focused on the weather and temperature in Norway when the animation is on Monday, it is unlikely that the user also perceives the weather in Spain at the same time without consciously moving his fixation while the animation is still on Monday.

The benefits of cartographic animations in relation to their static counterparts have been a topic of interest for many researchers. The reported findings from the literature are diverse and not unanimous in their conclusions (Tversky *et al.* 2002, Hegarty *et al.* 2003, Price 2004, Slocum *et al.* 2004, Fabrikant and Goldsberry 2005, Midtbø and Larsen 2005, Griffin *et al.* 2006). Animations are often compared to their static equivalents in the context of evaluating which is better, and potentially, why one is better than the other. A frequent underlying assumption in comparisons between static and animated maps is that they are informationally and computationally equivalent. Fabrikant *et al.* (2008) argue that this is not the case. Nevertheless, several challenges have been identified with spatial animations, in addition to the already mentioned challenges of change and inattentional blindness, these are: (dis)appearance, attention, confidence, and complexity (Harrower 2003, Dodge *et al.* 2008). Several solutions to the different challenges of animations have been suggested in the literature. Adding interactivity to allow the user to control and manipulate the animation, in particular controlling the playback, is one solution that can address many of the challenges (Harrower 2003). However, many argue that added interactivity also carries with it an added cognitive load which may not be desired (Tversky *et al.* 2002, Hegarty *et al.* 2003, Griffin *et al.* 2006, Fabrikant *et al.* 2008).

One largely unexplored solution to some of the animation problems is the incorporation of a temporal dimension in symbol designs (Midtbø 2001, 2007, Midtbø *et al.* 2007). The main reason for change and inattentional blindness, as well as (dis)appearance and attention, is the fact that the symbols are designed to display the information at the current temporal position. The symbols thus embrace

a short lifespan and results in an animation where past and future information is not available before they are displayed. The concept of semistatic animations is the idea that a temporal legend can be incorporated on the symbols themselves, which is the topic of paper I. At any given time in the animation, the user should be able to see information from the “past”, the “present” and the “future”. In the strongest sense this would mean that the animated part of the visualization contributes only to the facilitation of the user’s perception and not to controlling when information is displayed. As such, semistatic animations can in the most extreme situations display the complete information in every static frame of the animation.

To investigate the semistatic concept and explore its possibilities, a scenario was described that focused on weather map animations. The weather maps were differentiated between symbolic weather, like sun, rain, cloudy, and numeric temperature including both negative and positive numbers. Weather map animations are commonly used both on web pages, large displays and on television. In the scenario a non-interactive solution was desired to avoid any additional cognitive load and to better investigate the cartographic design, rather than the interaction design.

The symbols for the weather maps were redesigned to allow the viewer to see what had been displayed and what was about to be displayed. The weather symbols were implemented by adding a small temporal legend underneath the regular weather symbol. The regular weather symbol changed according to the current time in the animation, which was also reflected in the temporal legend. This new design makes intensive use of the visual variables: location, color, and shape to maximize the ease of interpretation and visual communication to the user. Figure 6 shows the results of the implementation of weather maps with explanations on the different key concepts. An obvious limitation of the temporal legend is the amount of information that can be displayed. In the implemented prototype, four days, using four symbols, made up the complete information. In other scenarios, one could easily imagine a larger set of information. One solution to this issue could be to only show a defined range in the past and future information, such as four in either direction, and then dynamically change the legend to reflect this. Another solution could be to use a fish-eye visualization (Furnas 1981, 1986) to achieve a similar effect. Both of these approaches would experience the previously described cognitive challenges but in a smaller degree than in the case of not having any additional information.

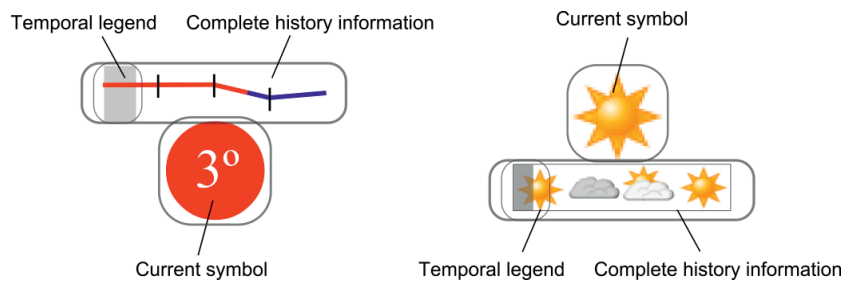


Figure 6: *Semistatic symbol for temperature maps to the left and weather symbol maps to the right.*

Temperature is numeric information which allows for a wider set of conventional visualization methods (Spence 2007, Heer *et al.* 2010). An overall approach, similar to the weather symbol design, was chosen for the temperature symbol. The current temperature was displayed using a conventional circle with the temperature number inside and filled with either red or blue to represent temperatures above or below the freezing point. A temporal legend was positioned above the conventional symbol to include the temperatures during the complete set of days covered in the animation. The main difference between the temporal legends for weather symbols was the visualization type used. The selected visualization for the temperature map was a line graph with time markers for each day. Figure 6 illustrates the symbol concept with labels. The line graph was chosen to better visualize the trend and the relationship to the temporal dimension. Other, similar visualization types can easily be incorporated such as sparklines (Tuft 1997), rose charts (Windhistory.org 2012), and even horizon graphs (Heer *et al.* 2010). The disadvantage of using a line graph in the temporal legend is the inability to accurately read the exact value of a line graph without including labels or axis marks. The choice of not including this was due to very limited available space if the redesigned symbol should have a comparable footprint as the conventional symbol.

An empirical experiment was designed and conducted to investigate how well the semistatic concept performed, in relation to a conventional animated equivalent. The experiment consisted of two individual parts. The first part aimed at comparing the performance between the semistatic and regular animations for both the weather symbol map and the temperature map. This was designed and conducted in a distributed web experiment with three different tasks: 1) trend on one location, 2) trend over space and time, and 3) memory task. In total, 265 subjects participated in the study. The main findings from the study related to the weather symbol maps where there was a significant increase in the amount of correct answers for the semistatic animations in task 1 (trend on one location) compared to the regular animation. Moreover, there was a similar significant

increase in the correct answers for the task 3 (investigating short term memory capabilities).

No similarly significant increase was found in the temperature animations. It was expected that task 1; trend on one location, would show a significant benefit from the semistatic concept. However, this was not the case, nor was it the case with the memory task. Task 2 (trend over space and time) did, however, get a significant increase in the amount of correct answers with the semistatic animation. These results were surprising, but can be attributed to the difficulty of obtaining an accurate reading from the line graph.

The second part of the experiment concentrated on fewer participants and collected the eye movements of the subjects using an eye-tracker while performing the exact same experiment. This version of the experiment is described in paper II and III. Eye-tracking is gaining increased attention due to its ability to study how users use maps and other stimuli (Brodersen *et al.* 2002, Fabrikant *et al.* 2008, Coltekin *et al.* 2009, Li *et al.* 2010). The availability and ease of use has made the technology a viable and interesting method for understanding use and user issues in both commercial and cartographic research. Eye-tracking records the subject's eye-movements by using infrared cameras and infrared light in combination with advanced algorithms to calculate where the subject is fixating at any given time. The regular sampling frequency was, at the time of conducting the experiment, around 50 times per second. However, at the time of writing, eye-trackers able to sample at 2000 times per second are commercially available (Ooms *et al.* 2012, SR-Research 2012). In any case, all of these sampling frequencies collect a massive amount of data. The method of analyzing eye-movement data in the quest for understanding the use and cognitive issues with visual stimuli has been criticized in the literature (Fabrikant *et al.* 2008). Eye-tracking samples only the fixation points which obviously does not cover the complete visual perception of humans. The peripheral vision is, for instance, completely ignored in all of the regular analysis techniques. Moreover, questions have been raised to whether analyzing eye-movements can provide the researcher with anything else than what can be achieved using conventional, and often more efficient, empirical evaluation methods – such as questionnaires, focus groups and similar (Fabrikant *et al.* 2008).

The eye-tracking experiment included the web experiment used for evaluating the semistatic concept, which was run in the same fashion as during the web experiment, but with an eye-tracker recording the eye-movements of the subjects. Another animated cartographic interface was additionally evaluated in parallel. The interface, described in Opach *et al.* (2011) and paper II, was a prototype of a map system with several linked visualizations, including an animated map. The system described a geographic phenomenon intended for exploration and learning. In total 10 participants were recruited for the eye-tracking study. In the first analysis of the data from the semistatic animations, described in

paper II and III, the methods used were standard methods for eye-movement analysis including: time to first fixation, observation length and fixation counts. The metrics were compared on the basis of the different tasks and the different animations. The results from the questionnaires were comparable between the eye-tracking experiment and the web experiment, which could indicate a similar and comparable subject population. However, when comparing the eye-movement metrics, the results were surprising. Observation length, fixation count and time to first fixation were surprisingly similar between the semistatic animation and the regular animation. These findings would indicate that the user behavior and comprehension were in fact very similar. In particular the results from the trend over space and time task are interesting. The hypothesis was that the subjects watching the regular animation would first look at either the first point of interest (Kristiansand) or the temporal legend and then move on to the next point of interest in sequence, following the temporal sequence of the animation. This was confirmed by the time to first fixation analysis for both the weather symbol map, depicted in figure 7, and the temperature map. A different pattern was expected to occur with the semistatic animation. The semistatic animation allowed the user to move back and forth and, regardless of the animation playback, be able to see the relevant information. When using regular analysis techniques, such as time to first fixation, it is very difficult to assess whether the participants made use of the ability to move back and forth in time. The regular analysis techniques are not designed to investigate patterns that occur across the temporal dimension. Bearing this in mind it is not surprising that the different patterns are similar.

A subject can, for instance, first look at the points of interest in the expected sequence, and then move back and forth after that, looking for more. This behavior cannot be investigated in a streamlined way using hitherto available analysis tools. Paper III explores the extension of a new way of analyzing eye-movement data that is specifically designed for changing stimuli, such as animations.

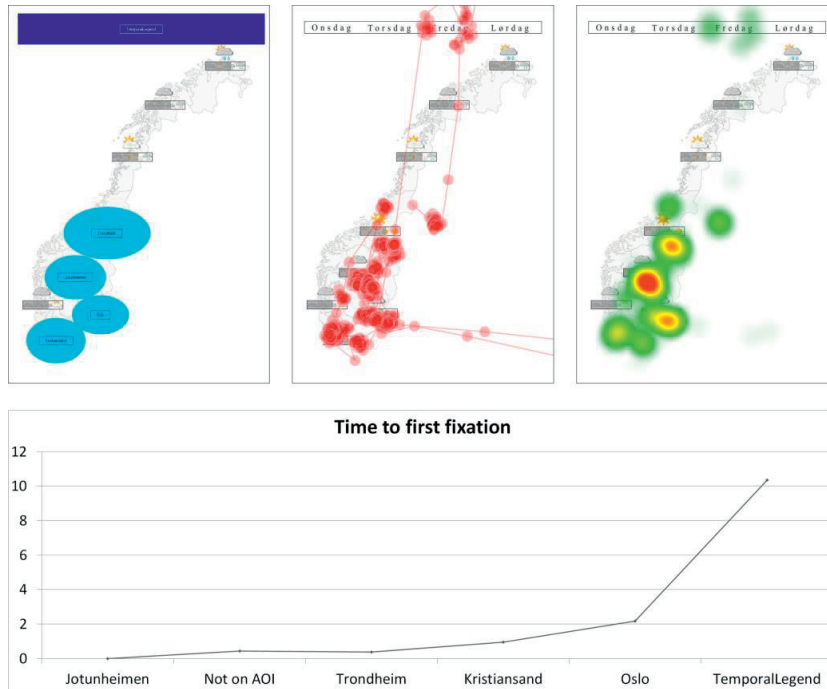


Figure 7: Eye-movements analyzed with standard methods. Top left: Areas of interest. Top center: A gaze plot, visualizing the fixations and saccades between them. Top right: A fixation density plot (“heatmap”), depicting the fixation frequency. Bottom center: Graph over time to first fixation on the areas of interest.

Using standard eye-movement analysis tools is not optimal for changing stimuli such as cartographic animations. Web pages, maps and dynamic information systems also fall into the same category and are equally hard to analyze using conventional methods. Relying solely on the standard analysis methods, without taking into account the dynamics of both the stimuli, but also the nature of eye-movements, can have ill effects on the results. However, eye-tracking can provide an insight into the effects of change blindness and inattention blindness, as well as other challenges of animations. Moreover, eye-tracking has the potential of providing information of where, when and in which sequence subjects are looking at different stimuli, but not without new specifically designed analysis tools and methods. Paper II and III are motivated by increasing the potential of eye-movement analysis through new ways of visualizing and looking at the eye-movement data.

Analyzing the dynamics of eye-movements is, as we have seen, challenging, in particular with dynamic and changing stimuli. Earlier work presented in Li *et al.* (2010) explores the possibility of using a space-time-cube (STC) to visualize eye-movement data which enables better exploration of the data in all three relevant dimensions; position of the fixation (X and Y) and the time of fixation (T). The space-time-cube visualization was first presented by Hägerstrand (Hägerstrand 1970) to alleviate the problem of ignoring time in geographic analysis and visualizations. The space-time-cube is a regular cube with three axes, well known from mathematics; however, the dimensions of the axis are slightly modified compared to a regular spatial cube. The X and Y axes represent the regular North/East, Latitude/Longitude or a similar geographic coordinate pair. The Z axis does, however, not represent the usual geographic dimension of height, but instead represents the temporal dimension. Shifting the Z axis to represent other dimensions proved to result in very elegant visualizations in which patterns could easily be seen. Successful examples are plentiful from several domains (Kraak 2003). In particular migration patterns can be very successfully visualized and allow for immediate appreciation of clusters in both space and time, but also patterns across time and space such as movement from the east and west coast of a country at the same period of time to a similar location.

When analyzing eye-movement data, regular analysis methods often do not consider the temporal dimension more than the usual, and already illustrated, time-to-first-fixation. Three essential components make up the eye-movement data: position of the fixation in X and Y, in addition to the time of the fixation, T. Looking back at Hägerstrand's space-time-cube, these are exactly the same three components that make up the space-time-cube. Li *et al.* (2010) made use of this realization in their work by visualizing eye-movement data in a space-time-cube. Paper III extends the idea and discusses it in the context of analyzing eye-movement data captured from dynamic stimuli. Three-dimensional visualizations can be impressive, useful and eye-opening. However, as with cartographic animations, three-dimensional visualizations similarly exhibit several challenges. One of the toughest problems is the inability of a cube to display all of the information without hiding some of the information. Severe cases of overlapping can easily occur in three-dimensional visualizations. Without any additional mechanisms, the viewer can experience problems perceiving information which renders the visualization less useful. When using traditional displays to show the visualization, it is most commonly shown on a two-dimensional display. Obviously, the three-dimensional visualization has to be projected to the two-dimensional surface. The projection and in particular the rotation and position of the three-dimensional objects, can result in a difficulty for the viewer to compare objects to each other (Spence 2007). To overcome some of the problems of three-dimensional visualization, user interaction is often the solution. Adding

interactivity allows the user to manipulate the visualization by methods such as: rotation, panning, and zooming. The user can obtain a better cognitive understanding of the information by looking at it from different perspectives and understanding the spatial relations between displayed entities. There is ample support for this in the literature where quotes such as: “for 3D to be useful, you’ve got to be able to move it” (Spence 2007) and “3D is for demos. 2D is for work” (Nielsen 2012a, 2012b), can be found.

Paper III goes into detail about how a space-time-cube can be used in better ways to support analysis and exploration of eye-movements as well as solving some of the problems mentioned above. One such solution is to explicitly visualize the projections of the space-time-cube in an interactive and linked manner which invites the user not only to manipulate the cube, but also to brush (Spence 2007) over the fixed two-dimensional projections of both XT, YT and the regular XY dimensions. Figure 8 depicts an illustration of such a concept that has been implemented as a working prototype. The implemented prototype used real eye-movement data and stimuli from the earlier eye-tracking experiment on semistatic animations.

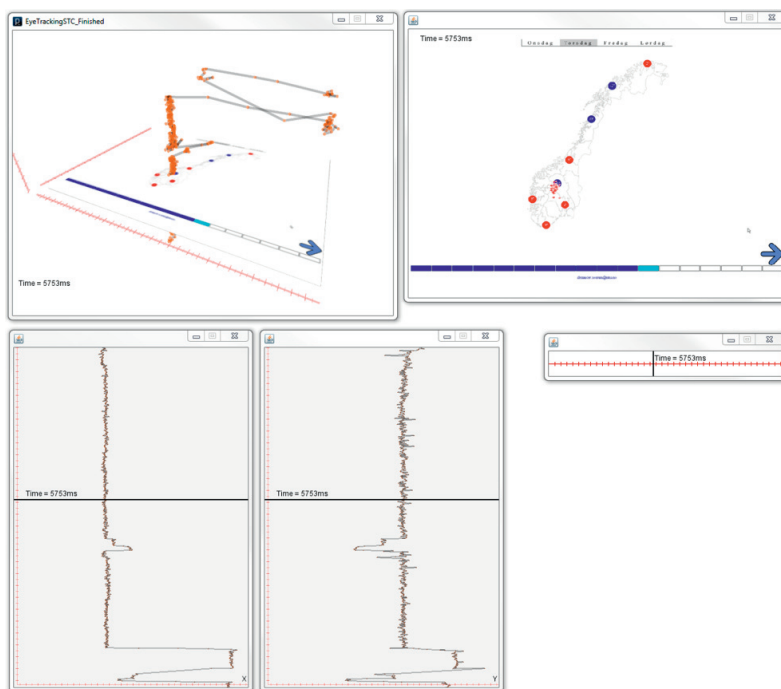


Figure 8: Screenshot of the prototype with several interlinked, dynamic and interactive, two-, and three-dimensional visualizations.

Figure 9 depicts an example of the benefits obtained by the multi-component linked layout and in particular from the two-dimensional projections in the XT and YT dimensions. Patterns in both of the projections can be identified. The most interesting pattern is the sequence of which elements are fixated upon and the point in time this occurs. From the highlights and labels it is apparent that the first element is fixated upon two times at the end of the animation, which could indicate that the user wants to get more information from this element. Although in the relevant task, this information would have already been displayed and was not available for the user at that point in time. These findings argue in favor of the semistatic concept, where this information would have been available to the user throughout the duration of the animation. It is also interesting to notice how the YT projections make it easy to see a pattern moving back and forth between the points of interest, in particular between the temporal legend and the map symbols.

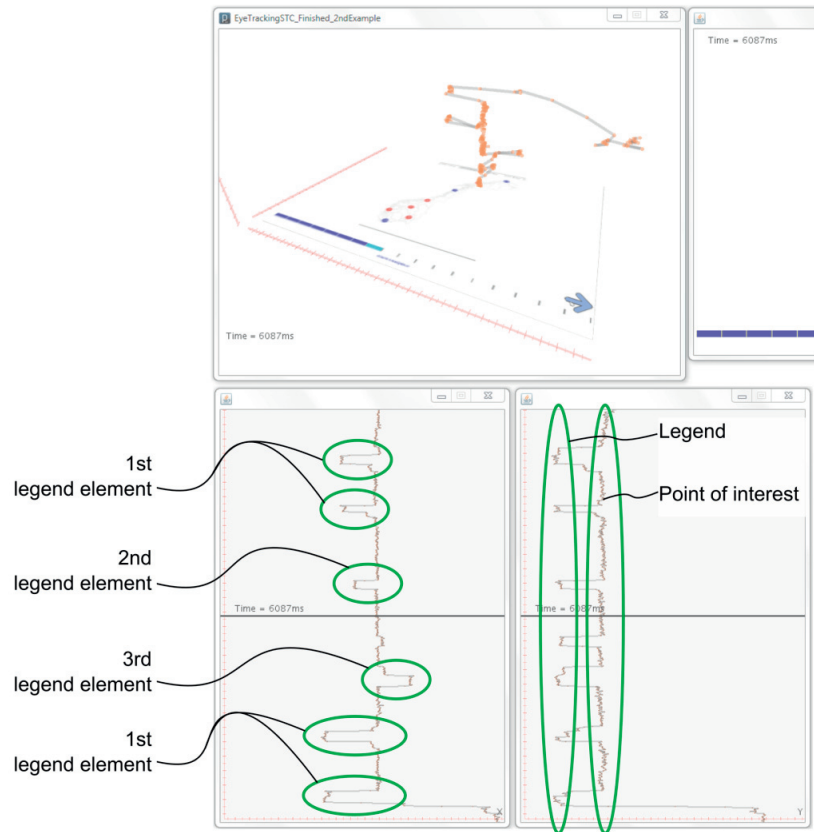


Figure 9: Example of a discovery of patterns in the two-dimensional XT and YT projections which are difficult to discover in the three-dimensional space-time-cube. The pattern found in the XT plot (bottom left), discovers movement between the legend elements in relation to the time. The YT plot depicts a pattern that is related to the different areas of interest in relation to the playback. Both plots show consistent patterns that would be impossible to detect in traditional analysis and difficult in a space-time-cube alone.

The concept of visualizing projections of three-dimensional cubes, linked together in an interactive interface, proves to be very useful for in-depth eye-movement analysis, in particular with dynamic stimuli. Further investigations on the concept are needed to investigate the full potential of the idea. Use in other domains and for other tasks would be very interesting to pursue. Examples of real-time monitoring

systems and real-time spatial awareness systems come readily to mind as potential application areas.

Glimpses of things to come: A guided tour of multi-storey indoor environments in the near future

Modern technology has increased the use of dynamic representations. Dynamic visualization is now taken for granted by users of modern computing and communication devices. Web maps, based on billions of tiles, with dynamic interactivity, such as brushing over route suggestions and visualizing live traffic situations, are an integrated part of many people's lives, both in front of desktop computers and mobile devices (Bing Maps 2011, Gartner 2011, Google Maps for Android 2012). Users expect spatial visualizations to be readily available everywhere, in an accurate and adapted way, tailored to the requirements of the user and the context. One area where they are not readily available yet is the indoor environment. Indoor environments are inherently more complex to map as they are often not publicly available and conventional mapping methods, such as aerial photogrammetry, are not viable solutions. An even more complex situation is the added vertical dimension caused by multiple floors. Multi-storey buildings are, as such, inherently more complex to map than outdoor environments like streets, forest etc.

Let us take a guided tour of how indoor environments could and should be supported by the technology of the near future. As our guide, let us enlist an imaginary friend, say Sophie, to help us understand the future potential of cartographic applications for multi-storey indoor environments. Sophie is a teenager, a high school student, and an avid consumer of indoor cartographic applications. She likes to hang out with friends, and loves social media like Facebook and Twitter, where she interacts with her friends using mobile devices. Sophie is also fond of shopping and is always hunting for bargains. Her favorite mall is The Mall of Europe, which has multiple stories, comprising over hundred different stores, a cinema and several restaurants. Before Sophie goes to the mall, she uses her mobile phone to get an overview of where her friends are to be found inside the mall, who they are hanging with and what they are posting on the various social media platforms.

This day could be an average day for Sophie in a not too distant future. Already, indoor positioning is viable and accurate enough for a significant number of different tasks - like the one described. Although indoor positioning is not as widespread as outdoor satellite based positioning systems, WiFi-based positioning systems are already being implemented in airports and other selected locations by

commercial enterprises (Google Maps for Android 2012). From the work presented in paper IV the investigations show that a commercially available WiFi-based positioning system can provide reasonable accuracy. With the support from reports found in the literature it is reasonable to project widespread use of indoor positioning systems in the future (Liu *et al.* 2007, Mautz 2009, Curran *et al.* 2011).

An unresolved issue in the quest to fully support Sophie's mall experience is: *What will Sophie see on her mobile device?* What type of map can best help Sophie to easily see where her friends are across multiple floors and compare their locations? This was the point of departure for paper V. The project, reported in the paper, developed a simple, yet innovative, way of visualizing entities across floors by using unique colors for each floor. The use of the visual variable *color* takes great advantage of the selective and ordering properties associated with color to communicate better the differentiation (selective) between floors, but also the relationship between them (ordering). A positive side effect is the independence of spatial building data. Only an outline, common in regular city maps, and the three dimensional position is necessary. The concept is called vertical color map. An illustration of several implementations of the concept is found in figure 10. An experiment was conducted to evaluate the vertical color map in comparison to a similar map with floor plan maps instead of color codes. Floor plan maps obviously depend on some knowledge of the interior structure. In total, 251 subjects participated in the experiment, all recruited from the student population of the University of Maine. Findings from the analysis show that the vertical color map is comparable to the floor plan maps, but comparison did not conclude with a strong statistical difference between the two. Further work implementing the vertical color map in a real life situation is hypothesized to be appreciated by the user in terms of spatial and social awareness tasks in familiar environments. Other areas of use for the vertical color map exist and should also be investigated further and evaluated to see if task differences occur. The vertical color map is strongly believed to have best success in situations where the user is familiar with the interior structure of the building – which can be said to be most of the time for most people. In any case, the independence of interior building data makes the vertical color map a very good alternative to floor plan maps in cases where interior building data are unavailable.

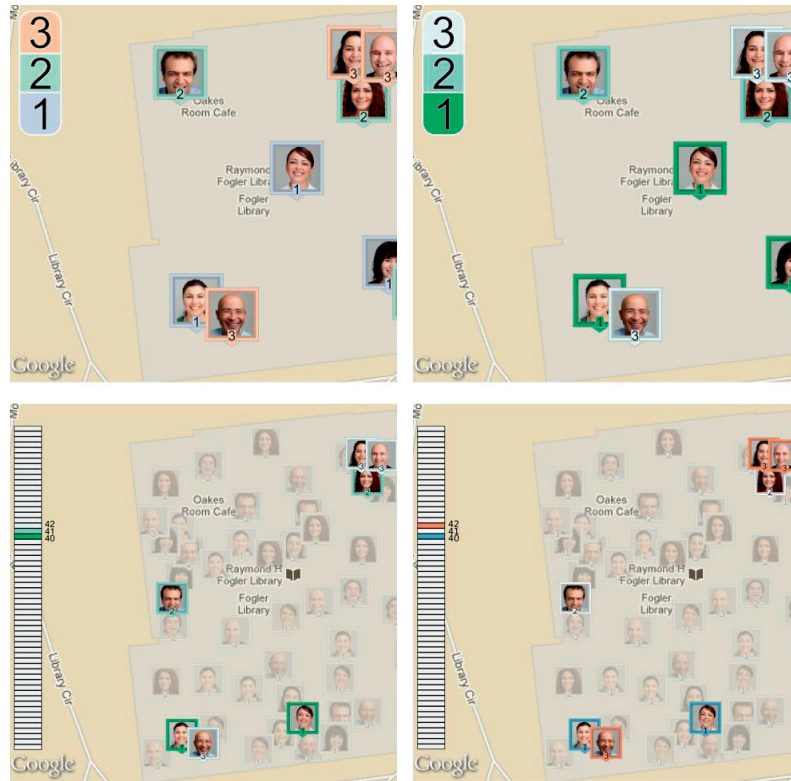


Figure 10: Four different implementations of the vertical color map varying the color scheme and the transparency to minimize visual cluttering.

Now, let us say that Sophie has finished high school, moved to another, much larger town, and has started studying at the university. Sophie still likes to go out with friends and keeps herself up to date on the social sphere with the social media that works even inside buildings using the virtual color map. She finds herself always in a rush to meet friends, play tennis, or go to yoga practice. In between, Sophie also experiences that she actually has a limited budget which also needs to cover groceries. After the first few months Sophie realizes that she needs to start doing her grocery shopping in the giant store ReMart, a couple of kilometers away from where she lives. Weekly or bi-weekly grocery shopping with preplanned lists and a spending budget is the ideal that Sophie tries to follow. The first time Sophie visited ReMart, she was flabbergasted by the size of the store, the number of products, the differences in quality and price. She used a whole hour and a half before reaching the check-out counter. After this experience, Sophie searched for solutions to her problem and found that, naturally: ReMart had an application for

guiding her through the shopping experience. The application worked on all devices, even desktop computers, and allowed her to type in her grocery list, suggest similar, often discounted, items and, probably the most useful feature of all, display a map of the store with lists of items displayed at their location. In the shop, Sophie used her mobile phone to track her movements in the store and get directional guidance. She also noticed that the application suggested items with heavy discounts in her close vicinity – she liked this, as the items were often very relevant for her.

The shopping experience described above is not only feasible with today's technology and methods, but is also partially being realized and implemented in several grocery stores (Bing Mall Maps 2011, Aisle411 2012, AisleFinder 2012, Google Maps for Android 2012, Rimi 2012). Figure 11 depicts several screenshots of location based grocery applications. An important aspect that simplifies the challenges of visualizing indoor environment of most grocery stores is the building layout that usually covers only one floor. The interior is also most often designed as aisles with a single entrance into the store and a single exit. This simplifies the visualization challenge tremendously. Visualization solutions covering single floor layouts are most successful when using a regular, stylized, floor plan maps. Customers are more likely to quickly comprehend a floor plan map and are, in general, used to the concept of floor plan maps. Findings from interviews in a wayfinding experiment, detailed in paper VII, suggest that users are quite familiar with, and appreciate, the regular floor plan layout – but find it difficult to use in multi-storey environments. During my thesis work, I deliberately did not go into detailed investigations on regular floor plan maps due to the reasons described above. In addition, there are reasons to believe that any work on floor plan maps would quickly be rendered outdated and irrelevant due to the pace at which commercial actors are racing towards floor plan map solutions for single-storey, and in some cases, multi-storey, buildings. Paper VIII discusses the different types of indoor map types that exist and their application areas, and proposes a method of classifying the different map types.

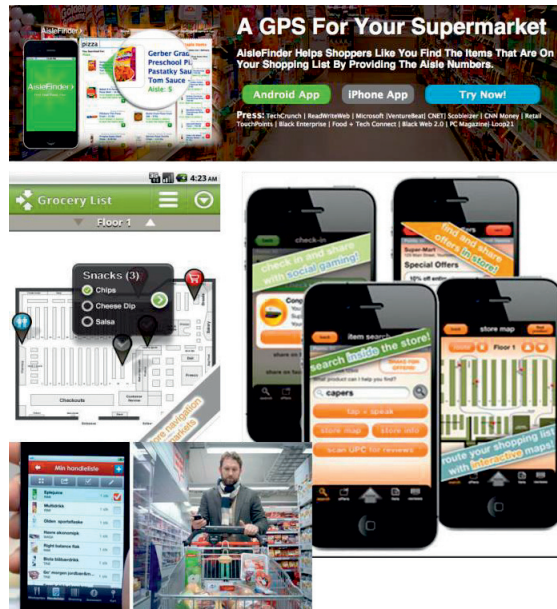


Figure 11: A collection of various examples of grocery shopping applications: *aislefinder.com* (AisleFinder 2012), *aisle411.com* (Aisle411 2012) and *Rimi pluss* (Rimi 2012).

For holidays, Sophie usually travels to foreign cities and places. All the travelling obviously involves stopping at many airports. On one of her stops, Sophie is greeted by a researcher inviting her to join a research project on a new map type for airports and indoor environments in general. Sophie is intrigued, as she is interested in the topic. She finds the current maps to be a bit confusing and not providing her with the ease of use she would like. The researcher presents her with what immediately looks like a subway map. After a short introduction to the concept Sophie is excited to see that it actually is a simplified and schematic map of the airport covering all the terminals, the different floors in each terminal and also the status and location of each gate – all without Sophie interacting with it.

The map presented to Sophie is an *IndoorTube* map. The *IndoorTube* map is, as Sophie noticed, directly inspired by transportation network maps. Harry Beck introduced the world to a new way of visualizing the London Underground system in the 1930s. Beck was an electrical engineer and was inspired by the schematic look and simple layout of circuit diagrams. When realizing the similarity between the London Underground and an electrical circuit, the result was astonishing. The tube map visualization considers only the topological accuracy of the transportation

network, has bends in the lines at only a few regular angles, such as 45 and 90 degrees, and aims at simplicity of the layout rather than geographical accuracy.

Indoor environments are, in several aspects, fundamentally different from transportation networks and in particular underground lines. However, conceptually, the similarities between underground lines and many indoor environments are surprising. Multi-storey buildings have the following salient features:

- Different and overlapping floors
- Floors are connected by elevators and stairs
- Floors are made up of corridors
- Each corridor has rooms

While underground lines have:

- Different lines
- Lines are connected by transfer stations
- Lines are made up of the geography of the line
- Each line has stations

While at the first glance underground lines and multi-storey buildings seem very different, they share many of the same concepts and structures. This was the realization of the IndoorTube map concept which is described and discussed in paper VI. The IndoorTube is in its essence an application of Beck's tube map on a multi-storey indoor environment. Figure 12 depicts the process of making an IndoorTube map. All corridors, common areas, rooms, elevators and stairs are typically digitized from an architectural building plan. The resulting layers of different floor lines are then aggregated into a single two-dimensional visualization. Due to the fact that many corridors and rooms physically overlap each other, adjustments have to be made to achieve an aesthetically pleasing result. The last step involves sacrificing metrical accuracy in return for better aesthetics and to avoid visual cluttering. In the rare case of smoothly bending corridors, they can be straightened out to achieve a schematic expression similar to the original tube map. Sacrifices of metrical accuracy can also be made to compress the space needed for the visualization. However, as will be evident later in paper VII, this was identified in a human subject experiment as leading to lower user acceptance and confusion in wayfinding tasks.

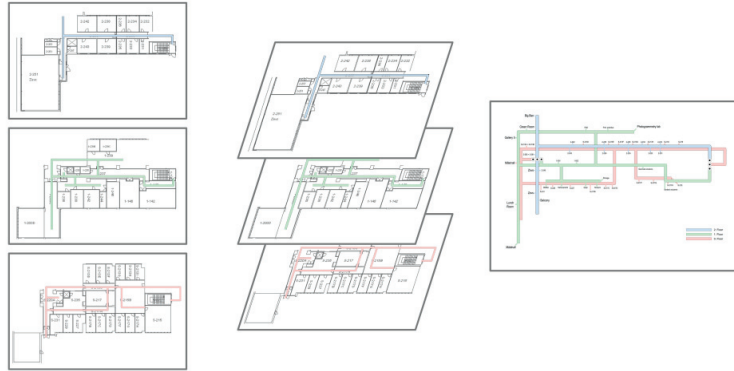


Figure 12: Illustration of the process of making an IndoorTube map from floor plans to finished map.

The color scheme is essential to the IndoorTube map. Colors are, similar to the vertical color map, used to differentiate between the different floors and thus represent the vertical dimension. The selected color scheme can be a qualitative scale which is appropriate for differentiating between the floors, but does not add any representation to the value or relationship between them (Brewer 1996, Brewer *et al.* 1997, Harrower and Brewer 2003). Another choice is to use a sequential color scale. In accordance with the visual variables of Bertin, (Bertin 1983, Spence 2007), a sequential color scale will allow differentiation between the different floors, but can at the same time represent the relationship, or value, of the vertical dimension such as floor 1 is below floor 2. Figure 13 illustrates the different color schemes on a simple IndoorTube map. As seen, the different color scales can have a wide range of different attributes and appearances, for example ranging from light to dark. For more literature and examples of the vast range of color scales the reader is referred to Brewer (1996, 2008), Brewer *et al.* (1997), Harrower and Brewer (2003), Peterson (2009), and Krygier and Wood (2011).

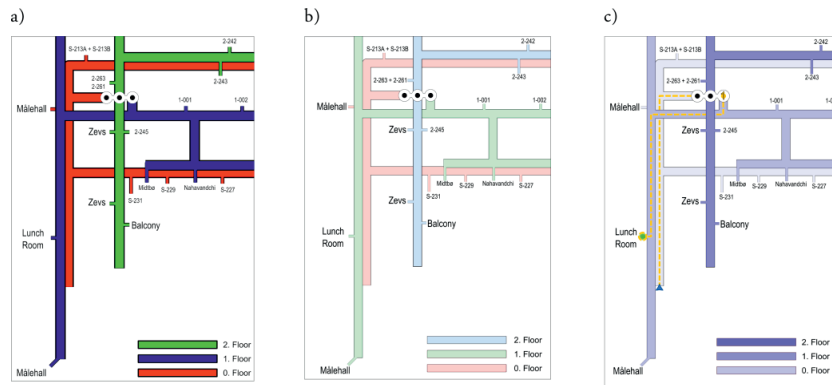


Figure 13: Illustration of three different color schemes applied on a simple IndoorTube map: a) high contrast qualitative scale, b) pastel qualitative scale and c) blue sequential scale to emphasize the vertical relationships.

In Sophie's situation at the airport, the IndoorTube map could be used as a dynamic, animated map showing the real-time updates of important information such as gate location, flight and gate status, security control location with waiting time and baggage location and status. Such a map can easily be designed to fit on large, non-interactive, displays as well as on mobile, highly interactive displays with location and user sensitive filtering and adaptation. Implementing a solution for Sophie will need to consider the previously discussed challenges of dynamic and animated visualization. Sophie would, as an example, be very prone to change and inattentive blindness when looking at a large display showing an animated IndoorTube map, and could potentially have problems perceiving an important gate change or a shorter waiting time at another security control.

On one of her trips abroad, Sophie is unfortunate and injures herself. Back home she is scheduled for a non-critical operation. The operation procedure is to first get a full pre-operative set of examinations during a fully scheduled day. Sophie has received an e-letter from the hospital with details about the examination day. Her schedule is: 10:00 blood samples, 11:15 waiting room MR imaging, 12:00 gastroenterology, and finally, 14:15 consultation at room GM53. Sophie has never been to the hospital in the city where she goes to college, and is obviously in need of some guidance to find her way around the building to arrive at the correct places on schedule. In the e-letter Sophie received, a map is included with guidance on the different locations and a suggested route to follow. After studying the map, Sophie feels prepared to find her way around the hospital and decides to bring the map with her for guidance.

The question under consideration is what type of map is Sophie using? Paper VII reports on a project investigating exactly the situation Sophie is in, and

what type of map that would best support the task at hand. At the airport, Sophie was presented with the IndoorTube map. When doing grocery shopping she used a stylized floor plan map. The research question for the wayfinding project was: How does the IndoorTube map compare to a sequence of stylized floor plan maps in providing routing guidance and navigating an unknown building?

Sophie's situation is not far from reality at the St. Olav's hospital in Trondheim, where patients are guided through a tight schedule during an examination day. However, wayfinding poses a major challenge for new, old or confused patients. To ameliorate the problem, many maps are displayed on posters and on monitors throughout the building. The maps used are stylized floor plan maps. Figure 14 depicts an example of the floor plan maps used today at one of the hospital buildings. An empirical experiment was designed and conducted to evaluate whether, and how, a version of the IndoorTube map compared against the currently used map. The scenario was similar to Sophie's experience. During the preparation of the IndoorTube map, several interesting challenges to the concept were identified and some solutions described. Figure 15 and appendix A depicts the resulting IndoorTube map used in the experiment. The resulting map makes use of a qualitative color scale to emphasize the differences between the floors, by taking advantage of the selective property of color, and at the same time allow for a sense of familiarity with the color scale by imitating a variant of the well-known color scheme of the London Underground map.

In the development process several issues for the future were identified:

1. Large areas, like lobby areas, should be visualized better in accordance with their physical size. This was done in the first floor of the map.
2. Sub-floors (such as floor 2.5) were not initially included in the concept and were solved by connecting the relevant floors with thinner lines to represent a "weak" connection.
3. An elevator opening both ways and thus connecting two corridors, potentially on the same floor, poses positioning and aesthetic issues. A good solution is yet to be developed. A reconsideration of the elevator and stair symbols should be of primary concern.
4. The intuitive qualities should be a design goal throughout the design process to make considerations on all abstractions made in the process.

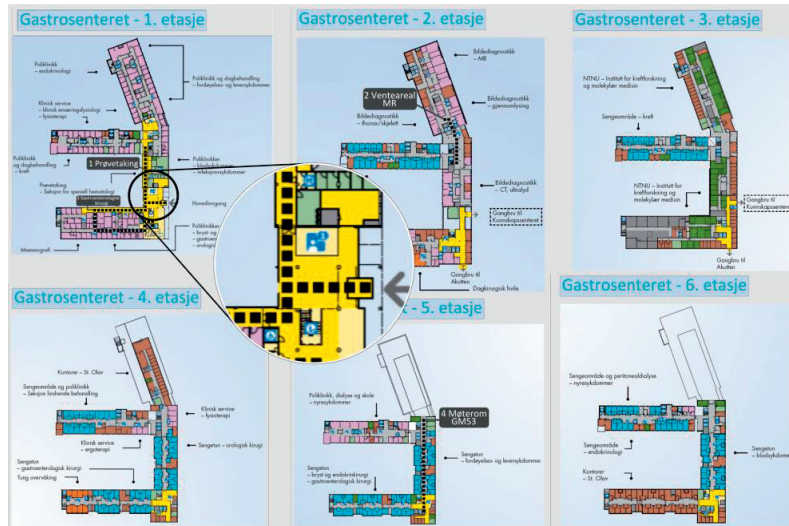


Figure 14: Extract of the modified floor plan maps used in the experiment. The maps are based on today's maps used at St. Olav's hospital. Details are magnified for this presentation and were not included in the experiment.

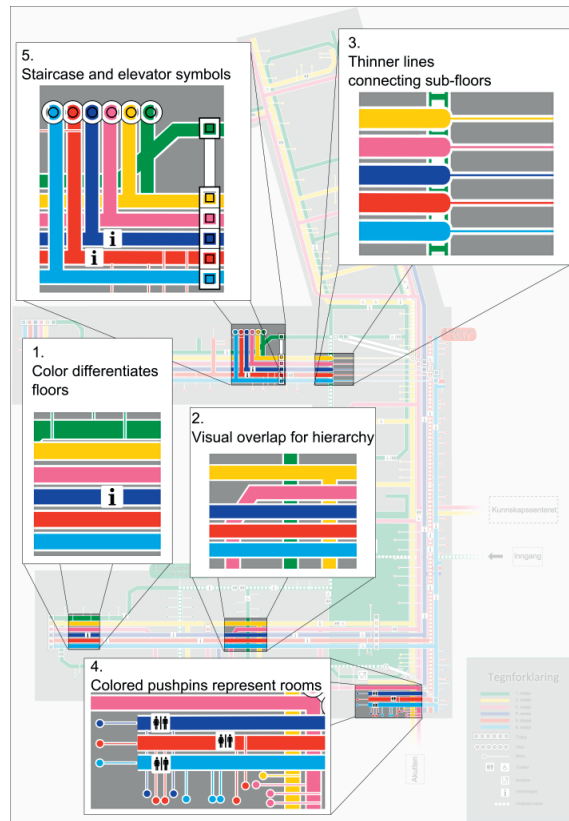


Figure 15: Illustration of the IndoorTube map of Gastrocenteret with highlighted and labeled details. The original map can be found in the appendix.

The experiment recruited 30 participants, mainly from the student population. None of the participants had any previous knowledge of the building in question. The subjects were to navigate as quickly as possible to a set of locations. There were 13 females and 17 males which were balanced across three groups: 1) control group, not using maps. 2) IndoorTube group 3) floor plan map group. The experiment was held during regular operating hours of the hospital as would be the situation in real-life. The time used to navigate to the different locations was recorded throughout the experiment for each subject. In the analysis of the results, the total time used was considered most important. When comparing the time used between the three groups, very small differences were found between the groups. An analysis of variance (ANOVA) yielded no significant differences between the three groups with respect to the total time to finish the wayfinding. Analyses of the dependencies between the different subject-variables were also performed yielding

no significant results. In conclusion the experiment does not confirm that the IndoorTube map, in the state it was used in the experiment, is significantly better to support patient wayfinding than the floor plan map. The lack of any statistically significant difference between the control group and both the floor plan map group and IndoorTube group could also be explained by the fact that the control group could have used the maps that were on display on posters and monitors throughout the hospital. This potential source of error was not documented rigorously in the experiment, but was on the other hand not observed by the experimenter either. Informal interviews with the participants after the experiment revealed that they were generally positive towards the IndoorTube concept but found it too abstract and would like it to be more metrically accurate. After some time it was easier to understand and use. The major issue with floor plan maps is that one map covers only one floor, and several maps are needed to cover a complete building. Subjects from all groups stated that they liked the idea of being able to see all floors in the same map. In addition some were strongly in favor of developing new indoor maps with quotes like: "... they [floor plan maps] do not connect to the architecture ..." and "...it's about time something new is made..."

The results from this PhD project have provided a starting point for developing the technology of Sophie's future world. Dynamic and animated maps are commonplace even today, but some issues still remain. Improvements in key areas like change and inattentive blindness have been proposed above. Visualization of single-storey indoor environments is rapidly being implemented by the industry locomotives (Bing Maps 2011, Google Maps 2011), who seem, however, to pay little attention to the issues of multi-floor visualization and the potential of traversing the vertical dimension.

Sophie's career will, as it happens, take her back to the same hospital where she once was a patient. Her medical degree will secure her a job as a junior doctor, and she will need to get acquainted with the interior environment of the hospital, a great variety of working equipment and most importantly the workflow of her colleagues. Large displays and mobile applications will support Sophie in her work. Indoor maps, maybe in the form of IndoorTubes, vertical color maps or even floor plan maps, will visualize the real-time, dynamic activity in the hospital buildings such as the location and status of colleagues, patients, equipment and rooms. Rapidly and continuously updated spatial and situational information is of great value in Sophie's workplace. Her increased situational awareness will facilitate her efficiency and enable her to better coordinate her own activities with the workflow of her colleagues.

After some major career steps, Sophie will become the head surgeon of one of the hospital departments. She will be responsible for coordinating the staff, their activities, the equipment and the patient flow in her department. In her daily work, Sophie will use advanced indoor-GIS, which will provide her with the same real-

time situational awareness which she was used to as a junior doctor, through dynamic and animated real-time visualizations like the IndoorTube map, or the vertical color map. In addition to her real-time awareness, Sophie will also be able to look back and forth in time by using semistatic animation techniques. This will allow her to easily query the visualization and see the trajectories of the staff in a surgery team including where they have been, their current position and their predicted movements as scheduled according to the enterprise resource planning systems. At a glance, Sophie can make decisions based on the actual status of patients, staff, equipment and other resources. The indoor-GIS also carry advanced analysis tools which can analyze the three-dimensional movement data, the interior building data, and the data from the enterprise resource planning tools, using adapted conventional GIS algorithms and methods. Results from this analysis can be visualized using a combination of linked projections, animations as well as the familiar IndoorTube map. Bottlenecks and suboptimal resource use are discovered and dealt with on a weekly basis.

These sketches of Sophie's future are not at all unrealistic. Full utilization of the methods and techniques developed in this thesis only requires minor technological developments and a substantial amount of effort in order to be realized. Dynamic, animated and real-time visualization of multi-storey indoor environments holds great unrealized potential for cartographic science and geographic information science generally. Industry is already eagerly implementing indoor maps. The quality and the usefulness of these remain to be seen. Based on the results presented in this thesis – there is great potential for improvement.

Concluding remarks

The various results presented in this overview and detailed in the listed papers explore the possibilities of dynamic, animated and interactive visualization of multi-storey indoor environments. Two themes define the structure of the work:

- 1) The first theme focuses on dynamic and animated visualizations. Different variants of spatial-temporal data have been used in the various subprojects. The *semistatic* design principle is shown to be effective and illustrates the potential of further development on the topic of dynamic and animated visualizations.
- 2) The second theme sheds light on the topic of visualization of multi-storey indoor environments. Two new design principles: the *IndoorTube* and the *vertical color map* have been developed and evaluated for different aspects of usage. In support, the aspects of positioning and conceptual frameworks have been discussed and addressed.

The topic of visualization of multi-storey indoor environments is little explored by the cartographic community and has just recently begun to gain traction. At the same time, IT industry leaders are racing to implement indoor positioning in conjunction with indoor visualization systems. A major obstacle for widespread deployment is the scarcity of comprehensive collections of interior building data. Indoor positioning is not, at the time of writing, as ubiquitous as outdoor positioning systems like GPS. From the experience gained through the project it is very likely that indoor positioning will become as widely available as wireless networks are today. We have already seen the beginning of indoor positioning and indoor visualization. However, the solutions need to be better scientifically founded in order to find the very best methods for the vast variety of tasks, users and platforms available. This thesis has presented two alternative solutions that address the core issue of dealing with vertically overlapping information.

While researching and developing these alternative visualizations, it became clear that no unifying framework exists which encompasses all aspects of indoor visualization. The work presented in paper VIII amounts to a proposition for such a framework. Hopefully, further effort through collaboration in the scientific community will allow it to reach its full potential.

The intersection of the two explored topics has been introduced and discussed throughout the thesis. It is highly reasonable to predict future technological solutions in the context of multi-storey indoor environments to be dynamic, interactive and animated. The challenges and solutions presented throughout the thesis can be a starting point for explorations of this intersection.

The contributions made in this thesis range from practical aspects, with the concrete propositions of visualization methods, to contributions to the general body of knowledge on the topic on spatial visualization. I have aimed at contributing both practical knowhow and theoretical results on the topic of visualization of multi-storey indoor environments, and in so doing, discovered new and interesting avenues for research. Hopefully others may also be inspired to join in and expand on some of the ideas presented.

References

- Aisle411, 2012. aisle411 | Shopping Just Got A Lot Easier [online]. Available from: <http://aisle411.com/> [Accessed 19 Nov 2012].
- AisleFinder, 2012. AisleFinder-A GPS For Your Supermarket. [online]. Available from: <http://www.aislefinder.com/> [Accessed 19 Nov 2012].
- Andrews, C., Endert, A., Yost, B., and North, C., 2011. Information visualization on large, high-resolution displays: Issues, challenges, and opportunities. *Information Visualization*, 10 (4), 341–355.
- Bederson, B. and Shneiderman, B., 2003. *The Craft of Information Visualization: Readings and Reflections*. Morgan Kaufmann.
- Bertin, J., 1983. *Semiology of graphics*. University of Wisconsin Press.
- Bing Mall Maps, 2011. Bing Mall Maps [online]. Available from: http://www.bing.com/community/site_blogs/b/maps/archive/2010/12/07/bing-s-new-mall-maps-get-in-get-out-and-the-avoid-the-crowds.aspx [Accessed 14 Sep 2011].
- Bing Maps, 2011. bing maps [online]. Available from: <http://www.bing.com/maps/> [Accessed 14 Sep 2011].
- Bjorke, J.T., 2005. *Kartografisk kommunikasjon*. Ås.
- Blok, C., 2005. Dynamic visualization variables in animation to support monitoring. *Proceedings 22nd International Cartographic ...*
- Brewer, C.A., 1996. Guidelines for Selecting Colors for Diverging Schemes on Maps. *Cartographic Journal, The*, 33 (2), 79–86.
- Brewer, C.A., 2008. *Designed Maps: A Sourcebook for GIS Users*. ESRI Press.
- Brewer, C.A., MacEachren, A.M., Pickle, L.W., and Herrmann, D., 1997. Mapping Mortality: Evaluating Color Schemes for Choropleth Maps. *Annals of the Association of American Geographers*, 87 (3), 411–438.
- Brodersen, L., Andersen, H.H.K., and Weber, S., 2002. *Applying eye-movement tracking for the study of map perception and map design*. Kort & Matrikelstyrelsen.
- Chabris, C. and Simons, D., 2011. The invisible gorilla: And other ways our intuitions deceive us.
- Chorianopoulos, K., Jaccheri, L., and Nossum, A.S., 2012. Creative and open software engineering practices and tools in maker community projects. *Proceedings of the 4th ACM SIGCHI symposium on Engineering interactive computing systems - EICS '12*, 333.

- Cleveland, W. and McGill, R., 1984. Graphical perception: Theory, experimentation, and application to the development of graphical methods. *Journal of the American Statistical ...*, 79 (387).
- Coltekin, A., Heil, B., Garlandini, S., and Fabrikant, S., 2009. *Evaluating the Effectiveness of Interactive Map Interface Designs: A Case Study Integrating Usability Metrics with Eye-Movement Analysis*.
- Cook, S.E.T., 1914. *The Life of Florence Nightingale*. Macmillan.
- Curran, K., Furey, E., Lunney, T., Santos, J., Woods, D., and McCaughey, A., 2011. An evaluation of indoor location determination technologies. *Journal of Location Based Services*, (1), 1–18.
- DiBiase, D., MacEachren, A.M., Krygier, J.B., and Reeves, C., 1992. Animation and the Role of Map Design in Scientific Visualization. *Cartography and Geographic Information Science*, 19 (4), 201–214.
- Dodge, M., McDerby, M., and Turner, M., 2008. *Geographic visualization: concepts, tools and applications: amazon.co.uk: martin dodge, mary mcderby, martin turner: books*. Wiley-Blackwell.
- Fabrikant, S. and Goldsberry, K., 2005. Thematic relevance and perceptual salience of dynamic geovisualization displays. In: *Proceedings of 22nd ICA international cartographic conference: mapping approaches into a changing world, A Coruna, Spain*.
- Fabrikant, S.I., Rebich-Hespanha, S., Andrienko, N., Andrienko, G., Montello, D.R., and Irina Fabrikant, S., 2008. Novel Method to Measure Inference Affordance in Static Small-Multiple Map Displays Representing Dynamic Processes. *Cartographic Journal, The*, 45 (3), 201–215.
- Fish, C., Goldsberry, K.P., and Battersby, S., 2011. Change Blindness in Animated Choropleth Maps: An Empirical Study. *Cartography and Geographic Information Science*, 38 (4), 350–362.
- Friendly, M., 2002. Visions and Re-Visions of Charles Joseph Minard. *Journal of Educational and Behavioral Statistics*, 27 (1).
- Fry, B., 2008. *Visualizing Data: Exploring and Explaining Data with the Processing Environment*. O'Reilly Media.
- Furnas, G.W., 1981. The FISHEYE view: A new look at structured files. Readings in information visualization.
- Furnas, G.W., 1986. Generalized fisheye views. In: *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '86*. New York, New York, USA: ACM Press, 16–23.
- Garland, K., 1994. *Mr. Beck's Underground Map: a history*. Capital Transport Publishing.
- Gartner, 2011. Competitive Landscape: Mobile Devices, Worldwide, 4Q10 and 2010. [online]. Available from: <http://www.gartner.com/it/page.jsp?id=1543014> [Accessed 9 Sep 2011].
- Giudice, N.A., Walton, L.A., and Worboys, M., 2010. The informatics of indoor and outdoor space. In: *Proceedings of the 2nd ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness - ISA '10*. New York, New York, USA: ACM Press, 47.

- Google Maps, 2011. Google Maps [online]. Available from: <http://maps.google.com/> [Accessed 14 Sep 2011].
- Google Maps for Android, 2012. Google Maps for android [online]. Available from: <http://maps.google.com/help/maps/starthere/index.html> [Accessed 19 Nov 2012].
- Griffin, A.L., MacEachren, A.M., Hardisty, F., Steiner, E., and Li, B., 2006. A Comparison of Animated Maps with Static Small-Multiple Maps for Visually Identifying Space-Time Clusters. *Annals of the Association of American Geographers*, 96 (4), 740–753.
- Harrower, M., 2003. Tips for designing effective animated maps. *Cartographic Perspectives*, 44, 63–65.
- Harrower, M. and Brewer, C.A., 2003. ColorBrewer.org: An Online Tool for Selecting Colour Schemes for Maps. *The Cartographic Journal*, 40 (1), 27–37.
- Hedley, N., 2011a. Real-time reification: how mobile augmented reality may redefine our relationship with geographic space. *In: to appear in: Lecture Notes in Geoinformation and Cartography*. Springer.
- Hedley, N., 2011b. Unlocking the third dimension in 3D time-space visualization. *to appear in: Cartography and Geographic Information Science*.
- Hedley, N., Billingham, M., Postner, L., May, R., and Kato, H., 2002. Explorations in the Use of Augmented Reality for Geographic Visualization. *Presence: Teleoperators and Virtual Environments*, 11 (2), 119–133.
- Heer, J., Bostock, M., and Ogievetsky, V., 2010. A tour through the visualization zoo. *Communications of the ACM*, 1–22.
- Hegarty, M., 2004. Dynamic visualizations and learning: getting to the difficult questions. *Learning and Instruction*, 14 (3), 343–351.
- Hegarty, M., Kriz, S., and Cate, C., 2003. The Roles of Mental Animations and External Animations in Understanding Mechanical Systems. *Cognition and Instruction*, 21 (4), 209–249.
- Hägerstrand, T., 1970. What about people in Regional Science? *Papers of the Regional Science Association*, 24 (1), 6–21.
- Koffka, K., 1935. Principles of Gestalt psychology, 1–14.
- Kraak, M.-J. and Ormeling, F., 2010. *Cartography: Visualization of Geospatial Data*. Pearson Education Ltd.
- Kraak, M.J., 2003. The space-time cube revisited from a geovisualization perspective. *In: Proc. 21st International Cartographic Conference*. Citeseer, 1988–1995.
- Krygier, J. and Wood, D., 2011. *Making Maps: A Visual Guide to Map Design for GIS*. Guilford Press.
- Köhler, W., 1929. Gestalt psychology.

- Li, X., Çöltekin, A., and Kraak, M.-J., 2010. Visual Exploration of Eye Movement Data Using the Space-Time-Cube. *In: S. Fabrikant, T. Reichenbacher, a. r. c. van Kreveld, and C. Schlieder, eds. Geographic Information Science. Berlin, Heidelberg: Springer Berlin / Heidelberg, 295–309.*
- Liu, H., Darabi, H., Banerjee, P., and Liu, J., 2007. Survey of Wireless Indoor Positioning Techniques and Systems. *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews)*, 37 (6), 1067–1080.
- MacEachren, A.M., 2004. *How Maps Work: Representation, Visualization, and Design*. 1st ed. The Guilford Press.
- MacEachren, A.M. and Kraak, M.J., 1997. Exploratory cartographic visualization: advancing the agenda. *Computers & Geosciences*, 23 (4), 335–343.
- Mackinlay, J., 1986. Automating the design of graphical presentations of relational information. *ACM Transactions on Graphics (TOG)*, 5 (April 1986), 110–141.
- Mautz, R., 2009. Overview of Current Indoor Positioning Systems. *Geodesy and Cartography*, 35 (1), 18–22.
- Midtbø, T., 2001. PERCEPTION OF TIME VARIABLES ON DYNAMIC MAPS. *In: Proceedings of the 20th International Cartographic Conference.*
- Midtbø, T., 2007. Advanced legends for interactive dynamic maps. *In: Proceedings of the 23th International Cartographic Conference.*
- Midtbø, T., Clarke, K.C., and Fabrikant, S., 2007. Human Interaction with Animated Maps: The portrayal of the passage of time. *In: Proceedings ScanGIS.*
- Midtbø, T. and Larsen, E., 2005. MAP ANIMATIONS VERSUS STATIC MAPS – WHEN IS ONE OF THEM BETTER? *In: , Proceedings of the joint ICA Commis- sions Seminar on Internet-based Cartographic Teaching and Learn- ing Madrid.* 1–6.
- Ngoc Nguyen, A.M., 2012. Finn frem på sykehuset. Norwegian University of Science and Technology.
- Nguyen, A.M.N. and Nossum, A.S., 2012. Selvinnsjekk på sykehuset - hvordan skal pasienten finne frem? *In: Geomatikkdagene 2012.* Lillehammer.
- Nielsen, J., 2012a. Usability in the Movies: Top 10 Bloopers (Jakob Nielsen's Alertbox) [online]. Available from: <http://www.useit.com/alertbox/film-ui-bloopers.html> [Accessed 19 Nov 2012].
- Nielsen, J., 2012b. 2D is Better Than 3D (Alertbox Nov. 1998) [online]. Available from: <http://www.useit.com/alertbox/981115.html> [Accessed 19 Nov 2012].
- Nossum, A. and Nguyen, A., 2012. Comparing Two Different Map Types for Patient Navigation Inside a Hospital. *In: giscience.org.*
- Nossum, A.S., 2010. Semistatic Animations-Integrating Past, Present and Future in Map Animations. *In: Proceedings, GIScience.*

- Nossum, A.S., 2012. Understanding spatial information science at the trans-disciplinary intersection between IT and New Media Art. *In: unpublished*.
- Nossum, A.S. and Krogstie, J., 2009. Integrated quality of models and quality of maps. *In: Enterprise, Business-Process and Information*. 264–276.
- Ooms, K., De Maeyer, P., Fack, V., Van Assche, E., and Witlox, F., 2012. Interpreting maps through the eyes of expert and novice users. *International Journal of Geographical Information Science*, 26 (10), 1773–1788.
- Opach, T., Midtbø, T., and Nossum, A., 2011. A New Concept of Multi-Scenario, Multi-Component Animated Maps for the Visualization of Spatio-Temporal Landscape Evolution. *Miscellanea Geographica - Regional Studies on Development*, 15 (-1), 215–229.
- OpenStreetMap, 2012. Indoor Mapping - OpenStreetMap [online]. Available from: http://wiki.openstreetmap.org/wiki/Indoor_Mapping [Accessed 7 May 2012].
- Palmer, S. and Rock, I., 1994. Rethinking perceptual organization: The role of uniform connectedness. *Psychonomic Bulletin & Review*, 1 (1), 29–55.
- Peterson, G.N., 2009. *GIS Cartography: A Guide to Effective Map Design*. CRC Press.
- Peterson, M.P., 1999. Active legends for interactive cartographic animation. *International Journal of Geographical Information Science*, 13 (4), 375–383.
- Price, S., 2004. Processing Animation: Integrating Information from Animated Diagrams. *In: A. Blackwell, K. Marriott, and A. Shimojima, eds. Diagrammatic Representation and Inference*. Springer Berlin / Heidelberg, 127–138.
- Rensink, R. a, 2002. Change detection. *Annual review of psychology*, 53, 245–77.
- Rensink, R.A., 2001. Change Blindness : Implications for the Nature of Visual Attention.
- Rensink, R.A., O'Regan, J.K., and Clark, J.J., 1997. To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, 8, 368–373.
- Rimi, 2012. Rimi Pluss [online]. Available from: <http://rimi.no/rimi-pluss> [Accessed 19 Nov 2012].
- Rubin, E., 1915. *Synsoplevede figurer: studier i psykologisk analyse. I. del*.
- Rush, M., 2005. *New Media in Art (World of Art)*. Thames & Hudson.
- Simons, D.J. and Rensink, R. a, 2005. Change blindness: past, present, and future. *Trends in cognitive sciences*, 9 (1), 16–20.
- Slocum, T., Sluter, R., Kessler, F., and Yoder, S., 2004. A Qualitative Evaluation of MapTime, A Program For Exploring Spatiotemporal Point Data. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 39 (3), 43–68.
- Spence, R., 2007. *Information Visualization: Design for Interaction*. Prentice Hall.

- SR-Research, 2012. SR-Research [online]. Available from: <http://www.sr-research.com/> [Accessed 19 Nov 2012].
- Szegö, J. and Miller, T., 1987. Human cartography: Mapping the world of man.
- Tufte, E.R., 1985. *The Visual Display of Quantitative Information*. Graphics Press.
- Tufte, E.R., 1997. *Visual Explanations: Images and Quantities, Evidence and Narrative*. Graphics Press.
- Tufte, E.R., 2006. *Beautiful Evidence*. Graphics Press.
- Tversky, B., Morrison, J., and Betrancourt, M., 2002. Animation: can it facilitate? *International Journal of Human-Computer Studies*, 57 (4), 247–262.
- Virrantaus, K., Fairbairn, D., and Kraak, M.-J., 2009. ICA Research Agenda on Cartography and GIScience. *Cartography and Geographic Information Science*, 36 (2), 209–222.
- Ware, C., 2004. *Information Visualization: Perception for Design (Interactive Technologies)*. Morgan Kaufmann.
- Ware, C., 2008. *Visual thinking for design*.
- Weber, C.R. and Battenfield, B.P., 1993. A Cartographic Animation of Average Yearly Surface Temperatures for the 48 Contiguous United States: 1897–1986. *Cartography and Geographic Information Science*, 20 (3), 141–150.
- Windhistory.org, 2012. <http://windhistory.com/> [online].

Papers

Paper I

Is not included due to copyright

Paper II

EVALUATING THE USABILITY OF CARTOGRAPHIC ANIMATIONS WITH EYE-MOVEMENT ANALYSIS

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1. EYE-TRACKING AS AN EVALUATION METHOD

Availability of time-series spatial data and wide access to computer tools has resulted in broad use of cartographic animations. A growing amount of animated maps poses new challenges, in which the efficiency of cartographic communication is of concern (Opach 2005).

There are various methods for studying usability of maps in general. The methods range from traditional surveys (Suchan and Brewer 2000) to unobtrusive data gathering such as eye-tracking. In recent years the use of eye-tracking in cartography has increased (Fabrikant *et al.* 2008, Çöltekin *et al.* 2009, Brodersen *et al.* 2001, Fabrikant *et al.* 2010, Li *et al.* 2010). Availability as well as development of both eye-tracking software and hardware is believed to be the major reason for this.

Eye-tracking provides the ability to record eye movements in unobtrusive manner relying on specialized equipment. Earlier studies using eye-tracking have primarily treated the stimuli as static representations. Although, several studies have also focused on exploring new approaches or analysis methods for eye-tracking data to accommodate better cartographic stimuli and qualities associated with this (Garlandini and Fabrikant 2009, Çöltekin *et al.* 2010).

Despite the increased focus on eye-tracking, the question remains unanswered on how eye-tracking is suitable as an evaluation method with cartographic animations as stimulus. In this paper we explore the suitability of eye-tracking on two different cartographic animations in an attempt to answer this question.

We have conducted two eye-tracking experiments with 10 participants each for both an isolated cartographic animation (semistatic animations) and a complex animated map (the Kampinos Forest animation). We have used standard analysis tools to assess and gain experience on their strengths and weaknesses when cartographic animations are used as stimuli. The experience gathered in this process is described throughout this article as well as our suggestions for improvements.

2. INTRODUCTION TO THE ANIMATIONS

2.1 Semistatic animations, integrating past, present and future

Traditional map animations have several issues associated with them. The most notable are split attention and disappearance (Harrover 2003, 2007). They are both affected by the fact that animations display frames with changing content. In effect, the viewer needs to pay attention to the animation in order to not miss information. In addition, the animation may have several different elements that are attracting the user's attention, such as timeline or legend. This causes the viewer to choose between the information and risk the possibility of losing information displayed at the same moment on other parts of the animated map.

Static maps are not affected by the same issues as map animations. First of all the information does not change, allowing the viewer to use unlimited amount of time for viewing. However, static maps are ill-suited, compared to animated maps, in displaying information which changes over time. Animations have been the most accepted by the non-expert user.

Semistatic animation is a concept which combines the qualities from both static and animated map representations (Nossum 2010). The idea is to represent all information of an animation in every single frame of the animation. This allows the user to visually look back and forth in time in the animation without the need to control the flow of the animation. Figure 1 illustrates two different proof-of-concept implementations of the semistatic concept using weather and temperature maps as a case study. Figure 2 explains the symbols used to incorporate the complete information in the map animations. Temperature and weather were chosen to investigate the possibility of different information classes: numeric (temperature) and textual (weather/symbolic).

A web experiment has been conducted to test the performance of the concept (Nossum 2010). In total the experiment included over 200 participants and aimed at comparing the semistatic implementation with its traditional equivalent. The analysis has given surprising results related to the performance of different

tasks in comparison with our expectations. In later sections we will compare the results from the web experiment with the outcomes from the eye-tracking tests carried out in this study.

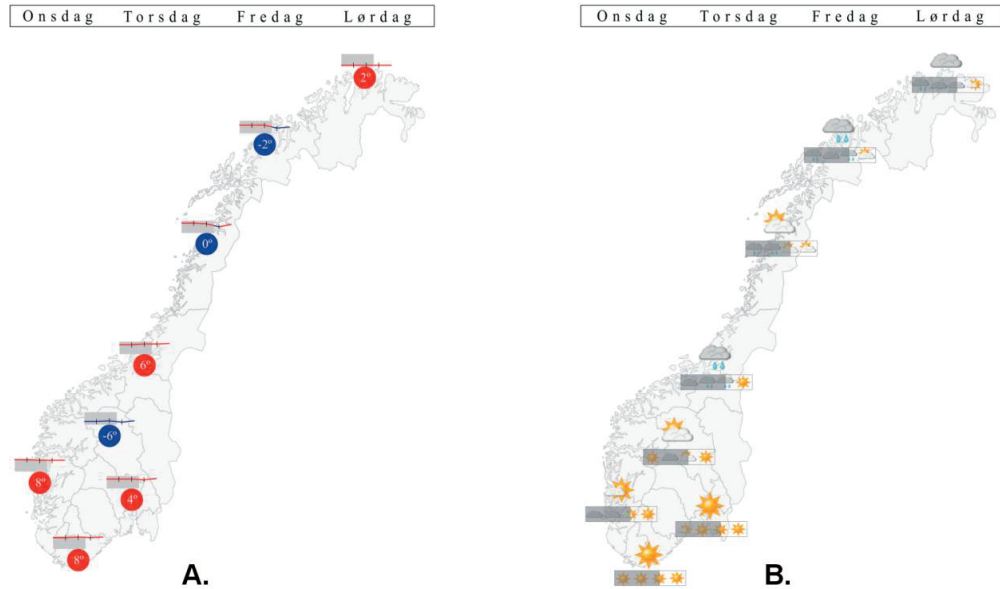


Figure 1. Proof of concept implementation of the semistatic concept: A. temperature map animation, B. weather map animation.

Animations available at: <http://geomatikk.ntnu.no/projects/semistatic/>.

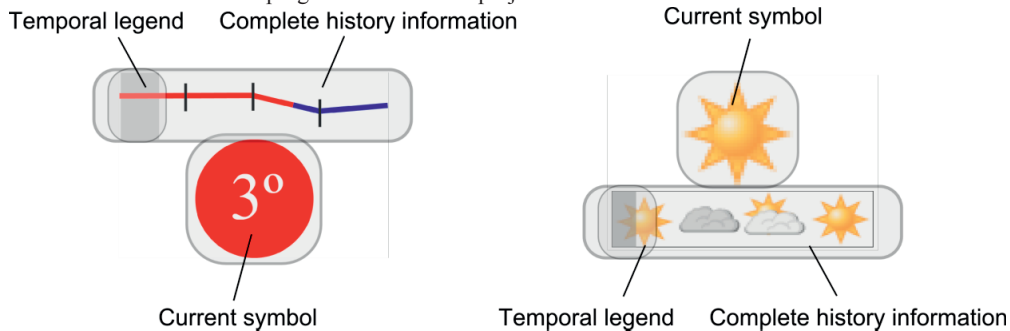


Figure 2. Essential elements of the symbols incorporating the complete information of the animation. To the left: Temperature symbol with numeric information visualized as a line graph. To the right: Textual information visualized using pictograms.

2.2 The Kampinos Forest animated map, multi-scenario and multi-component

Multi-scenario and multi-component animated map of the Kampinos Forest (Figure 3) was introduced to facilitate understanding the spatio-temporal landscape changeability as well as to investigate factors which influence an effective use of complex cartographic applications.

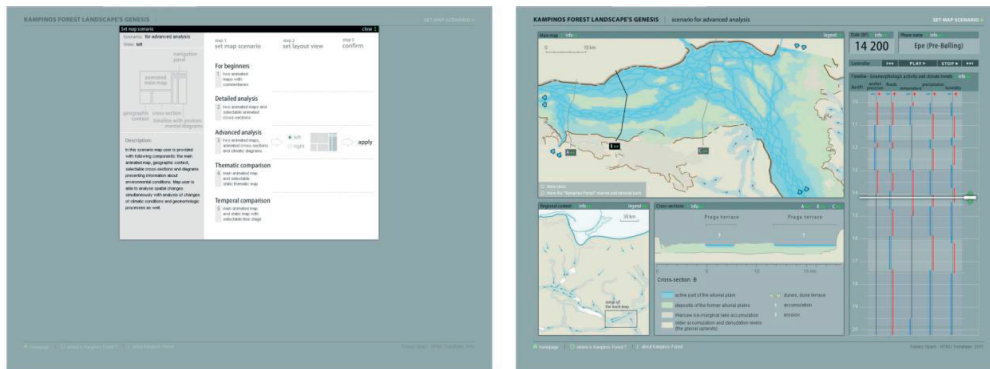
When visualizing spatio-temporal geographic changeability it is often not enough to display one animation (Monmonier 1992). Sometimes it needs to be coupled with other “components” (maps or non-cartographic presentations) to identify the associations between different variables. Variety of used components depends on topics and presented areas. In general, the following components can be listed: the main animated map, various navigation panels, animated/static cross-sections, animated/static diagrams and small animated maps with geographic context.

The usefulness of multi-component animated maps relies on their functional advantages. Of great importance is to investigate possible fields of use and to define suitable sets of components. Therefore the cartographer should specify the sets of components which are important for the knowledge acquisition and

the task solving. We called these sets of components “map scenarios”. The Kampinos Forest animated map has been divided into five map scenarios. Figure 4 shows their structure.

It is also the cartographer who should make easy accessible map scenarios. To meet this challenge we designed the opening window (Figure 3A) – an introductory element of the map interface which describes all map scenarios and map components in a suggestive manner.

The linking of various visualization techniques may increase the efficiency of the cartographic communication process. However, the role of multi-component animations should be investigated deeper. Split attention is of concern as the main disadvantage when using such cartographic applications. As a result the eye-tracking technique has been employed for revealing how the Kampinos Forest animated map is used.



A. **B.**
Figure 3. Screen snapshots captured for the opening window (A) and the scenario “for advanced analysis” (B). This scenario comprises the main animated map, the small animated map, animated cross-sections and navigation components with set of graphs.

Prototype available at: <http://www.geomatikk.ntnu.no/prosjekt/KampinosForest/>.

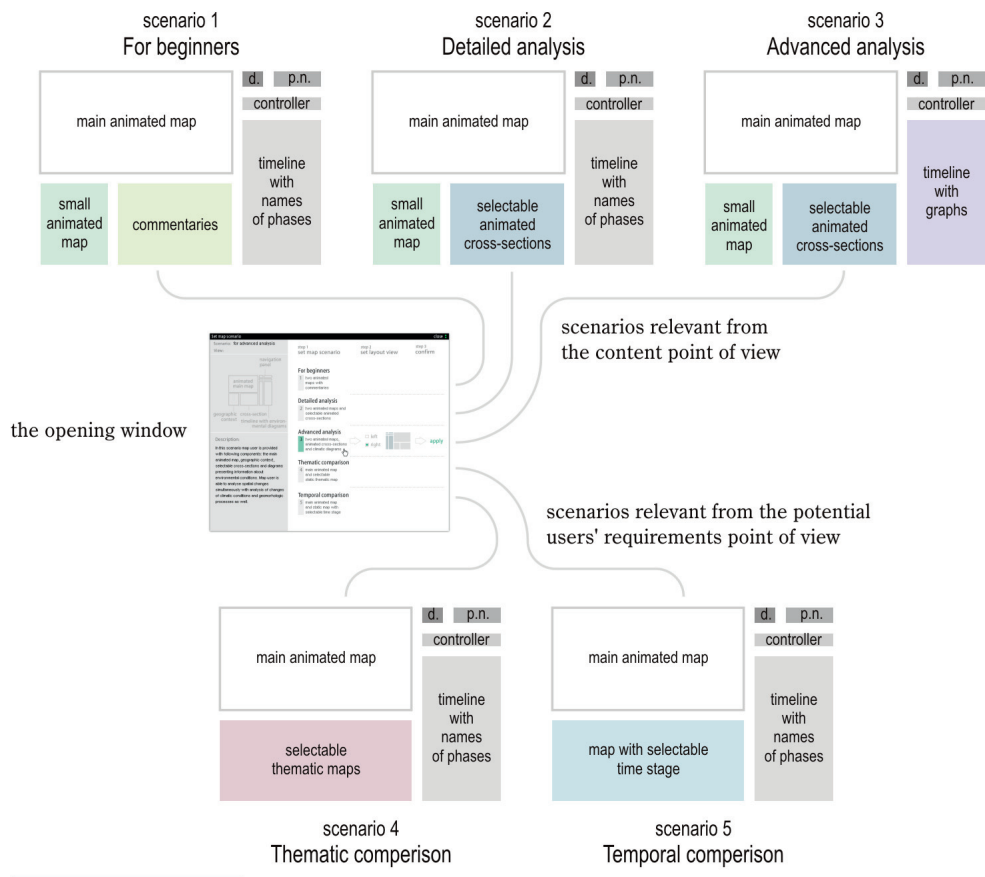


Figure 4. Five map scenarios implemented in the Kampinos Forest animated map.

3. EXPERIMENT

The experiment was conducted during week 12 in 2010 in the usability laboratory of the Norwegian University of Science and Technology and St. Olavs Hospital. In total 10 participants were recruited. All tests were performed in a dedicated room. The hardware used was a Tobii X120 eye-tracker and PC with a 19" screen. Video and audio recordings were controlled by Tobii Studio using a standard HD web camera. The experiment was divided into two consecutive parts and lasted around 35 minutes per participant. The first part consisted of the semistatic map animations; the second part comprised the Kampinos Forest map. The stimulus were implemented as web pages and displayed using the built-in browser functionality in Tobii Studio. During the tests the participants were presented tasks that they should solve by either using or looking at the displayed stimuli. Answers on the tasks were recorded using HTML forms with predefined options.

4. ANALYSIS OF EYE-TRACKING DATA

4.1 Semistatic animations analysis/results

The results from the earlier web experiment (Nossum 2010) are used in comparison against the eye-tracking experiment. Several differences in the performance of semistatic and traditional animations were identified in the mentioned web survey. The eye-tracking experiment used the exact same stimulus and questionnaires as the web experiment did. But, of course with fewer participants the results are not representative for a population. However, the results follow the same pattern as the web experiment. We use both of these results as basis for the following analysis. The eye-tracking data provides an insight into the behaviour and can support better the exploration of *why* the performance differs between the web experiment and the eye-tracking experiment.

The eye-tracking experiment was divided into two map animations: temperature and symbolic weather. The participants were given three tasks for each animation: trend on one location, trend over space and time and a memory task.

We have used the built-in areas of interest (AOI) tool in Tobii Studio to calculate statistics of the eye-movement data. Figure 5A shows an example of this. Tobii Studio includes additional tools, where “heat maps” and “gaze plots” are the most common. For this experiment the gaze plot and heat maps were not suitable. Figures 5B and 5C show examples of a gaze plot and a heat map for one task only. The gaze plot results in an enormous visual clutter, not suitable to use further. The heat map aggregates too much and not respecting the temporal variation which results in not uncovering anything other than what we already knew; that participants were going to look at the points of interest. This is reminiscent of the early arguments against using eye-tracking for cartographic studies (Fabrikant *et al.* 2008).

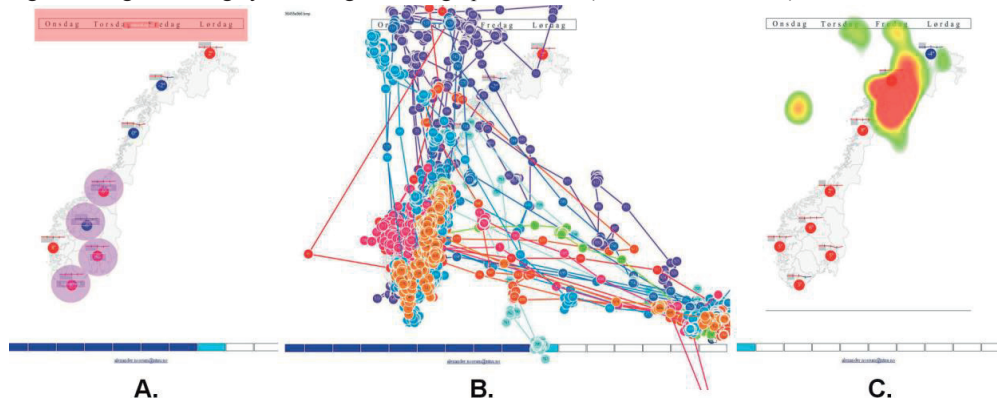


Figure 5. Examples of: (A) areas of interest, (B) gaze plot and (C) heat map.

The statistics produced by Tobii Studio using the defined AOIs provided more insight into the participant’s behaviour. For each task, for both the temperature and symbolic weather animation, we have analyzed three different statistics: fixation counts, observation length and time to first fixation. For all of these statistics the variance in the data is unfortunately very high. This can be due to few participants and that the tasks and visual stimulus open for a lot of variance in viewing strategies and general user behaviour.

As a result of the very high data variance the statistics can only be used to provide indications on a general pattern and not provide representative results. However, several interesting patterns were discovered in the analysis of the data.

The results from the earlier web experiment (Nossun 2010) indicated that there was a significant difference in the performance (correct answers) between the semistatic and the traditional animation. Based on this we expected the viewing behaviour to be similarly different between these two types. However, in general the analysis of the eye-tracking data revealed that the viewing behaviour were surprisingly similar. All three of the metrics used indicated very similar viewing strategies and behaviour. Figure 6 shows the results of the questionnaires from the web experiment and the eye-tracking experiment respectively. Both of these results indicate a difference in the performance of the two different animations. Based on this it is natural to assume that the cause comes from different user behaviour. However, Figure 7 shows the results from the eye movement analysis. All of the three metrics shows a very similar behaviour for both the traditional and the semistatic animations. There are only minor differences between the fixation counts and the observation length. The similar behaviour is in some ways contradicting our initial beliefs from the questionnaires. However, the eye movement analyses are based on 10 participants where the data has a very high variance. Averaging the data may produce a false view of the actual behaviour.

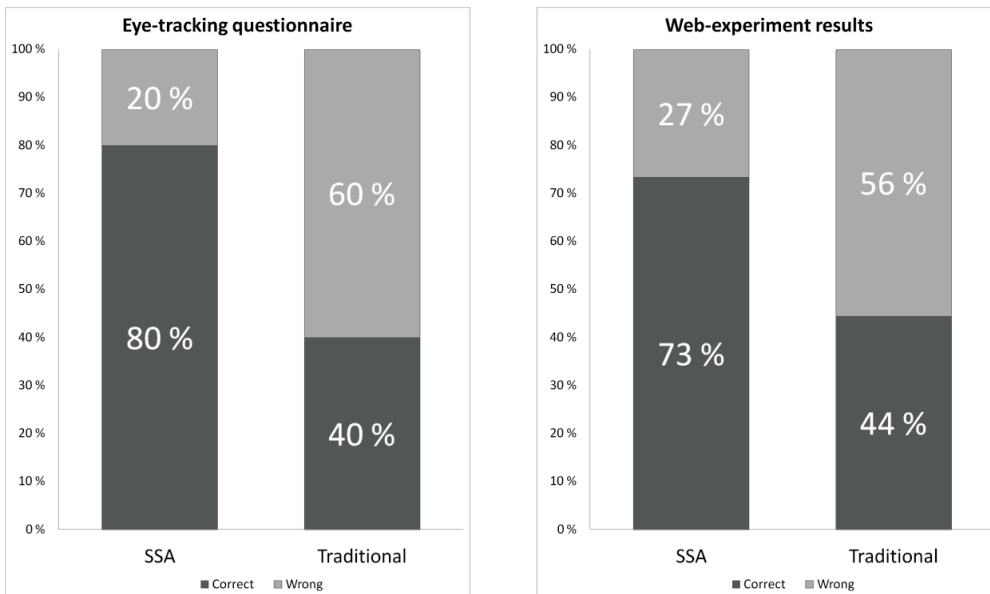


Figure 6. Results from the questionnaires in the web experiment and eye-tracking experiment respectively.

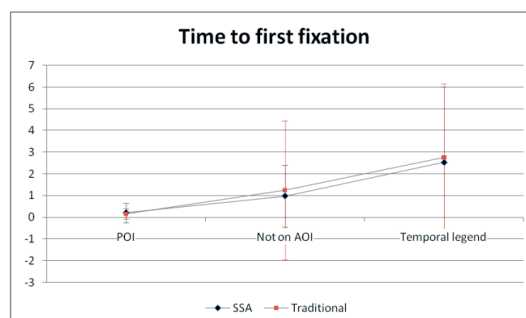
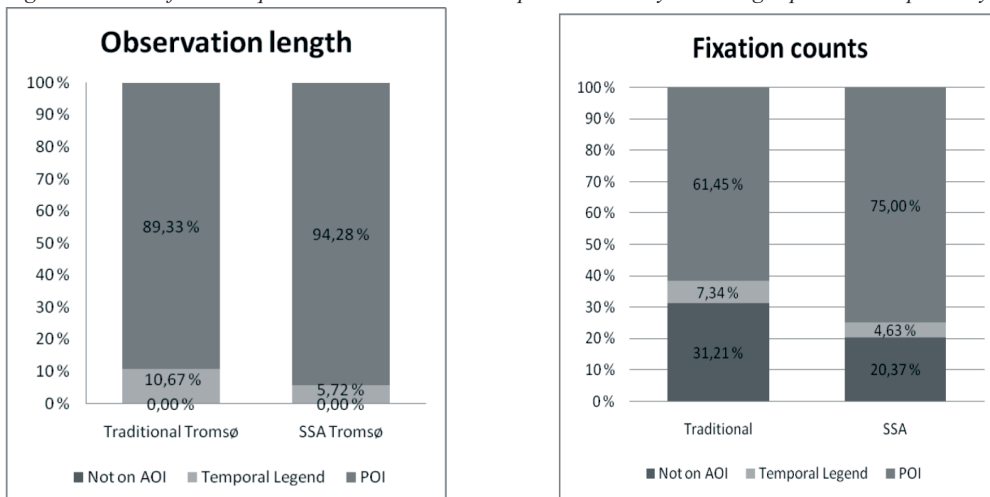


Figure 7. Results from the eye movement analysis. Showing very similar behavior for both the traditional and the semistatic animations.

The observation of different indications based on different experimental techniques underlines the necessity of including several methodologies in evaluating maps and map animations especially. The results presented here do not provide an in-depth answer to why the difference in answers occurred. Other more sophisticated analysis methods are needed to properly analyze the individual participant and compare their eye movements both in relation to the spatial behaviour but also in relation to the temporal dimension. As illustrated here the standard analysis methods do not facilitate this. Although Tobii Studio does include the possibility of investigating individual participants and re-play their eye-movements with the stimulus – we find this method not satisfying. Even with our experiment involving only 10 participants the data becomes too rich to manually re-play and analyze in an adequate and accurate way.

Despite the similarities in most of the eye movement analyses there are some interesting results we like to emphasize. The task; Trend over space and time was believed to be the most challenging task. The participants were asked to imagine they were planning a trip and were interested in the weather. They spent one day at each location. The semistatic animation has the advantage that it is possible to look both in the past and future of the information, regardless of the animations current time. This is not possible in the traditional version where the user needs to pay close attention to both the current time and to look at the correct position at the correct time in order to get the correct information.

Figure 8 shows the graph over time to first fixation for the different AOIs, one for the symbolic weather map and one for the temperature map. The results from both questionnaires indicated that for the symbolic weather map the semistatic animation performed worse than the traditional animation. For the temperature animation the results were opposite and the semistatic animation performed better than the traditional animation. Interestingly the graphs in Figure 8 shows that for both the symbolic weather animation as well as the temperature animation the viewing strategy seems to be more or less equal. The similar observation is made for both observation length and fixation counts. This can indicate that the additional information included in the semistatic, symbolic weather animation distracts or confuses the users and do not support this task very well. These findings would have been very hard and nearly impossible to discover from a web experiment alone.

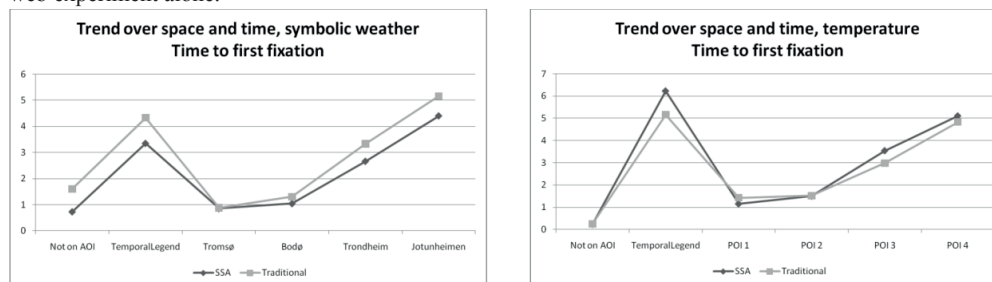


Figure 8. Time to first fixation on relevant areas of interest for both symbolic weather animation and temperature animation for the task; trend over space and time.

The eye-tracking experiment has provided us with insight and experience on its usage for evaluating cartographic animations. The results were, in general, quite surprising. Almost all of the metrics we used showed more or less similar behaviour for the traditional and the semistatic animation. The results from the questionnaires, both from the earlier web experiment and during the eye-tracking experiment indicated a large difference in performance – we expected as such a similarly large difference in the eye movements.

4.2 The Kampinos Forest animated map analysis/results

When conducting this part of the research two detailed questions (research problems) have been specified: 1) Is a complex map interface usable without a tutorial session? 2) Do map users follow various map components when using complex map animation? The first question refers to the idea of intuitiveness. We assumed that a complex map system does not have to be equipped with a tutorial session. However, to keep users performance with a high level of confidence, the concept of “opening window” has been introduced (Figure 3A). Split attention is of concern while carrying on investigations on animated maps (Harrower 2003, 2007). Therefore we focused on this challenge while shaping the second research problem.

For every map scenario of the Kampinos Forest map a separate task was proposed – in total five tasks. They consisted of two parts: At the beginning the participants were asked to select the most suitable map scenario. If the participant chose the wrong scenario, we asked to change for the correct one. After the map scenario displayed, the participants were asked to answer the question.

Three kinds of data have been recorded after finishing user testing: eye-movements, chosen scenarios and given answers. We had to omit one participant due to low accuracy.

Figure 9 shows participants' answer times for the tasks. On average they needed 41,9s for choosing map scenario and four times more for answering question. People took much longer to choose a map scenario in initial tasks what might be caused both by the learning effect and the routine as well. We also observed major differences between response lengths for various tasks. The most time consuming was task 4, the least task 5. These metrics do not vary greatly across participants thus we argue that participants' answer times depend on tasks' levels of complexity.

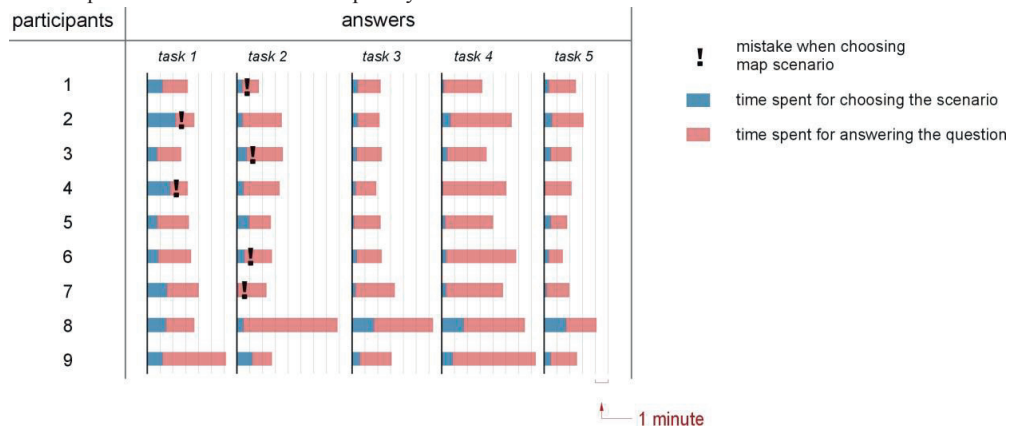


Figure 9. Participants' answer times.

In general, the participants have managed with their attempts to choose the most suitable scenario and mistakes occurred only in two first tasks. Further the eye movement analysis gave us possibility to get better insight into participants' behavior. We delineated AOIs and analyzed descriptive statistics. In task 1 participants who have chosen incorrect scenario surprisingly were viewing the opening window almost twice longer ($M=119,7s$ vs. $M=67,1s$) and paid more attention on its manifold elements. For instance they were looking at the "Description panel" (Figure 10) three times longer and almost four times longer at the "Rest of selection panels". These differences are suggestively presented on heat maps (Figure 10, variable: relative duration). Revealed facts may indicate that people who analyzed the opening window attentively failed to choose the correct map scenario. In contrary, those who were less attentive have succeed. However, this cannot be accepted as an exact explanation because participants could use more time due to incomprehension.

Eye-movement analysis of the data from task 2 revealed that participants who have chosen a correct scenario have been concentrating more on the "Correct selection panel" (Figure 11). On the other hand participants with an incorrect selection have been concentrating mainly on the first scenario selection area. Moreover they have been viewing the "Components description panel" more than four times shorter. It is likely that their wrong decision was caused by the routine.



Figure 10. Two heat maps with delineated AOIs prepared for participants who made a correct choice (left) and a wrong choice (right) when selecting map scenario in task 1.

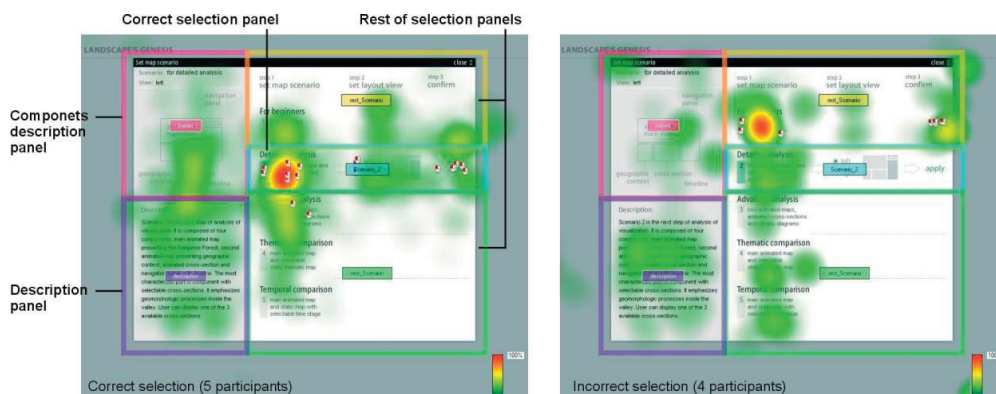


Figure 11. Two heat maps with delineated AOIs prepared for participants who made a correct choice (left) and a wrong choice (right) when selecting map scenario in task 2.

When responding most of participants selected correct answers (Figure 12). However, there were answers that surprised us. Only one participant succeeded to respond correctly in task 1. Analysis of the eye-movements revealed that this participant has been concentrating just on the interface area where the answer was “hidden”. But similar behavior has also observed in few other participants who gave a wrong answer. Tasks from 2 to 5 the participants managed almost in total. Both task 2 and task 5 got one mistake. Two mistakes occurred in task 4. Their eye-movement analysis revealed that participants did not answer because they had not managed with displaying the legend component.

| participants | answers | | | | | <ul style="list-style-type: none"> ! mistake when choosing map scenario correct answer incorrect answer "don't know" answer |
|--------------|--------------|-------------|---------|-----------|-----------|---|
| | task 1 | task 2 | task 3 | task 4 | task 5 | |
| 1 | correct | ! incorrect | correct | correct | correct | |
| 2 | ! incorrect | correct | correct | correct | correct | |
| 3 | correct | ! incorrect | correct | correct | correct | |
| 4 | ! incorrect | correct | correct | correct | correct | |
| 5 | correct | correct | correct | incorrect | incorrect | |
| 6 | correct | ! incorrect | correct | correct | correct | |
| 7 | "don't know" | ! incorrect | correct | correct | correct | |
| 8 | correct | correct | correct | correct | correct | |
| 9 | correct | incorrect | correct | incorrect | correct | |

Figure 12. Participants' chosen scenarios and given answers.

The research question about simultaneous viewing of various map components is more confusing. Broadly speaking, on the basis of the experience of this research we argue that when using the eye-tracking as a research technique, stimulus should be designed especially towards this technique. The manner how participants were viewing the Kampinos Forest animated map depends on the research tasks not on the general behavioral patterns. That is why people have been mostly looking at these components where the answers were expected to be found. Moreover, it is obvious that the participants spent more time looking at descriptive component (e.g. 52% of total fixation length in task 1) than at illustrative part of the interface. It is nothing new that reading needs more time compared against viewing.

Additional information (e.g. about viewing sequences) could be obtained from the gaze plots analysis. The point is that when investigating a lot of or long trajectories visual overlapping makes it impossible to reveal patterns across participants. The gaze plots analysis is then useless.

The positive results of the tasks dealing with the Kampinos Forest map revealed that participants did not have problems neither with understanding the map's content nor with intuitive use of the interface. Their positive attitude towards the interface was visible in the self-confidence when using the opening window as well as other interactive elements. Although further eye-movement data analysis using AOIs and heat maps uncovered some interesting patterns it has not brought out a clarification. While the differences in

behavior of participants who gave correct and incorrect answers were specified, exact explanation was not given. We might indicate *when* and *where* the difference occurred, but we cannot explain *why*.

Participants' ability to split attention appeared as doubtful and at least questionable. The AOI analysis uncovered that participants have been looking at several components during test sessions. However, due to the lack of suitable tools, the sequence analysis could not be provided.

5. DISCUSSION AND CONCLUSION

General evaluation of two cartographic animations and gaining experience on use of eye-tracking for animated stimuli were of major importance for the study. We underline that only the standard tools were examined for the data analysis purpose.

First off all, only ten participants attended the test sessions. Thus when analyzing the data it is evident that the variances of the eye-movement metrics are high. This may be affecting the indications of the similar behaviour and in general our results as a whole. A useful experience is that the stimuli should be designed specifically for use in an eye-tracking survey. In order to avoid large data variance the stimuli could be designed to minimize the possibilities of different viewing strategies. However, this will inevitably also affect the point of performing an experiment – a proper balance is needed for the best outcomes.

The most important approach in both parts of the research were statistical metrics based on AOIs. These statistics are informative but also debatable. The eye-tracker used in this experiment proved to have accuracy issues, probably due to a simple calibration process. This becomes an issue when using AOIs that are defined in a crisp matter. Figure 13 illustrates this problem; several of the fixations are recorded as inside the blue AOI, however they are more likely to actually be within the purple AOI. Future work should take this into consideration. The concept of fuzzy sets could prove to be successful to address this problem. The AOIs would then not have sharp edges but allow the edges to be fuzzy with respect to a membership function. Fuzzy sets could also be applied in more general to the eye movements. Currently only discreet fixations are available. This eliminates the analysis of the peripheral vision (Irwin 2004, Fabrikant and Garlandini 2010). Introducing dynamic or fuzzy buffers around the fixations could allow for better analysis of the actual vision of the user and not only the discreet fixations.

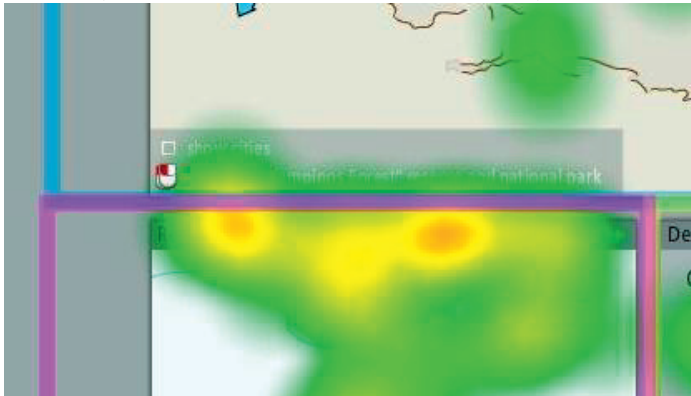


Figure 13. Which of the AOIs should the fixations be associated with? It is likely that due to an imprecise calibration the fixations are a bit shifted downwards comparing with the real viewing points.

Our study reveals that the eye-tracking approach could be applicable for examining the use of cartographic and interactive animations. However, some points need to be considered more thoroughly. We argue the following ideas should be examined in further works:

- Ability to investigate eye movements on individual level and being able to compare them immediately and in relation to the temporal dimension. Temporal alignment of the eye movement data can be an issue (Fabrikant *et al.* 2008). Stimulus design could limit this.
- Implement and standardize better aggregation techniques including both the spatial but also the temporal dimension of the eye movements. Current work on applying the space-time-cube is promising (Li *et al.* 2010).
- Consider applying fuzzy set theory on both the concept of fixations as well as areas of interest.
- Accuracy of the table mounted eye-tracker is an issue. Need better calibration methods. Other eye-trackers, such as head mounted and “glasses” may provide better accuracy.

- The complexity of the stimulus should be limited to facilitate better the analysis of the eye movements and get more high quality recordings with limited variance suitable for generalization.
- Combine the eye-tracking technique with other evaluation methods in order to get a more diverse picture of the user's behaviour. Especially when animated maps are used as stimulus.

Our conclusion is that eye-tracking as a method for evaluating cartographic animations is a valuable tool providing insight into the user's behaviour not easily accessible from other methods. However, there are still limitations associated with the accuracy of the recorder, but especially with the analysis methods.

REFERNCES

- Brodersen, L., Anderson, H. H. K. and Weber, S. (2001), Applying eye-movement tracking for the study of map perception and map design, Kort & Matrikelstyrelsen, Denmark.
- Çöltekin, A., Fabrikant, S. I. and Lacayo, M. (2010), Exploring the efficiency of users' visual analytics strategies based on sequence analysis of eye movement recordings, *International Journal of Geographical Information Science* 24(10): 1559–1575.
- Çöltekin, A., Heil, B., Garlandini, S. and Fabrikant, S. I. (2009), Evaluating the effectiveness of interactive map interface designs: A case study integrating usability metrics with eye-movement analysis, *Cartography and Geographic Information Science* 36(1): 5–17.
- Fabrikant, S. I., Rebich-Hespanha, S., Andrienko, N., Andrienko, G. and Montello, D. R. (2008), Novel method to measure inference affordance in static small-multiple map displays representing dynamic processes, *the Cartographic Journal* 45(3): 201–215.
- Fabrikant, S. I., Rebich-Hespanha, S. and Hegarty, M. (2010), Cognitively inspired and perceptually salient graphic displays for efficient spatial inference making, *Annals of the Association of American Geographers* 100(1): 13–29.
- Garlandini, S. and Fabrikant, S. I. (2009), Evaluating the Effectiveness and Efficiency of Visual Variables for Geographic Information Visualization, *LNCS (5756)*: 195–211.
- Harrower, M. (2003), Designing Effective Animated Maps, *Cartographic Perspectives* (44): 63–65.
- Harrower, M. (2007), The Cognitive Limits of Animated Maps, *Cartographica* 42(4): 349–357.
- Irwin, E. (2004), Fixation location and fixation duration as indices of cognitive processing, in *The Integration of Language, Vision, and Action: Eye Movements and the Visual World*, ed. by Henderson, J. M. and Ferreira, F., pp. 105–134, New York: Psychology Press.
- Li, X., Çöltekin A., Kraak M.-J. (2010), Visual Exploration of Eye Movement Data Using the Space-Time-Cube, *LNCS (6292)*: 295–309.
- Monmonier, M. S. (1992), Authoring Graphic Scripts: Experiences and Principles, *Cartography and Geographic Information Science* 19(4): 247–260.
- Nossum, A. S. (2010), Semistatic Animations – Integrating Past, Present and Future in Map Animations, *Proceedings, GIScience 2010, Zurich: (CD-ROM)*.
- Opach, T. (2005), Semantic and pragmatic aspect of transmitting information by animated maps, *Proceedings, 22nd ICA International Cartographic Conference, A Coruna: (CDROM)*.
- Suchan, T. A. and Brewer, C. A. (2000), Qualitative Methods for Research on Mapmaking and Map Use, *Professional Geographer* 52(1): 145–154.

Paper III

Exploring eye movement patterns on cartographic animations using projections of a space-time-cube.

Analysis of eye movements has been used for decades as a method for assessing the performance of visual stimuli. Until recently, this has mainly been applied to static and non-cartographic stimuli, but due to technological developments and reduced cost of equipment, interactive and cartographic applications are now feasible. Li et al. (2010) suggest a new analysis method which applies Hägerstrand's Space-Time-Cube (Hägerstrand 1970) to eye movement data. However, in an interactive three-dimensional Space-Time-Cube (STC), identifying and exploring key behaviors can be difficult. In order to ameliorate these difficulties, we propose a variation of the STC method, which uses two-dimensional projections of the STC onto the XT and YT planes. These two-dimensional projections are found to facilitate rapid identification of significant patterns in the data set. A prototype implementing this and other dynamical methods has been developed, and is presented with examples illustrating the benefits of working with two-dimensional projections of the STC.

Introduction

The success of cartographic design is measured in the degree to which the users perceive and comprehend the intended information. Drawing on insights from psychology and human-computer interaction, numerous methods have been developed to record and understand how humans respond to visual stimuli (Scinto & Barnette 1986; Goldberg 1999). Questionnaires, observation studies, think aloud recordings and interviews are a few of the vast array of different methods available.

In this connection, eye movements have been of interest to researchers for decades. Early studies used ways of recording eye movements that required physical contact with the subject (Kolers et al. 1981; Mackworth 1976; Just & Carpenter 1976). In recent years, however, advances in technology have made it possible to measure eye movements using near infrared light and high definition cameras. This makes the recording physically unnoticeable for the

subject which disturbs the experimental task less than other empirical methods (Johansen et al. 2011; Duchowski 2007).

However, a discussion on the conceptual motivation for performing this kind of studies has arisen in recent years. Early studies during the 1970's and 1980's (Kolers et al. 1981; Mackworth 1976; Just & Carpenter 1976) were primarily motivated by measuring where users fixed their gaze and developed methods which enabled this. The results often confirmed what was already known, or assumed, based on theoretical or empirical methods (Fabrikant et al. 2008; Brodersen et al. 2002). The recognition that the measurements and analysis gave little new knowledge formed the basis for a discussion on whether analyzing eye movements is necessary (Brodersen et al. 2002; Fabrikant et al. 2008). Given recent advances both in technology and empirical methods, the conceptual motivation for analyzing eye movements has changed. In modern user studies, the goal tends to delve deeper into the exploration of why users are reacting or behaving as they do (Fabrikant et al. 2008). These studies are often combined with other empirical methods, not only to confirm their findings, but to enhance their analyses and provide different perspectives for analysis.

Eye movement analysis methods

In commercial settings, the visual stimuli of interest can here be found in web pages, advertisements or product shelves (Chandon et al. 2009; Chandon et al. 2001; Buscher et al. 2010; Djamasbi et al. 2010). The goal of analysis is typically to decide what gets the most attention or what is more attractive for the user or consumer. This question is usually answered by analyzing where most of the participants fix their gaze. Not many studies take dynamically changing visual cues into account. The standard analysis methods thus tend to focus primarily on static visual stimuli. The most common eye tracking metrics and outputs are: fixation density

maps (“heatmaps”), gaze plots, replay of the fixations, clustering of the fixations, time to first fixation, fixation count, and length of fixations. These standard analysis methods are not optimal when the stimulus is dynamic. One of the major issues with the standard methods listed above, is the inability of analyzing eye-movements in a spatio-temporal context. Modern, cartographic, stimuli are often of a dynamic and interactive nature, with more complexity than traditional web pages or advertisements (Scinto & Barnette 1986; Goldberg & Kotval 1998; Goldberg 1999). Temporal aspects are thus often important for the user experience and for the analysis of user behavior.

When looking at eye movement recordings, the similarities with geographic spatio-temporal information is striking. Applying these analysis methods from geographical information science have proven to be successful at analysing eye movement data (Li et al. 2010; Griffin et al. 2006; Fabrikant & Goldsberry 2005; Fabrikant et al. 2008; Garlandini & Fabrikant 2009). There are also several suggestions on how to best analyze eye movement data using other methods inspired by psychological studies and cartographic studies (Buswell 1935; Goldberg & Kotval 1998; Hegarty et al. 2010; Keehner et al. 2008; Poole & Ball 2005; Ponsoda et al. 1995; Gitelman 2002; Ooms et al. 2012). Among the suggested methods Fabrikant et al. (2008) address a temporal issue, caused by the lack of experimental control, found in eye movement recordings. Patterns occurring across the normal temporal timeline are hard to discover using standard analysis methods. The authors approached this by applying a sequence alignment algorithm primarily intended to align DNA sequences (Sankoff & Kruskal 1983). The alignment algorithm orders the eye movement data in similar sequences for each of the participant, making it possible to discover patterns that were initially temporally scattered and hard to find using traditional methods.

Spatiotemporal analysis approach

In recent years, the amount of information with a geographic relation has exploded (MacEachren & Kraak 2001). A significant amount of this data is inherently temporal as well as geographic. GPS-tracking and migration studies are two of an abundant amount of examples concerning temporal and geographic information (Zhao & Fu 2001; Kwan & Lee 2004; Gams et al. 2009; Ekpenyong et al. 2009; Dias et al. 2007). Visualizing temporal data has been of great importance for centuries (Friendly 2002), but visualizing both the geographical and the temporal components introduces new challenges. Hägerstrand (1970) developed an elegant method of combining and visualizing both the two geographic dimensions and the temporal dimension simultaneously in what is known as the space-time-cube (STC). The STC is a cube with the X-Y dimension referring to the geographical dimensions, while the Z-axis refers to the temporal dimension. The STC enables the viewer to detect patterns and clusters which depends on both the temporal and spatial dimension. Li et al. (2010) apply the STC method on eye movement data to develop a prototype suited for eye movement analysis.

Extending the spatiotemporal analysis approach

A 3D cube can be visually overwhelming and require much interactivity to get the correct perspective to reveal interesting patterns (Keehner et al. 2008). In several situations the interesting viewing patterns are not found across all three dimensions (XYT), but in the two-dimensional projections of the three-dimensional space. This renders the three-dimensional visualization, such as the STC, to be overly complex. Motivated by this, a prototype has been developed that implements 2D projections of the space-time-cube interlinked with other visualizations.

Figure 1 shows a screenshot of the software with separate windows for each of the components. The components are all linked together, enabling them to react and dynamically change, in an interlinked fashion. There are some other GIS implementations which also use an interlinked strategy (Anselin et al. 2002; Wright et al. 2003; Hardisty 2009; Gahegan et al. 2002; MacEachren & Kraak 1997). By contrast with these, the components in the prototype we are presenting here includes; a space-time-cube with the stimuli in the XY plane, two graphs with the projected XT and YT projections of the space-time-cube, a fixation plot, and a timeline. All components are interactive with respect to manipulating which time to display. When moving the mouse within a component the time is changed respectively and all components will reflect the current time in their respective ways. An important feature of the components is the dynamic visualization of the stimuli, in addition to the linked dynamic visualization of the eye movements. This changes, with respect to the time and reflects what was displayed to the user at the exact time of recording. The space-time-cube additionally implements both zoom, pan and rotate to allow the user to investigate the eye-movement trajectories closer

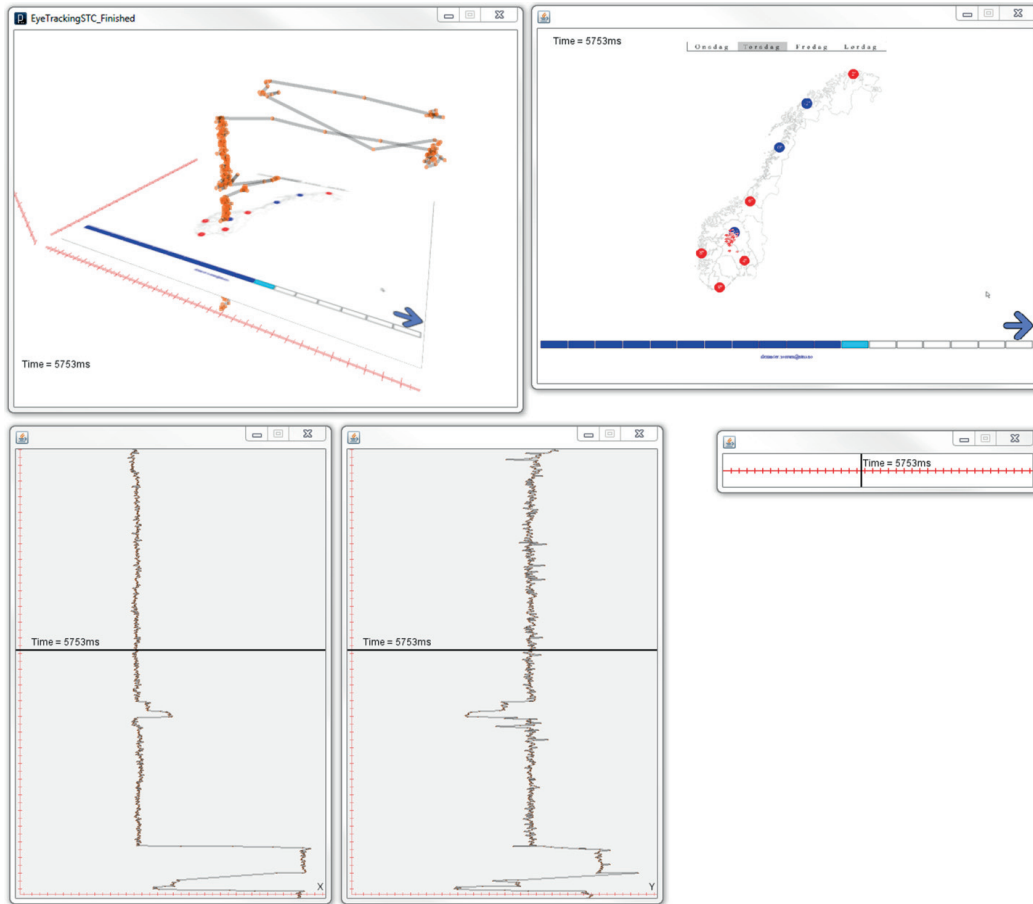


Figure 1. Screenshot of the prototype with several interlinked visualization components and in particular the two-dimensional projections of the STC.

Figure 2 is a screenshot of the prototype with a single participant's eye movements recorded during a travel planning task. The eye movement data is an extract from a previous experiment. The stimuli in the experiment were two types of weather map animations, one classic animation and one that allowed the viewer to visually move back and forth in time. Nossum (2011) and Opach & Nossum (2011) describe the stimuli and experimental design in detail. One important question in the experiment was whether the user in fact used the possibility of visually

moving back and forth in time. In figure 2 the expected and other interesting patterns are highlighted. The YT plot shows clearly that the participant is in fact *not* looking only forward in time, but is moving backwards in time as well. This shows that there is an interest in information that has already been shown in the animation. Figure 3 shows the exact same eye movements, but analyzed using traditional methods: gaze plot, heatmap and time to first fixation. Discovering the viewing pattern described here is impossible in both the gaze plot and heatmap. Time to first fixation can provide indications of the viewing order of the different locations. However, as figure 2 clearly shows, the overall viewing pattern is in fact quite different than what is shown by the time to first fixation analysis. For this analysis the YT projection is very valuable and clearly reveals patterns that are hard to find using traditional analysis tools. This example illustrates the benefits of the 2D projections of the STC.

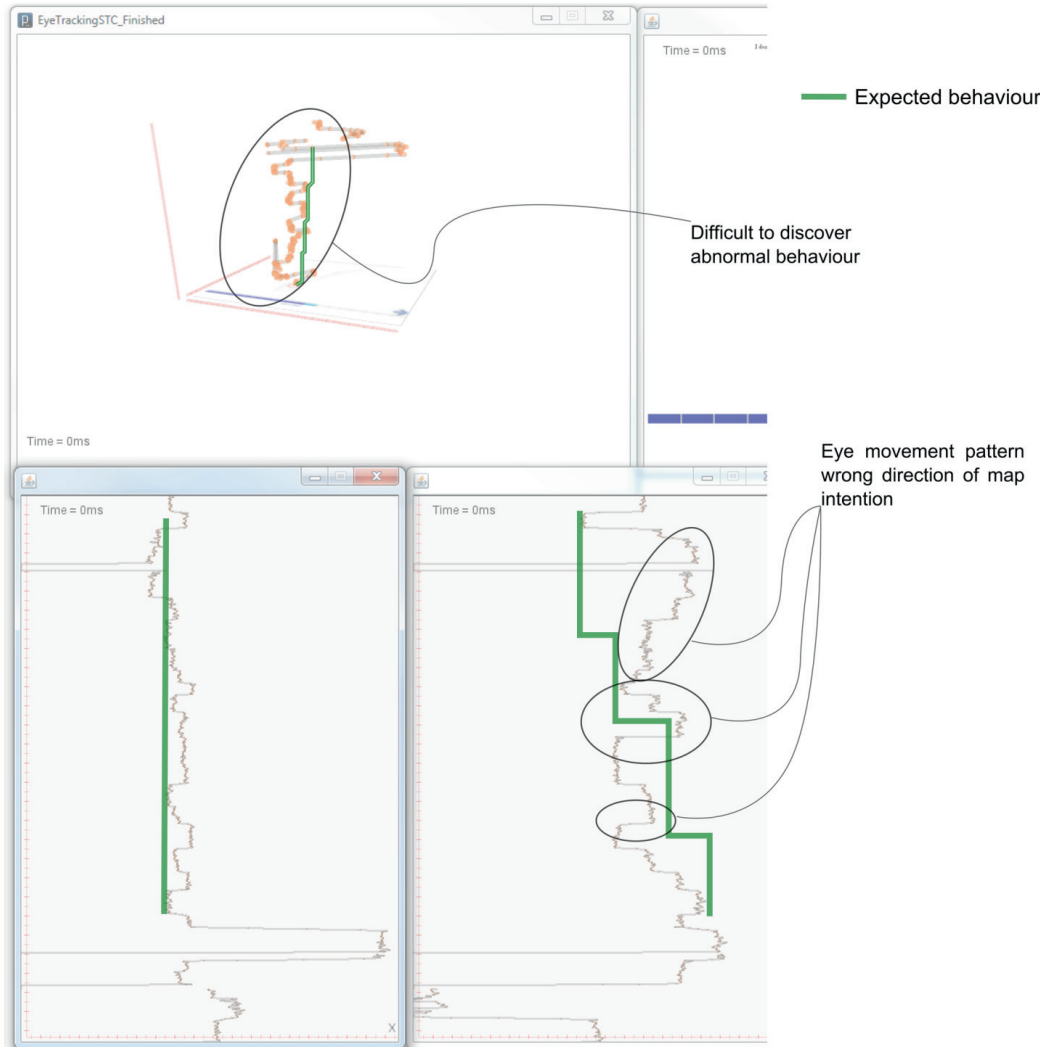


Figure 2. Discovery of a viewing pattern impossible or difficult to discover with traditional analysis methods. The patterns are difficult to discover in the interactive STC, in the top window, compared to the two-dimensional XT and YT projections found in the two bottom windows.

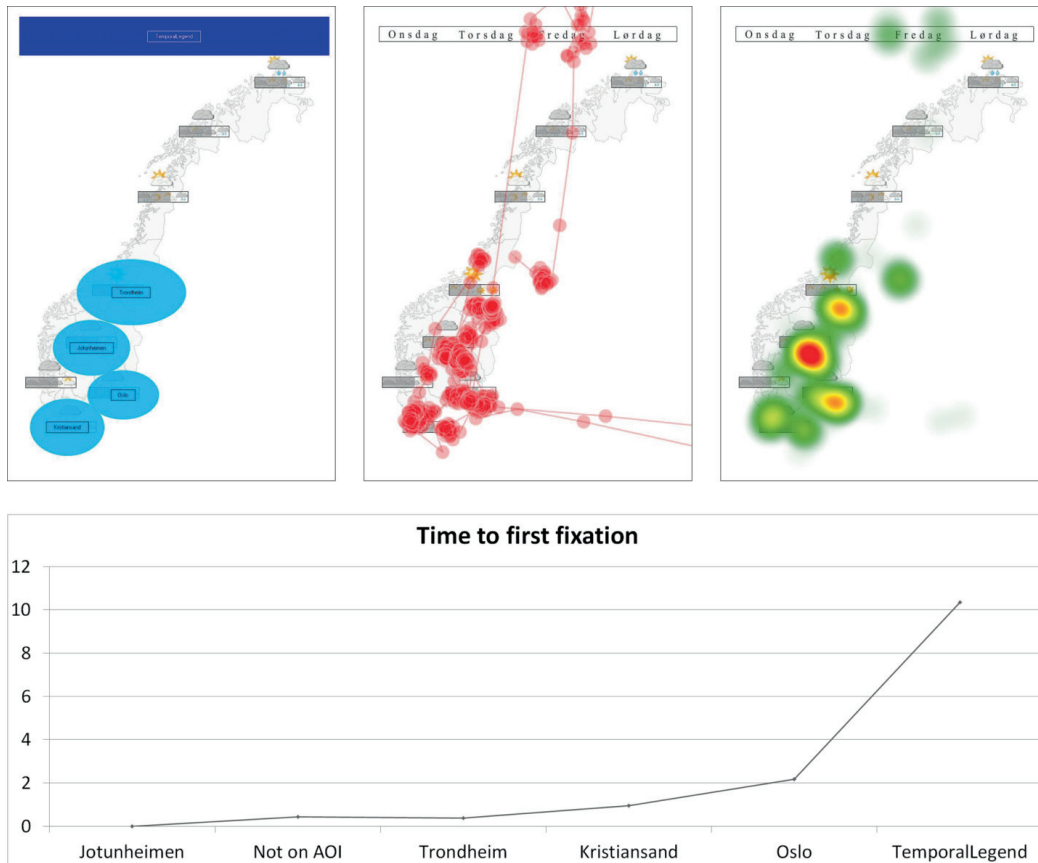


Figure 3. Eye movements analyzed with traditional methods. Top left: Areas of interest. Top center: A gaze plot visualizing the fixations and saccades between them. Top right: A fixation density plot (“heatmap”), showing the frequency of fixations. Bottom: Graph over time to first fixation on the areas of interest.

A second example that illustrates other benefits of the 2D projections of the STC visualization is found in figure 4. The data set is from the same experiment as in the previous example. However, the task and stimuli are different, which gives slightly different analysis requirements. The subjects were instructed to pay attention to the weather at one single point of interest (POI) for the duration of the animation, and then answer questions relating to the trend of

the weather for that period of time. The stimuli consisted of a standard weather forecast map, and required the participants to look at the legend to find out the dates of the forecast while the animation was playing. An important aspect to investigate is when the subject's attention is focused on the legend, and at which part of the legend the user's gaze is fixed. Using traditional analysis tools, this can be hard to answer. Traditional analysis can give the time to the first fixation and a gaze plot that could reveal indications that the subject at least looked once at the legend areas and also looked at each of the different days in the legend. However, one important aspect is difficult to address by the traditional analysis tools, namely whether the subject shifted attention between the legend and the POI while the animation was playing, and if so, whether the viewing order followed the sequence of the animation or if it was arbitrary. Figure 4 shows how these questions could easily be answered by looking at the patterns of the 2D projections. These patterns can also be found in the three dimensional STC. However, the 2D projections are hypothesized to be easier and more natural tools for discovering these kinds of patterns.

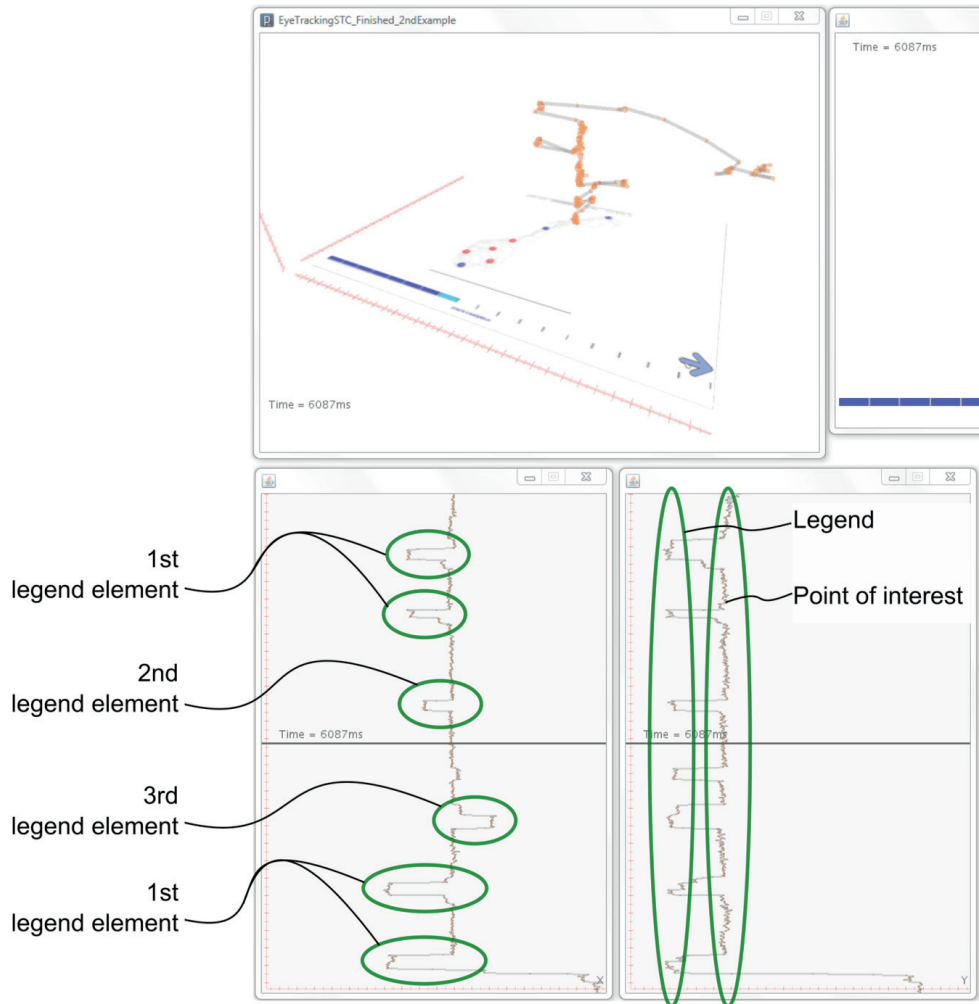


Figure 4. Discovery of patterns in the two-dimensional projections in the bottom windows that is difficult to find in the STC in the top window. The pattern found in the XT plot (bottom left) discovers movement between the legend elements in relation to the time. The YT plot shows a pattern that is related to the different areas of interest in relation to the time. Both plots shows consistent patterns that would be impossible to detect in traditional analysis and difficult in a STC alone.

Similarly, the different 2D perspectives of the space-time-cube are believed to support even more individual trajectories than the space-time-cube in isolation. This is supported by the

findings of Keehner et al. (2008), where the authors found that 3D visualizations do not necessarily improve performance in itself. There will, inevitably, be a threshold for any visualization regarding how much data can be visualized simultaneously. At some point, filtering and aggregation is necessary. Li et al. (2010) proposed dynamic filtering within the 3D visualization. This could be extended into implementing a concept of semi-automatic aggregation methods. Such methods could enable the user and the system to collaborate in complex decision making during the analysis. The fixed 2D projections of the space-time-cube can be very suitable with respect to this. Integrating these features with standardized analysis methods, such as fixation density maps and area of interest statistics, could provide better support for data exploration and analysis.

Conclusions

Eye movement recordings are generally assumed to be closely linked to the cognitive process of the subject, and to reflect the subject's perception and comprehension (Just & Carpenter 1976; Fabrikant et al. 2009). In order to explore this correspondence, proper analysis is crucial. This paper proposes a new method that, in combination with other methods, provides a new perspective into eye movement analysis. The new visualization technique proposed here integrates several different perspectives of the space-time-cube as components in an interactive process. Fixed, two-dimensional, projections of the space-time-cube can aid the analyst in exploring and finding patterns which are hard to discover by automated methods or by exploring the space-time-cube as a single entity. Our proposal has been implemented in a prototype to demonstrate the possibilities of integrating several analysis methods in one interlinked tool. Significant benefits are demonstrated through examples using eye movement recordings from a previous experiment. Patterns in eye movement recordings across the temporal dimension have

proven to be easier to identify with the two-dimensional projections than using standard analysis methods alone. We believe that combining this analysis method with other empirical methods can significantly benefit the overall analysis of eye movement data.

References

- Anselin, L., Syabri, I. & Smirnov, O., 2002. Visualizing multivariate spatial correlation with dynamically linked windows. *Urbana*, 51.
- Brodersen, L., Andersen, H.H.K. & Weber, S., 2002. *Applying eye-movement tracking for the study of map perception and map design*, Kort & Matrikelstyrelsen.
- Buscher, G., Dumais, S.T. & Cutrell, E., 2010. The good, the bad, and the random: An eye-tracking study of ad quality in web search. In *Proceeding of the 33rd international ACM SIGIR conference on Research and development in information retrieval*. ACM, pp. 42–49.
- Buswell, G.T., 1935. *How people look at pictures*, University of Chicago Press.
- Chandon, P. et al., 2009. Does in-store marketing work? Effects of the number and position of shelf facings on brand attention and evaluation at the point of purchase. *Journal of Marketing*, 73(6), pp.1–17.
- Chandon, P., Hutchinson, W.J. & Young, S.H., 2001. *Measuring the value of point-of-purchase marketing with commercial eye-tracking data*, INSEAD.
- Dias, E., Edwardes, A. & Purves, R., 2007. Analysing and aggregating visitor tracks in a protected area. In *5th International Symposium on Spatial Data Quality proceedings. Electronic Proceedings. Enschede, ISPRS*. pp. 15–6.
- Djamasbi, S., Siegel, M. & Tullis, T., 2010. Generation Y, web design, and eye tracking. *International Journal of Human-Computer Studies*, 68(5), pp.307–323.
- Duchowski, A., 2007. *Eye tracking methodology: Theory and practice*, Springer.
- Ekpenyong, F., Palmer-Brown, D. & Brimicombe, A., 2009. Extracting road information from recorded GPS data using snap-drift neural network. *Neurocomputing*, 73(1-3), pp.24–36.
- Fabrikant, S. et al., 2008. Novel Method to Measure Inference Affordance in Static Small-Multiple Map Displays Representing Dynamic Processes. *Cartographic Journal, The*, 45(3), pp.201-215.

- Fabrikant, S. & Goldsberry, K., 2005. Thematic relevance and perceptual salience of dynamic geovisualization displays. In *Proceedings of 22nd ICA international cartographic conference: mapping approaches into a changing world, A Coruna, Spain*.
- Fabrikant, S., Hespanha, S.R. & Hegarty, M., 2009. Cognitively Inspired and Perceptually Salient Graphic Displays for Efficient Spatial Inference Making. *Annals of the Association of American Geographers*, 100(1), pp.13-29.
- Friendly, M., 2002. Visions and Re-Visions of Charles Joseph Minard. *Journal of Educational and Behavioral Statistics*, 27(1).
- Gahegan, M. et al., 2002. GeoVISTA Studio: a geocomputational workbench. *Computers, Environment and Urban Systems*, 26, pp.267–292.
- Gams, E., Rehrl, K. & Kaschl, D., 2009. Using other People's Trails for Navigation Assistance.
- Garlandini, S. & Fabrikant, S., 2009. Evaluating the effectiveness and efficiency of visual variables for geographic information visualization. *Spatial Information Theory*, pp.195–211.
- Gitelman, D.R., 2002. ILAB: A program for post experimental eye movement analysis. *Behavior Research Methods, Instruments, & Computers*, 34(4), p.605.
- Goldberg, J., 1999. Computer interface evaluation using eye movements: methods and constructs. *International Journal of Industrial Ergonomics*, 24(6), pp.631-645.
- Goldberg, J. & Kotval, X., 1998. Eye movement-based evaluation of the computer interface. *Advances in occupational ergonomics and safety*, pp.529–532.
- Griffin, A.L. et al., 2006. A Comparison of Animated Maps with Static Small-Multiple Maps for Visually Identifying Space-Time Clusters. *Annals of the Association of American Geographers*, 96(4), pp.740-753.
- Hardisty, F., 2009. GeoJabber: Enabling Geo-Collaborative Visual Analysis. *Cartography and Geographic Information Science*, 36(3), pp.267-280.
- Hegarty, M., Canham, M.S. & Fabrikant, S.I., 2010. Thinking about the weather: How display salience and knowledge affect performance in a graphic inference task. *Journal of experimental psychology. Learning, memory, and cognition*, 36(1), pp.37-53.
- Hägerstrand, T., 1970. What about people in Regional Science? *Papers of the Regional Science Association*, 24(1), pp.6-21.
- Johansen, S.A. et al., 2011. Low cost vs. high-end eye tracking for usability testing. In *Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems - CHI EA '11*. New York, New York, USA: ACM Press, p. 1177.

- Just, M.A. & Carpenter, P.A., 1976. Eye fixations and cognitive processes. *Cognitive Psychology*, 8, pp.441-480.
- Keehner, M. et al., 2008. Spatial Reasoning With External Visualizations: What Matters Is What You See, Not Whether You Interact. *Cognitive Science: A Multidisciplinary Journal*, 32(7), pp.1099-1132.
- Kolers, P.A., Duchnick, R.L. & Ferguson, D.C., 1981. Eye movement measurement of readability of CRT displays. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 23(5), pp.517-527.
- Kwan, M.P. & Lee, J., 2004. Geovisualization of human activity patterns using 3D GIS: a time-geographic approach. *Spatially integrated social science*, 27.
- Li, X., Çöltekin, A. & Kraak, M.-J., 2010. Visual Exploration of Eye Movement Data Using the Space-Time-Cube. In Sara Fabrikant et al., eds. *Geographic Information Science*. Berlin, Heidelberg: Springer Berlin / Heidelberg, pp. 295-309.
- MacEachren, A.M. & Kraak, M.J., 1997. Exploratory cartographic visualization: advancing the agenda. *Computers & Geosciences*, 23(4), pp.335-343.
- MacEachren, A.M.A.M. & Kraak, M.-J.M.J., 2001. Research Challenges in Geovisualization. *Cartography and Geographic Information Science*, 28(1), pp.3-12.
- Mackworth, N., 1976. Stimulus density limits the useful field of view. *Eye movements and psychological processes*, p.1976.
- Nossum, A.S., 2012. Semistatic animations - integrating past, present and future in animations. *Cartographic Journal, The*, 49(1), pp.43-54.
- Ooms, K. et al., 2012. Analysing the spatial dimension of eye movement data using a visual analytic approach. *Expert Systems with Applications*, 39(1), pp.1324-1332.
- Opach, T. & Nossum, A.S., 2011. Evaluating the usability of cartographic animations with eye-movement analysis. In A. Ruas, ed. *Proceedings of the 25th International Cartographic Conference*. Paris, France.
- Ponsoda, V., Scott, D. & Findlay, J.M., 1995. A probability vector and transition matrix analysis of eye movements during visual search. *Acta Psychologica*, 88(2), pp.167-185.
- Poole, A. & Ball, L.J., 2005. Eye tracking in human-computer interaction and usability research: current status and future prospects. *Encyclopedia of human computer interaction*, pp.211-219.
- Sankoff, D. & Kruskal, J.B., 1983. *Time warps, string edits, and macromolecules: the theory and practice of sequence comparison*, Addison-Wesley Publication.

- Scinto, L.F.M. & Barnette, B.D., 1986. An algorithm for determining clusters, pairs or singletons in eye-movement scan-path records. *Behavior Research Methods*, 18(1), pp.41–44.
- Wright, D.J. et al., 2003. Why Web GIS may not be enough: A case study with the virtual research vessel. *Marine Geodesy*, 26(1-2), pp.73–86.
- Zhao, J. & Fu, H., 2001. Application of GIS in the Study of the Migration of the Population Gravity Center [J]. *Engineering of Surveying and Mapping*, 3.

Paper IV

Are indoor positioning systems mature for cartographic tasks?

Evaluating the performance of a commercial indoor positioning system

Terje Midtbø, Alexander S. Nossum, Trond A. Haakonsen, Robert P.V. Nordan

ABSTRACT: Better indoor mapping are linked together with better indoor positioning. This paper gives a brief overview over existing methods for indoor positioning. To get an impression of how well a WiFi based commercial indoor positioning system works as an input to indoor real time visualization, a network of control points were established. Accurate coordinates for existing access points were also measured to see if these could improve the WiFi measured coordinates. Our experiment indicates that the geometry of the access points/mobile platform, the nearness to the access points and obstacles, as for example walls, are the dominating limitations when it comes to measure more accurate positions.

KEYWORDS: Indoor maps, indoor positioning, WiFi positioning

Introduction

When we talk about maps most people will imagine some kind of graphic representation of our outdoor environment. Maps have been made for hundreds of years, and in the last decade the amount of collected data and their representation and visualization on Internet based media has been growing in an accelerating tempo. A new trend is to extend the collection of data to include spatial environments inside the buildings. Google has for example recently extended the well known Google Street View to include indoor environments.

Multi-storey buildings represent new challenges in structuring, displaying and perceiving the indoor environment (Walton & Worboys 2009; Giudice et al. 2010; Raubal & Egenhofer 1998; Raubal et al. 1997). Cognitive integration of multi-storey buildings is different than outdoor environment. Additionally, the added vertical dimension introduces cartographic challenges that are not present in the outdoor environment in traditional cartography. Two dimensional floor plan maps is one of the most common map type used for indoor environments. The abstraction level range from architectural style, to high abstraction levels like airport and mall maps. New alternatives to regular floor plan maps have been suggested in the literature and in commercial projects. Some of which investigates possibilities of haptic representation for smartphones (Raja 2011), adaptation of metro maps (Nossum 2011) and "street view" photographic environments (Google Art Project 2012). Similar to all projects related to cartographic representations of indoor environments is that they either rely on accurate positioning or have a significant added value in the case of accurate position.

As GPS has been the key to success for outdoor location based services; indoor positioning is the key to success for indoor location based services. In most outdoor environments GPS is the technology that is most relevant for the "average man". However, when we move indoor, GPS is way more limited. Indoor GPS signals can be amplified by the use of **GPS repeaters** (Jardak & Samama 2009) and there exist high sensitive GPS receivers that, up to a certain limit, can be used indoors (Zhang et al. 2010). However, GPS repeaters are supplementary equipment that is not very widespread, and high sensitive GPS receivers are still quite limited in complex multi-storey buildings. For indoor positioning, other technologies exist which are based on local equipment as opposed to the use of global satellites. For example Liu et al. (2007) and Nordan (2011) gives a detailed overview over different systems: **RFID-systems** (*Radio Frequency IDentification*) is based on sensing passive or active RFID chips when it comes within the range of a receiver. With passive

systems the sensors are typically placed at key positions such as doorways to enable room-scale positioning. **Ultrasound-based systems** work by transmitting ultrasound waves from tags, which are frequency modulated for identification and are picked up by dedicated receivers. Calculation of the position is based on measurement of the strongest signal, and since the ultrasound signal is hampered by walls etc., the technology is best suited for positioning on room level. There have also been some experiments using **infrared signals**. However, the necessity of a free line of sight between the transmitter and the receiver is a major drawback for this technology. All these technologies are based on a local infrastructure that includes sensor/transmitters of relative high density. This results in a dedicated infrastructure that needs to be installed solely for navigational purposes. Consequently, these are systems that are adequate when positioning is essential, and not for indoor positioning in general. **Cellular phone triangulation** is on the other hand based on the existing infrastructure for mobile communication. By comparing signal strength readings to known locations of cell towers the position of the hand-held equipment can be calculated. The accuracy of the distance measured from the transmitter to the receiver is in the first place poor. However, one advantage of this method is that the signals penetrate buildings, and Otsason et al. (2005) shows that by using fingerprinting techniques the method can be adequate for room-scale positioning.

WiFi positioning systems are one of the more promising techniques for indoor positioning. Wireless access points have become a natural infrastructure in buildings and some outdoor environments in urban areas, and the signals, which penetrate walls, can be handled by most handheld equipment like cell phones, tablets, laptops etc. Because this is an existing infrastructure, the cost for utilizing it for navigational purposes is low. It is also a fact that WiFi signals from each transmitter cover a much wider area than it is possible to obtain from for example infrared or bluetooth systems.

The most common method for WiFi positioning is to measure the strength of the signals from several wireless access points, and use this information to triangulate the position of the mobile device. There also exist systems where characteristics such as time of arrival or angle of arrival of the signals are used to determine the location (Köbben 2007). This will however require the employment of additional hardware. Yeung and Ng (2007) introduces an algorithm where the signal strength from mobile device to the access points is measured together with signal strength generated by the access points. They claim to have improved the accuracy of the location estimation by between 12 and 38%.

Today there exist several commercial systems for WiFi positioning systems, and many authors have investigated the accuracy and precision of these systems. Zandbergen (2009) tested the accuracy of iPhone location by the use of Assisted GPS, WiFi and cellular positioning in natural environments. He concluded that the WiFi positioning system was far below expectations based on published performance by Skyhook Wireless. This is the system employed on the actual iPhone. Uneven distribution of wireless access points is assumed to be a reason for lower accuracy. The accuracy for WiFi positioning was however substantial better than the corresponding cellular positioning.

Gallagher and Kealy (2009) investigated the use of Ekahau Positioning Engine (EPE) and Skyhook Wireless Positioning System (WPS) for indoor environments. In their trials they found the EPE to have an accuracy of about 10-15 meters, while the typical error for the WPS was 30-60 meters. However, it seems like only the EPE was based on fingerprinting techniques in their trials.

Fingerprinting techniques, or calibration for the received signal, is used to store information about average strength of the received signal in various locations. When the mobile device receives signals from multiple access points the strengths of these signals can be compared to initial measurements stored in a database. Signal strength "profiles" can for example be stored for each room in a building to make room-scaled positioning better.

There is an abundant amount of related work which includes prototypes of indoor positioning in various manners (Ciavarella et al. 2004; Yang et al. 2007; Dahl 2006; Schrooyen et al. 2006; Huang et al. 2009). Most of the existing efforts have not included a rigorous evaluation method and measurements of accuracy and precision drawing on knowledge from the established field of land surveying. Surveys providing overview of different positioning methods and technologies are found in the literature as well (Mautz 2009; Curran et al. 2011; H. Liu et al. 2007). The different techniques available range from high precision and accurate laser positioning, commonly used in surveying to coarse IP geolocation, this paper focus primarily on available and non-dedicated infrastructures, which WiFi positioning is able to fulfill.

NTNU and Wireless Trondheim's WiFi positioning system

As described by Nordan (2011), the Norwegian University of Science and Technology (NTNU) uses the Cisco Mobility Services Engine (MSE) as a WiFi positioning system. The MSE is connected to the system of wireless access points that provides WiFi coverage to students and employees. Each access point is given a position based on a local coordinate system for each building. The coordinates are extracted from a drawing of the building, and due to the fact that positioning is a secondary task of the WiFi system, the locations of the access points are not necessarily optimized. The actual position of a handheld device is determined by signal triangulation from the access points to the device. Internally, one can, through the Wireless Control System (WCS), track any device connected to the network, while externally an API is exposed through a separate system named GeoPos.

The GeoPos system uses web services to connect to the WCS in order to extract the position information. GeoPos then adds value to the information by translating the relative coordinates to absolute coordinates. WGS84 longitude and latitude and UTM 32 coordinates are returned along with information about the actual building. The MSE/WCS system does not have any functionality for remembering previous positions of a device. Consequently, only the current known position of a device will be passed on. With a user account and appropriate cryptographic certificates, one can use the GeoPos system to track the position of devices with known MAC addresses. (This mainly limits you to track devices in your own possession.) The system is illustrated in Figure 1.

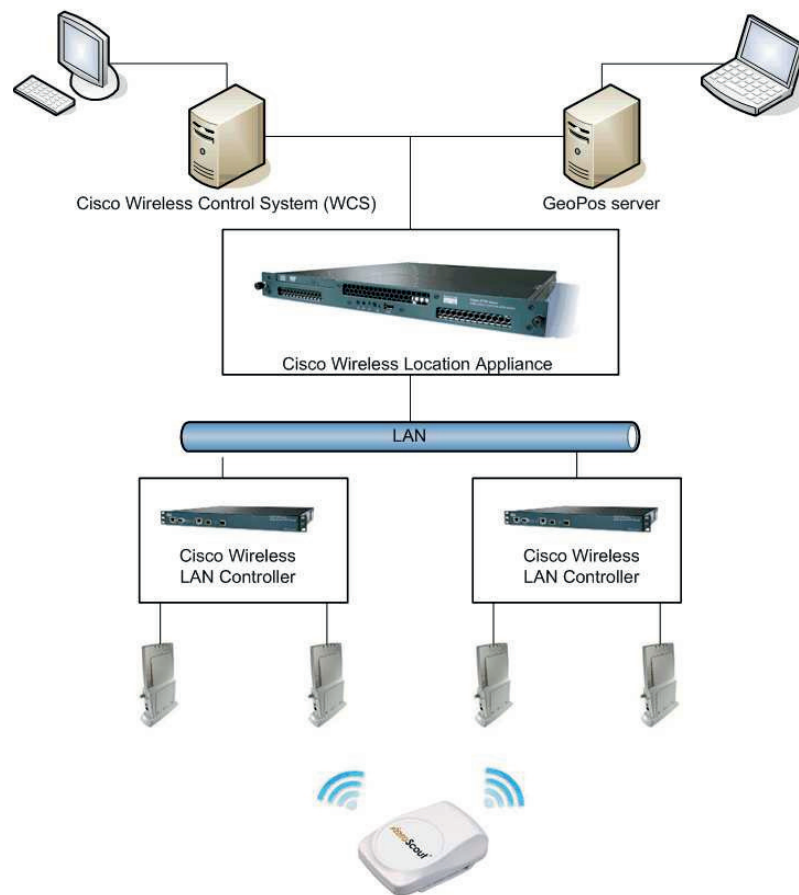


Figure 1: NTNU and Wireless Trondheim positioning system (Moen & Jelle 2007)

Investigation of the functionality and accuracy of the Cisco positioning system

Köbben (2007) presents a list of evaluation criteria for WiFi-based location systems. This includes factors such as accuracy, precision, calibration, responsiveness, scalability, self-organization, cost, power consumption and privacy. In this work we will primarily study accuracy and precision for the Cisco system at NTNU. We will also include calibration through fingerprinting methods.

Nordan (2011) completed an initial experiment where the accuracy of the actual WiFi positioning system was explored. His experiment was based on measurements both with and without fingerprinting techniques. He could not find any significant improvement by using the fingerprint information. Measuring 36 points he found the mean error to be 9.9 meters without fingerprinting techniques and 8.3 meters with, both with a quite high variance. The experiment in Nordan (2011) revealed however some problems regarding the measurement of precision and accuracy for the WiFi positioning at NTNU:

- The calculations of new positions are based on triangulation between access points and the

wireless equipment. However, the wireless network is built for data communication, not for navigation. Consequently, the best geometry for calculations of the positions is not taken into consideration when access points are installed.

- For navigational purposes the access points need to be located in a reference system, either local for the building or a geodetic coordinate system. For wireless communication this is less important. The intention in Nordan (2011) was to run the experiment in a hospital building. However, when inspecting the data for the access points it turned out that most of the access points were given the same coordinate - in the garden outside the building. His experiment was consequently moved to a building with better configured access points. But even then the coordinates for the access points are picked out from sketches on maps, and the difference between the given and the real position can often be measured in meters.

To achieve a better understanding of the wireless navigation system at NTNU, it was decided to carry out more thorough experiments to answer research questions as; does the system provide sufficient accuracy for turn-by-turn navigation in indoor environments, will improved positioning of the access point give better accuracy in the navigation, and does fingerprinting techniques implemented in the Cisco system improve the solution.

Though the network geometry still would be a limitation, the questions about more accurate coordinates for the access points and repeatable measurements were solvable. Consequently, it was decided to establish a permanent network of control points inside the Lerkendal building at NTNU. This network would be the frame of reference both for the investigation of the current wireless positioning system and for the measurements in another project that involves pseudolites for indoor GPS navigation. The network was also established in a way that made it possible to engage in future experiments involving new technologies. Development in accuracy and precision may then be studied.

The network was realized by the help of red enamel varnish and a custom/made tool for making permanent marks in the linoleum on the floor in the test building. 31 points were marked at different locations at first floor, while the second floor contained 9 points, and the basement 5 points in central areas (Figure 2). This gives 45 points all together.



Figure 2: Control points established in the building.

The Cisco Wireless Location Appliance uses a local reference system for each building where foot is set as the unit. Since the primary task for this kind of equipment is network communication it is expected that the locations of the access points remain more uncertain. The actual coordinates are most likely extracted from a sketch of the building. To investigate this, the locations of the access points were measured using surveying equipment and well known surveying methods. These measurements showed that the internal accuracy for the access point locations was rather poor (several meters). Table 1 shows the difference between the existing and actual coordinates (accurate measurements) for the access points.

Table 1: Accurate coordinates and their differences from the coordinates picked from a drawing. All the values are in feet.

| Access point | Old X | Old Y | Accurate X | Accurate Y | dX | dY | 2D diff. |
|--------------|--------|--------|------------|------------|-------|-------|----------|
| A0-03 | 63,00 | 383,38 | 58,26 | 363,99 | 4,74 | 19,39 | 19,96 |
| A0-01 | 54,13 | 280,84 | 58,37 | 270,34 | -4,24 | 10,50 | 11,33 |
| A0-02 | 59,06 | 333,01 | 57,98 | 320,86 | 1,08 | 12,15 | 12,20 |
| A1-13 | 283,79 | 274,61 | 278,63 | 266,92 | 5,16 | 7,69 | 9,26 |
| A1-14 | 262,80 | 339,24 | 261,40 | 329,95 | 1,40 | 9,29 | 9,39 |
| A1-06 | 209,65 | 355,31 | 201,16 | 341,57 | 8,49 | 13,74 | 16,15 |
| A1-07 | 170,93 | 285,43 | 162,16 | 277,94 | 8,77 | 7,49 | 11,54 |
| A1-08 | 138,45 | 336,61 | 137,7 | 332,95 | 0,75 | 3,66 | 3,74 |
| A1-11 | 230,64 | 251,64 | 230,25 | 244,57 | 0,39 | 7,07 | 7,08 |
| A1-10 | 186,02 | 229,00 | 176,06 | 221,67 | 9,96 | 7,33 | 12,37 |
| A1-09 | 117,45 | 228,02 | 114,52 | 221,6 | 2,93 | 6,42 | 7,05 |
| A1-02 | 43,71 | 264,81 | 45,14 | 259,58 | -1,43 | 5,23 | 5,42 |
| A1-03 | 44,73 | 329,35 | 45,02 | 323,27 | -0,29 | 6,08 | 6,09 |

| | | | | | | | |
|--------------|--------|--------|--------|--------|--------|--------|-------|
| A1-04 | 46,26 | 387,80 | 44,87 | 378,00 | 1,39 | 9,80 | 9,90 |
| A1-05 | 109,58 | 370,41 | 98,92 | 357,62 | 10,66 | 12,79 | 16,65 |
| A1-01 | 52,82 | 225,72 | 48,57 | 219,41 | 4,25 | 6,31 | 7,61 |
| A1-12 | 276,25 | 230,97 | 270,64 | 222,93 | 5,61 | 8,04 | 9,80 |
| A2-07 | 28,87 | 362,86 | 28,00 | 379,85 | 0,87 | -16,99 | 17,01 |
| A2-06 | 30,51 | 321,19 | 28,11 | 332,31 | 2,40 | -11,12 | 11,37 |
| A2-05 | 37,07 | 281,82 | 34,38 | 301,15 | 2,69 | -19,33 | 19,52 |
| A2-02 | 38,06 | 248,03 | 34,47 | 260,11 | 3,59 | -12,08 | 12,6 |
| A2-01 | 20,34 | 204,4 | 16,16 | 208,45 | 4,18 | -4,05 | 5,82 |
| A2-03 | 92,16 | 210,92 | 95,71 | 218,75 | -3,55 | -7,83 | 8,60 |
| A2-04 | 164,36 | 212,34 | 166,69 | 224,57 | -2,33 | -12,23 | 12,45 |
| A2-14 | 278,37 | 209,97 | 292,32 | 217,77 | -13,95 | -7,80 | 15,98 |
| A2-11 | 201,42 | 329,68 | 206,58 | 343,35 | -5,16 | -13,67 | 14,61 |
| A2-08 | 97,86 | 326,83 | 100,36 | 336,84 | -2,50 | -10,01 | 10,32 |
| A2-09 | 145,34 | 291,34 | 153,78 | 303,85 | -8,44 | -12,51 | 15,09 |
| A2-10 | 146,00 | 265,09 | 153,74 | 270,26 | -7,74 | -5,17 | 9,31 |
| A2-12 | 250,66 | 295,60 | 266,25 | 306,93 | -15,59 | -11,33 | 19,27 |
| A2-13 | 253,28 | 260,83 | 267,38 | 269,72 | -14,10 | -8,89 | 16,66 |

The access points were measured together with the network of indoor control points. Based on six first order outdoor benchmarks measured with RTK-GNSS, a high precision network was measured with a total station in a global reference frame. Estimated 3D standard deviations for access points in the measured global system were all in the magnitude of one centimeter. All the positions were measured in UTM, Zone 32N.

Using the two sets of plain 2D access point coordinates, the relation between the global and the local system were found mathematically, estimating the four unknown parameters in a conform plain Helmert transformation. Finally, a set of accurate, "corrected", coordinates ensuring uniform internal geometry in the local system were determined, transforming the measured data set from the global to the local system.

Application for running an indoor positioning experiment

A web application was developed to collect and store positions from the Cisco Wireless Location Appliance (WLA) throughout the experiment. The application was implemented as a web page with necessary server side functionality for requesting positions from the WLA as well as from HTML5 GeoLocation, and storing results in a database. The client controlled the positioning frequency and input parameters to the positioning system together with necessary information to store in the database. In an effort to get the most accurate positioning from the WLA positioning system, the client has the ability to do an HTML5 GeoLocation request. In Mozilla Firefox, the GeoLocation request is implemented to send out signals on present WiFi devices on all channels to all access points (Mozilla 2012). Requesting a position from the GeoLocation API results also in an additional position measurement based primarily on IP address and WiFi access point data which could be compared with the results from the indoor positioning system in question. To maintain security and privacy, the application was password protected and the communication between server and positioning system was encrypted. All requested positions and the complete result from the positioning system were stored in a SQLite database which could be accessed using a lightweight administration panel and an export application. The result from the positioning system consisted of

coordinates in several coordinate systems including a horizontal local system, the UTM system and a geographic coordinate system – all in combination with a textual representation of the current floor. In addition the result included a confidence measure provided directly from the positioning system.

Measurements of positions by WiFi equipment

A custom-built “vehicle” was built to provide a stable and consistent platform for measurement of the coordinates provided by the wireless network (Figure 3). Since the position of the WiFi antenna inside a laptop is difficult to establish, it was decided to use an external WiFi unit that was connected through one of the USB connections on the laptop. This also made it easy to position the WiFi unit exactly over the control point on the floor and to keep the unit at a consistent height over the floor. Based on the expected accuracy of the positions provided by the wireless positioning system it might seem superfluous to arrange for precise placement of the equipment. It was however decided to avoid the inclusion of unnecessary incorrectness and to prepare for future analysis of future, more accurate, systems.

10 control points in the first floor of Lerkendalsbygget were selected for further investigation. This included both control points in halls and open areas as well as points inside offices. In the selected locations there were variation in both the coverage of the wireless network and the geometry related to access points reached by the WiFi unit. The measurement campaign was accomplished in a period with few people present at campus (between semesters for the students and in the summer vacation for employees). Consequently, the general activity on the wireless network was low and stable.



Figure 3: Movable platform for measuring control points.

The Cisco Wireless Location Appliance is equipped with calibration techniques, where the expected signal strengths in different locations are included in the calculation of the position (fingerprinting). In this experiment it was also interesting to study how fingerprinting (FP) influenced the determination of the various positions. Consequently, a series of measurements were carried out for all 10 control points both with and without FP. Since the accurate determination of both access points and control points provided new coordinates for these, the new positions for the access points could be implemented into the Cisco Wireless Location Appliance. To find if new coordinates had any effect on the position, new series of measurements were carried out both with and without FP.

For all the measuring series, each point was measured 5 times. After a study of auto correlation functions computed from representative time series measured in an early phase, it was decided to use at least 1 hour delay between the measurements of the same point to avoid time correlation. The coordinates were recorded as simple measurements to simulate a mobile platform moving around in the building. This gives no repeated measurement over time for each recorded point. Our systems for recording of the data stored measured coordinates as local coordinates in feet as well as UTM coordinates processed through the GeoPos server. For the further study in this paper the local

coordinates in feet were used.

During the measurement campaign we did some observations:

- If we were going to make several measurements in the same point it was necessary to disconnect and then connect the wireless network. Even then the system seemed to use the first coordinates in an algorithm for improvement of the position.
- It was always necessary to disconnect and then connect the wireless network between measurements in different control points, especially when the points were close. If not doing this, the coordinates for the previous point would be included in the calculation of the next.
- When doing the measurements we did not consider the orientation of the antenna to be of any importance.

Results

The measured coordinates for the control points are presented in *Table 2* and *Table 3*. In addition it can be mentioned that all the measurements showed the correct floor for the control points.

Table 2: True values and the mean values of the measured coordinates for the control points, dataset 1 to 4.

| Control point | True val. x y | Mean values | | | |
|---------------|---------------------|----------------|----------------|------------------|------------------|
| | | 1 Old no FP | 2 New no FP | 3 Old with FP | 4 New with FP |
| P-1 | 18 364,6 | 40,7 397,8 | 53,4 390,6 | 64,3 378,6 | 61,4 366,1 |
| P-13 | 40,5 266,1 | 42,7 268,2 | 48,0 263,5 | 48,1 277,7 | 45,9 273,4 |
| P-24 | 154,4 284,9 | 145,7 295,5 | 182,8 277,5 | 163,2 292,2 | 161,2 268,6 |
| P-18 | 64,7 226,8 | 48,2 219,8 | 51,0 235,4 | 79,3 233,7 | 62,4 235,2 |
| P-05 | 60,6 354,5 | 57,8 375,0 | 55,7 368,1 | 71,0 359,7 | 69,3 356,2 |
| P-17 | 41,5 225,1 | 57,0 259,8 | 56,7 254,5 | 54,5 255,5 | 61,8 255,5 |
| P-09 | 40,3 340,1 | 62,7 332,8 | 80,3 290,5 | 66,3 350,7 | 77,2 307,6 |
| P-28 | 113,8 347,4 | 118,4 362,8 | 106,3 343,8 | 107,8 360,7 | 102,5 343,1 |
| P-10 | 43,1 305,6 | 43,9 311,3 | 54,8 309,5 | 62,5 293,3 | 67,4 308,8 |
| P-02 | 88,1 369,9 | 83,2 396,8 | 53,8 403,6 | 79,5 375,2 | 60,1 372,3 |

Table 3: Differences, standard deviation and variance in measured coordinates. Measurements with old and new coordinates for access points and with and without FP.

| Control point | Difference from true value | | | | Standard deviation | | | | Variance | | | |
|---------------|----------------------------|----------------|------------------|------------------|--------------------|----------------|------------------|------------------|----------------|----------------|------------------|------------------|
| | 1 Old no FP | 2 New no FP | 3 Old with FP | 4 New with FP | 1 Old no FP | 2 New no FP | 3 Old with FP | 4 New with FP | 1 Old no FP | 2 New no FP | 3 Old with FP | 4 New with FP |
| P-1 | 22,7 | 35,4 | 46,3 | 43,4 | 19,2 | 12,2 | 12,4 | 13,7 | 370,5 | 148,1 | 154,1 | 187,0 |
| | 33,2 | 26,0 | 14,0 | 1,5 | 6,0 | 11,9 | 3,8 | 7,1 | 36,1 | 142,2 | 14,4 | 50,6 |
| P-13 | 2,2 | 7,5 | 7,6 | 5,4 | 1,5 | 2,5 | 2,6 | 0,7 | 2,3 | 6,1 | 6,9 | 0,5 |
| | 2,1 | -2,6 | 11,6 | 7,3 | 10,2 | 9,5 | 10,1 | 16,4 | 103,9 | 90,0 | 102,7 | 268,9 |
| P-24 | -8,7 | 28,4 | 8,8 | 6,8 | 28,2 | 28,0 | 7,3 | 4,9 | 796,4 | 781,3 | 53,6 | 23,9 |
| | 10,6 | -7,4 | 7,3 | -16,3 | 19,2 | 19,0 | 9,2 | 9,5 | 367,4 | 362,4 | 84,1 | 89,6 |
| P-18 | -16,5 | -13,7 | 14,6 | -2,3 | 31,2 | 28,6 | 21,7 | 2,5 | 973,0 | 817,4 | 471,2 | 6,4 |
| | -7,0 | 8,6 | 6,9 | 8,4 | 15,9 | 22,5 | 7,8 | 8,7 | 254,2 | 505,1 | 61,6 | 75,4 |
| P-05 | -2,8 | -4,9 | 10,4 | 8,7 | 10,5 | 10,3 | 6,5 | 11,2 | 110,8 | 105,6 | 42,8 | 124,6 |
| | 20,5 | 13,6 | 5,2 | 1,7 | 11,8 | 12,7 | 15,8 | 21,6 | 139,7 | 161,6 | 248,7 | 466,3 |
| P-17 | 15,5 | 15,2 | 13,0 | 20,3 | 13,2 | 10,8 | 6,5 | 8,2 | 173,0 | 115,9 | 41,7 | 67,8 |
| | 34,7 | 29,4 | 30,4 | 30,4 | 11,0 | 22,5 | 15,4 | 11,5 | 121,1 | 507,5 | 237,9 | 132,7 |
| P-09 | 22,4 | 40,0 | 26,0 | 36,9 | 11,6 | 18,3 | 12,7 | 4,4 | 135,2 | 336,6 | 161,7 | 19,6 |
| | -7,3 | -49,6 | 10,6 | -32,5 | 24,6 | 26,5 | 25,2 | 14,8 | 602,8 | 702,4 | 634,1 | 217,8 |
| P-28 | 4,6 | -7,5 | -6,0 | -11,3 | 10,9 | 15,6 | 5,8 | 5,1 | 119,0 | 243,5 | 34,2 | 25,9 |
| | 15,4 | -3,6 | 13,3 | -4,3 | 9,9 | 29,5 | 5,9 | 5,1 | 97,8 | 872,3 | 35,1 | 26,5 |
| P-10 | 0,8 | 11,7 | 19,4 | 24,3 | 11,1 | 16,1 | 6,5 | 8,7 | 123,9 | 258,2 | 42,2 | 75,2 |
| | 5,7 | 3,9 | -12,3 | 3,2 | 26,5 | 44,9 | 13,6 | 13,2 | 704,7 | 2015,8 | 185,3 | 173,3 |
| P-02 | -4,9 | -34,3 | -8,6 | -28,0 | 19,9 | 26,0 | 16,0 | 4,6 | 396,7 | 675,0 | 257,5 | 20,8 |
| | 26,9 | 33,7 | 5,3 | 2,4 | 17,1 | 11,1 | 2,3 | 0,8 | 292,7 | 122,4 | 5,5 | 0,6 |

A brief study of the results indicates that there are poor improvements by introducing more accurate coordinates for the access points. It also seems like the fingerprinting calibration, as it exists in the system today, has little effect on the positions measured by WiFi. However, the results show, with some exceptions, that the variances for the measured control points are lower when fingerprinting is turned on. It is also interesting to notice that the differences between WiFi measurements of the control points and the true values have a tendency to depend on the location of the actual control point. With some exceptions this location seems to be more vital for the calculation of the coordinates than the precision in the location of the access points or the fingerprint calibration.

Looking closer into the data sets we found a high correlation between coordinates measured in the same points but with different parameters. These large correlations can possibly be explained by the identical obstacles around the points, independent of which series that are measured. The geometry between the mobile platform and the access points was also similar for each point.

Table 4: Correlation coefficients computed between the x-components, dataset 1 to 4.

| | X1 | X2 | X3 |
|----|-------|-------|-------|
| X2 | 0,659 | | |
| X3 | 0,582 | 0,753 | |
| X4 | 0,717 | 0,890 | 0,918 |

Table 5: Correlation coefficient computed between the y-components, dataset 1 to 4.

| | Y1 | Y2 | Y3 |
|----|-------|-------|-------|
| Y2 | 0,768 | | |
| Y3 | 0,436 | 0,166 | |
| Y4 | 0,511 | 0,802 | 0,342 |

To check for significant differences between x- and y-components of the different dataset 1-4, a zero hypothesis based on paired T-tests have been performed. Rejecting the zero hypothesis: $H_0: \mu_d = \mu_0$, when the expectation value of paired differences are different from zero. The test did not show a significant difference between the measurements in dataset 1 to 4. Based on high standard deviation of the measured coordinates this was no surprise.

As the results in Table 3 shows, the differences between the WiFi measurements and the true values are between 1.5 and 49.6 feet (0.5 and 15 meters). Some of the WiFi measured coordinates seem to have a tendency to get differences in the same magnitude, independent of new or old coordinates with and without fingerprinting. For example the x-coordinate of P-13 have low difference for all the measurement methods. This also shows very low variance for the measurement.

As stated earlier, positioning is a secondary task for the WiFi system, and when moving around inside a building the geometry of the involved access points and the mobile platform will be varying. Likewise will there be a variation in the distance to the closest access point and the number and thickness of walls a signal has to pass. Figure 4 shows the measured points during the campaign together with relevant access points. P-13 is the measured control point with the shortest distance to an access point where there are no walls or windows in between.

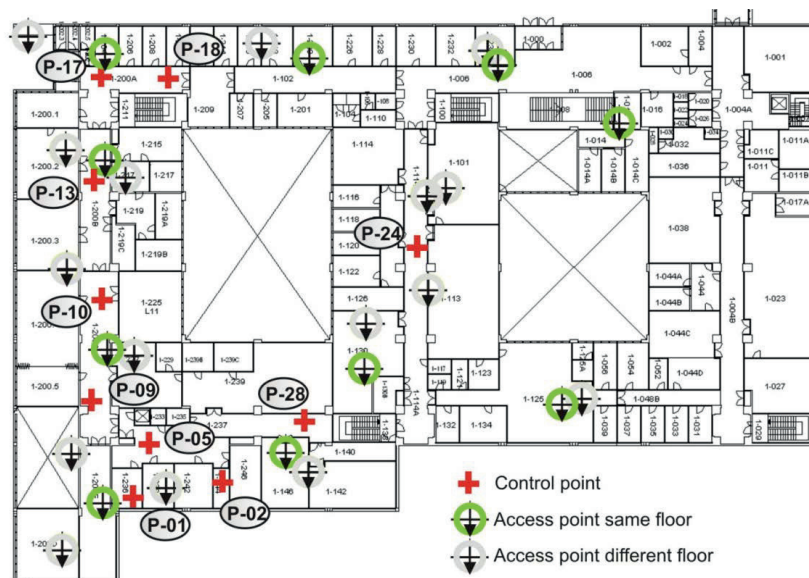


Figure 4: Measured points together with relevant access points.

Conclusion

When it comes to the questions: "Will new and better coordinates for the access points improve the WiFi positioning" the short answer is; No. Our results indicate no significant improvement in the measured coordinates when new coordinates for the access points were introduced. We suspect that the variation of the location of the mobile platform and the geometry between this and the access points are the dominating obstacle for better precision and accuracy in the measurements.

In this study we did not store information about access points used in each measurement. To get a better insight into how geometry and obstacles influence on each measurement this would be interesting to look into in a further study.

The Cisco Mobility Services Engine provides improvement of the measured coordinates by using fingerprinting (FP). Even though we have some indications that FP gives lower variance between the measurements, no significant improvement in the difference between the WiFi measured positions and their true values are evident in our results.

Even though the results from this project has revealed levels of accuracy, precision and update frequency well below what is the industry standard of outdoor GPS positioning, the results have also shown that a commercial off-the-shelf indoor positioning system is capable of providing positions which can be used for many cartographic tasks. The requirements of high accuracy, precision and update frequency depends greatly on the task at hand. The explosion of GPS enabled handheld devices have contributed to a parallel explosion in the development of systems taking advantage of outdoor positioning. However, we argue that the high precision and high accuracy, possible with modern GPS devices, is not always required, or necessary for the majority of location based applications. Similarly, we argue that this is true for indoor location based applications. The need for high accuracy and precision becomes, however, prominent for some application groups, primarily turn-by-turn navigation. Turn-by-turn navigation requires very high accuracy, precision and not least, a reliable update frequency. The results found in this experiment do not support the ability for this kind of application with the positioning system in question. On the other hand, one can easily imagine several applications that do not set forward requirements for high precision and accuracy such as asset tracking and social applications. Asset tracking can be highly useful in larger buildings such as hospitals, large stores and malls. When dealing with problems of finding assets, the precision and accuracy does not need to be as high as for turn-by-turn navigation. Finding, for instance a patient, a wheel chair (Nordan 2011) or an ultrasound machine can be greatly helped by accuracies within 15 meters, and would be of even more help with better accuracy combined with correct vertical location.

Social applications, where the task is to get an overview of other peoples location, can also function equally well without an accurate and precise position. Providing users with systems that can filter out the friends within approximately 50 meters can be just as useful as systems that know which friend is close to you right now. Museum, library and shopping applications can similarly benefit from the accuracy found in the reported experiment. Museum applications can indicate approximately which objects are close to the user while shopping applications can give the consumer location sensitive coupons, both without accurately knowing the location of the user, but with an approximate location.

GPS positioning, navigation and location based systems have enabled users to "look into the future" by informing which turn is the next, if a gas station is within 50 miles and if there will be a congestion on the highway. Accuracy, precision and update frequency requirements for these applications are well below the full potential of GPS positioning. Designing systems able to take advantage of coarse indoor positions should be well within reach by clever system design and visualization. Are commercial off-the-shelf indoor positioning systems mature for cartographic

tasks? With support from the results and experience during this project, we argue that they are for many cartographic tasks if the design is adapted to the limitations of the current positioning systems.

References

- Ciavarella, C., Paternò, F. & Paterno, F., 2004. The design of a handheld, location-aware guide for indoor environments. *Personal and Ubiquitous Computing*, 8(2), pp.82–91.
- Curran, K. et al., 2011. An evaluation of indoor location determination technologies. *Journal of Location Based Services*, (1), pp.1–18.
- Dahl, Y., 2006. "You have a message here": enhancing interpersonal communication in a hospital ward with location-based virtual notes. *Methods of information in medicine*, 45, pp.602–609.
- Gallagher, T. & Kealy, A., 2009. Trials of commercial Wi-Fi positioning systems for indoor and urban canyons.
- Giudice, N.A., Walton, L.A. & Worboys, M., 2010. The informatics of indoor and outdoor space. In *Proceedings of the 2nd ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness - ISA '10*. New York, New York, USA: ACM Press, p. 47.
- Google Art Project, 2012. Google Art Project. Available at: <http://www.googleartproject.com/>.
- Huang, H., Gartner, G. & Ortag, F., 2009. *Cartography in Central and Eastern Europe*. G. Gartner & F. Ortag, eds., Berlin, Heidelberg: Springer Berlin Heidelberg.
- Jardak, N. & Samama, N., 2009. Indoor Positioning Based on GPS-Repeaters: Performance Enhancement using an Open Code Loop Architecture. *IEEE Transactions on Aerospace and Electronic Systems*, 45(1), pp.347–359.
- Köbben, B., 2007. Wireless Campus LBS: A Test Bed for WiFi Positioning and Location Based Services. *Cartography and Geographic Information Science*, 34(4), pp.285–292.
- Liu, H. et al., 2007. Survey of Wireless Indoor Positioning Techniques and Systems. *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews)*, 37(6), pp.1067–1080.
- Mautz, R., 2009. Overview of Current Indoor Positioning Systems. *Geodesy and Cartography*, 35(1), pp.18–22.
- Moen, H.L. & Jelle, T., 2007. The Potential for Location-Based Services with Wi-Fi RFID Tags in Citywide Wireless Networks. In *Wireless Communication Systems, 2007. ISWCS 2007. 4th International Symposium on*. pp. 148–152.
- Mozilla, 2012. Mozilla. Available at: https://developer.mozilla.org/en/Using_geolocation.
- Nordan, R., 2011. *A Framework for Testing Indoor Positioning Systems*. Norwegian University of Science and Technology.
- Nossum, A.S., 2011. IndoorTubes A Novel Design for Indoor Maps. *Cartography and Geographic Information Science*, 38(2), pp.193–201.
- Otsason, V. et al., 2005. Accurate GSM Indoor Localization. In *UbiComp 2005: Ubiquitous Computing*. pp. 141–158.
- Raja, M.K., 2011. *The Development and Validation of a New Smartphone Based Non-Visual Spatial Interface for Learning Indoor Layouts*. University of Maine.
- Raubal, M. & Egenhofer, M., 1998. Comparing the complexity of wayfinding tasks in built environments. *Environment and Planning B*, 25(6), pp.895–913.
- Raubal, M., Egenhofer, M. & Pfoser, D., 1997. Structuring Space with Image Schemata: Wayfinding in Airports as a Case Study. *Spatial Information Theory*.
- Schrooyen, F. et al., 2006. Real Time Location System over WiFi in a Healthcare Environment. *Journal on Information Technology in Healthcare*, 4(6), pp.401–416.
- Walton, L. & Worboys, M., 2009. Indoor Spatial Theory.
- Yang, B. et al., 2007. Indoor positioning performance of Galileo signal. In *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*.
- Yeung, W.M. & Ng, J.K., 2007. Wireless LAN Positioning based on Received Signal Strength from Mobile device and Access Points. *13th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2007)*, (Rtcsa), pp.131–137.
- Zandbergen, P.A., 2009. Accuracy of iPhone Locations: A Comparison of Assisted GPS, WiFi and Cellular Positioning. *Transactions in GIS*, 13, pp.5–25.
- Zhang, J. et al., 2010. Evaluation of high sensitivity GPS receivers. In *Proceedings of 2010 International Symposium on GPS/GNSS*. Taipei, Taiwan, pp. 1–6.

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Paper V

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Paper VI

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Paper XIX

Investigating the wayfinding potential of IndoorTubes in a hospital

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Abstract

Wayfinding in hospitals can be problematic for users new to complex multi-storey buildings, like hospitals. Many patients get lost or are late to the examinations at the hospital, which delays the scheduled patient flow and affects patient satisfaction. One of the solutions for guiding hospital users at the local hospital are modified floor plan maps. A new map design is proposed as an alternative to the current floor plan map. The new design is an implementation of the IndoorTube concept, able to display all floors simultaneously. Results from a human subject experiment show that the currently used floor plan map does not lead to subjects navigating faster than not using the map at all. The results were inconclusive with regards to comparing the two different maps. Participants did, however, report that alternatives to the current floor plan are desired and can aid in a better hospital experience.

Keywords: Indoor visualization, IndoorTube, wayfinding, indoor maps, cartography

Wayfinding in hospitals

Navigating complex multi-storey buildings found in modern hospitals can be challenging for people working in the hospital, and not the least for people unfamiliar with the building. During the construction of new buildings at the St. Olav's hospital in Norway, one objective was to eliminate the need for information desks in the entrance, and rely solely on good information screens, signs, and flyers. However, the problem of patients getting lost was significant, leading to the building of an information desk together with the required staff, despite the efforts of facilitating wayfinding with aids like a floor plan map. The currently used floor plan map is primarily designed based on CAD drawings, although with stylized rooms and appropriate labels for important areas and sections of the building. The maps are found throughout the entrance area on wall signs, information screens and printed hand-outs. Despite the ubiquitous maps and information signs, patients and visitors regularly get lost and requests guidance from the staff. Are the current floor plan maps successful? Do alternative map designs exist – and how do they compare to the current floor plan maps? These research questions initiate the following investigations.

An alternative design to floor plan maps

In the thirties, Harry Beck introduced a new design of the London Underground Tube Map. The new design was inspired by electrical diagrams, and was a schematic form of map, disregarding the actual geography while preserving the topology of the underground network (Garland 1994). By simplifying the network and making the map abstract and schematic, the users are able to get a better overview, perceive the structure of the system more easily and make it easier to find relationships between different parts in the network. The design is today used by millions of travelers using public transportation all around the world.

Multi-storey hospital buildings are obviously different than transportation networks. However, many tasks faced by users of the two environments are similar, for instance; 1) get an overview, 2) find relationships and 3) navigate from one location to another. When looking closer, and more conceptually, on multi-storey hospital buildings, one can imagine a conceptual similarity between Mr. Becks' tube map design and multi-storey buildings. Imagine floors as tubes with the corridors making up the line, rooms as stations and elevators and stairs as different connecting stations. By investigating the possibility of applying Mr. Beck's method on indoor maps it is evident that there are several benefits compared to floor plan maps from CAD drawings. Multiple floors can be drawn simultaneously, providing clearer relationship between floors and the building as such. The topology of rooms, elevators and other items can be kept correct while metrical accuracy can be decreased in favor of higher aesthetic qualities. Through the abstract nature of the tube map, unwanted details are more naturally avoided and overview of large areas, both horizontal and vertical can be better. Applying the tube map design to multi-storey indoor environments have been termed the "IndoorTube" (Nossum 2011). Although transportation networks and maps share properties with indoor environments the actual use will inherently be different between the two. In particular, the users need to attend to and comprehend their surroundings will stand out as a difference. In transportation networks, the user may only be required to comprehend and count the number of stops between entering the transportation method and leaving. Navigating indoor environments requires, at least, that the user moves and comprehends the surroundings in addition to a certain level of orientation, either topologically or globally. Despite the differences between the use of transportation maps and indoor maps, an interesting research question arises: Can the IndoorTube facilitate wayfinding in hospitals?

Related work

There is a significant amount of earlier work on the issues of maps of indoor space and the issues of wayfinding in general and specifically for hospitals. In the last few years, several major commercial actors in the map industry have started incorporating indoor maps in their solutions. Most prominent are the indoor maps from Google Maps (Google Maps 2011) and Bing Mall maps (Bing Mall Maps 2011). Both of these use a highly stylized and simplified version of a floor plan map with floor legends as vertical navigation tools. OpenStreetMap, the initiative for an open map database, has also taken initiative to include indoor environments in their database (OpenStreetMap 2012). In addition, several building or area specific products and applications are also focused on visualization of indoor space like: *Point Inside*, which focus on facilitating the shopping experience (Point Inside 2011), *My Way Aéroports de Paris*, which is limited to the airports in Paris (My Way 2011), and *Floorplanmapper*, which primarily focus on office spaces and business applications (Floorplanmapper 2012). From the academic literature several projects and reports can also be found. Radoczky (2007) investigates the use of active and passive landmarks in navigation tasks. The author also argues that floor plan maps are better than verbal guidance, images, videos and 3D presentations. However, at the same time, floor plan maps are arbitrarily made from CAD programs and drawings, and needs a common design to be standardized. The requirements of precision and topological information have also been the topic of discussion as illustrated by the claim: "*Precision does not seem to play an important role in the navigation process, as long as essential topological information can be extracted and distortion is not disproportionately high* (Radoczky 2007, 303)" (Agrawala and Stolte 2000; Evans 1980; Moar and Bower 1983; Klippel 2003). Ciavarella and Paterno (2004) present a location based museum guide which utilizes a floor plan map as one of its main components. The museum guide is evaluated through a user study. One of the results from the evaluation is that the users are not satisfied with the floor plan map and thinks it needs improvement.

Klippel, Freksa, and Winter (2006) and Klippel, Hirtle, and Davies (2010) investigate the design and guidelines of you-are-here-maps which are maps for locating oneself in complex multi-storey buildings. The maps are commonly used for emergency purposes to help people find their way in the case of a fire or other emergencies. Self-locating is essential in these situations. The authors find several issues, where especially misalignment of the map in comparison with the physical placement and environment, was one of the most prominent. Moreover the authors identify a lack of design criteria and guidelines for you-are-here-maps. Motivated by these findings, the authors propose a set of criteria for evaluating you-are-here-maps.

Recent advances in the study of indoor positioning systems show promising results. Accuracies and performance are reported to be comparable to consumer grade GPS devices (Jung et al. 2012) with uprisng development of WiFi based positioning systems indoors. Simultaneously, the trust between the positioning system and the end users is being studied, which increase our understanding of not only the technological aspect of positioning technologies, but also the social aspects (Wei and Bell 2012). The promising research within positioning technologies in indoor environments gives reason to believe that accurate and reliable positioning will be available in the near future.

Wayfinding, both in hospitals and in other indoor environments, have also been discussed earlier, both in the fields of spatial cognition, psychology and architecture. Cooper (2010) approaches the problem of wayfinding in the local hospital. One of the top complaints from patient surveys were that wayfinding was problematic. To better aid patients navigating the hospital, the authors redesigned the signage system throughout the hospital. The new signage system used color categories and color-coordinated signs to group similar things in the hospital. The signage system also used street names and addresses familiar to the patients from city navigation to familiarize the environment. Signs were also designed in a similar fashion as the street names of familiar cities. The results were immediate and complaints dropped to virtually zero. A similar concept has been used by Allison (2007) with the notion of “hospital as a city”. Making the environment more familiar to the user by incorporating urban-like concepts is the main strategy. The concepts and strategy draws on knowledge from Kevin Lynch’s “the image of the city” (Lynch 1992).

Moving from physical intervention to virtual, Jiang & Li (2007) use a virtual hospital to evaluate the sense of direction in senile and early dementia patients. The results from an evaluation show that there is a significant difference in the sense of direction for healthy subjects. Raubal et al. (1997) and Raubal & Egenhofer (1998) utilize advanced computer knowledge and explore the possibility of developing a computer model to compare the complexity of wayfinding which draws on human wayfinding behavior. Lyardet et al. (2008) and Kritsotakis et al. (2008) approach wayfinding similarly with computer knowledge by including context awareness in indoor navigation. The route calculation includes knowledge of human wayfinding behavior to better aid in the navigation task. Hölscher et al. (2006) and Hölscher et al. (2005) study the effect of wayfinding strategies in multi-storey buildings and conclude that a *floor strategy* is preferred and in general most efficient. The floor strategy relies on routes that prioritize vertical navigation before horizontal. The level of detail in maps has also been investigated by Meilinger et al. (2007) where several different schematic maps were compared with a floor plan map equivalent. The authors conclude that route knowledge is more crucial than survey knowledge for wayfinding in unknown environments.

Conceptual similarities to the schematic layout of the IndoorTube are found in work relating to modeling of both indoor and urban environments. Modeling of indoor environments is

often related to automated routing algorithms and other kinds of spatial analysis. One common approach is to use a graph based strategy which in essence, is very similar to the schematic maps like transportation maps and the IndoorTube map. Wallgrün (2005) is one example from the literature, where the result is conceptually similar to the proposed IndoorTube design, even with a very different approach. The authors present the use of a generalized Voronoi diagram to allow autonomous robots to be able to navigate an office-like indoor environment based on route calculations. The resulting graphs shares a similar visual expression with the IndoorTube design. Kwan and Lee (2004) reports on research on three-dimensional topological modeling of indoor environments. The approach aims at facilitating spatial analysis and visualization of multi-storey indoor environments by means of advanced topological representations. The resulting data models have similar visual properties as the IndoorTube, with vertical relationships explicitly represented along with horizontal relationships. This work illustrates well both the need for both the representation and visualization of indoor environments. Lee (2004) propose a geometric network model for modeling three-dimensional urban environments and in particular interior environments with the aim of facilitating modeling of possible movement within buildings for a more access-oriented approach to modeling and analysis. The proposed model makes use of medial axis transformations (Lee 1982) and proposes supporting algorithms for generating a geometric network model. Visualization of the resulting model shares some properties with the IndoorTube design and demonstrates that automatic generation are not only theoretically possible, but also practical with the correct models and algorithms. Kwan and Lee (2004), Wallgrün (2005) and J. Lee (2004) makes reason to believe that modeling and representation of indoor environments will be easier to achieve and better standardized in the future, making spatial databases of indoor geometry as ubiquitous as the massively available sources of spatial databases of outdoor environments are today. In addition, the supporting algorithms found in the literature demonstrate the capacity to automatically generate models with very similar properties as required for the IndoorTube design making it reasonable to expect easier automatic generation of IndoorTube maps in the future.

Investigating the potential of IndoorTubes in a hospital

Wayfinding in multi-storey buildings is problematic for many user groups. Patient complaints reveal that the issue is present in hospitals as much, or equal to other buildings. Many have approached the issue with better route calculation methods, restructuring the environment and with floor plan maps. Evidence that floor plan maps are supporting wayfinding in hospitals is scarce. At the same time, floor plan maps are, in general, considered to be the standard map design for indoor environments. In the search for better maps to support wayfinding for hospital environments, we suggest an alternative design to the current floor plan map at the St. Olav's hospital in Norway. The suggested alternative is an implementation of the IndoorTube concept (Nossum 2011) with modifications made to accommodate the building and scenario in question.

The selected building is a central building of the hospital with patients, staff, and visitors. Patients are often sent on pre-surgery examinations in different locations throughout the building and easily get lost and ask for guidance. The building consists of 6 stories above ground and is considered to be reasonably complex by both staff and patients. Figure 2 shows the current floor plan maps used for the building. A selection of the rooms was implemented in the IndoorTube map.

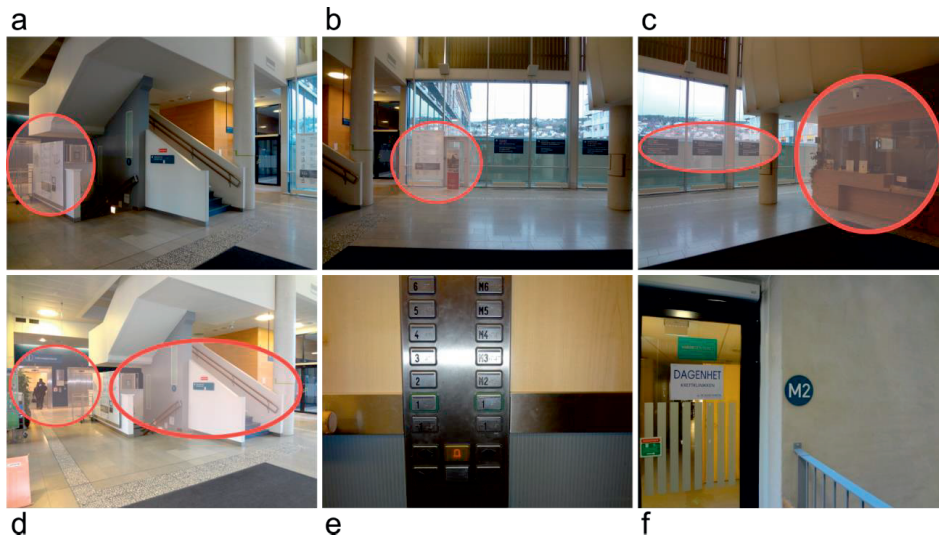
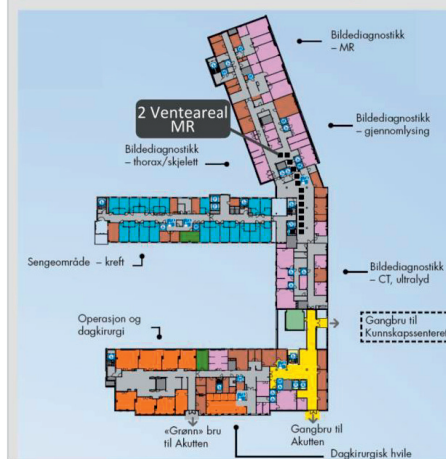


Figure 1: Pictures of the environment with important aspects highlighted, a) map to the left of the main entrance, b) map and information straight ahead of the main entrance, c) information signs with direction and manned information desk to the right of the main entrance, d) staircase and elevators to the left of the main entrance, e) illustration of the sub-floor issue in the elevator (M-floors) and the sub-floor labeling (M2) in f).

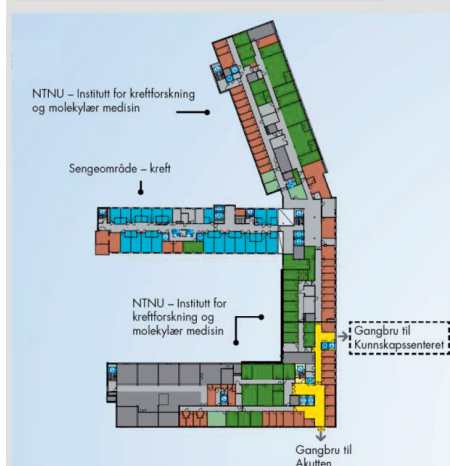
Gastroenteret - 1. etasje



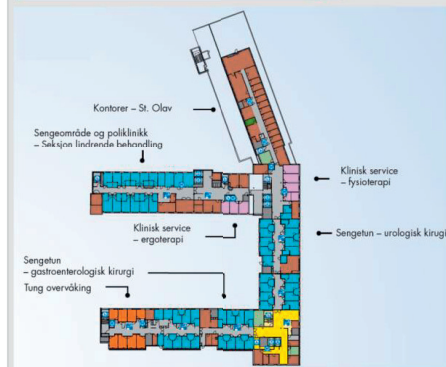
Gastroenteret - 2. etasje



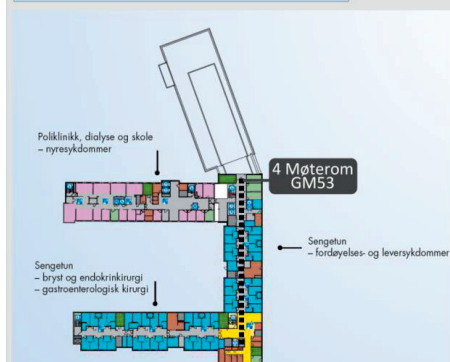
Gastroenteret - 3. etasje



Gastroenteret - 4. etasje



Gastroenteret - 5. etasje



Gastroenteret - 6. etasje

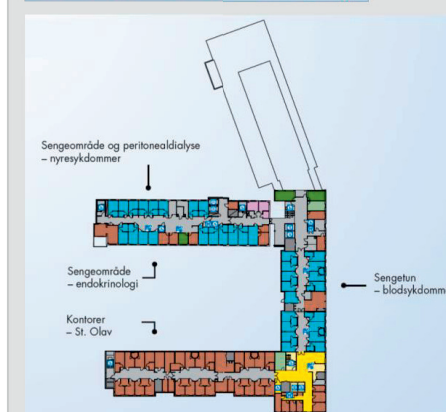


Figure 2: Maps used as stimuli for the floor plan map group. The maps are based on the maps currently used at the hospital building. High resolution figure can be found at: http://issuu.com/alexanno/docs/figure2_floorplanmaps

Gastroenteret - IndoorTube

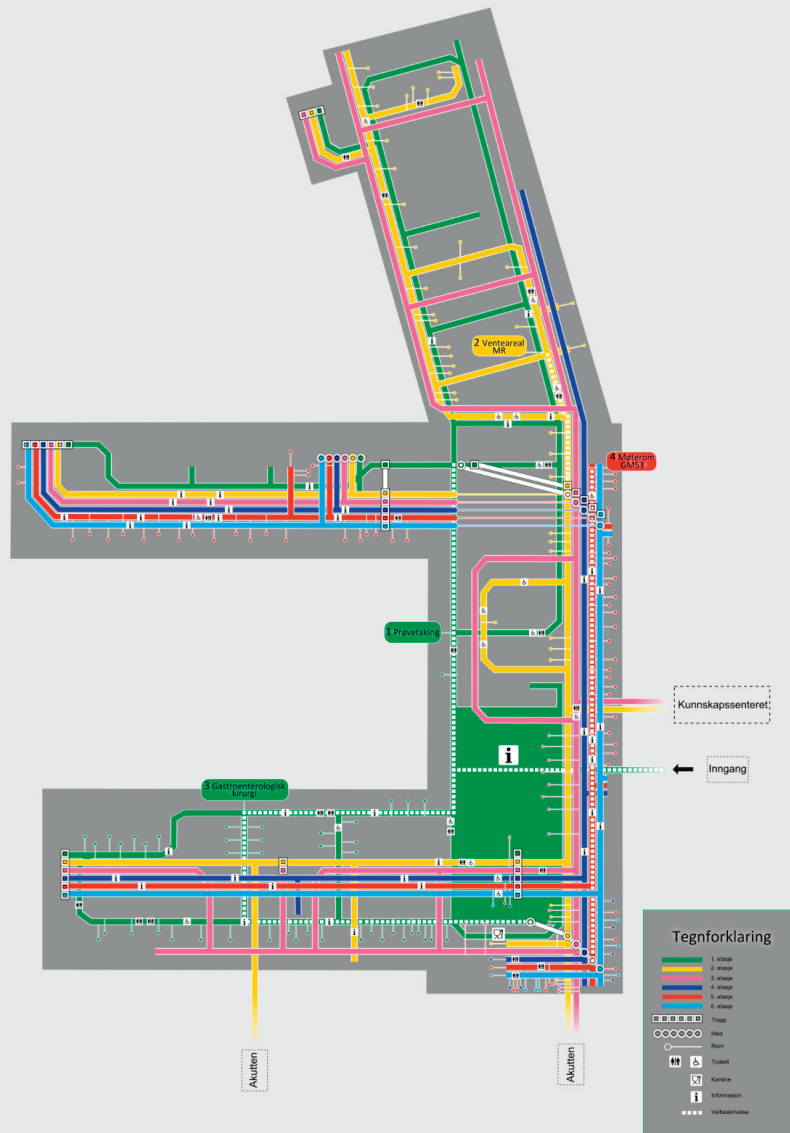


Figure 3: IndoorTube map used as stimulus for the IndoorTube group. High resolution figure can be found at: http://issuu.com/alexanno/docs/figure3_indoortube

Figure 3 depicts the actual IndoorTube map used as stimulus for the IndoorTube group. Figure 4 depicts the IndoorTube map along with the different concepts highlighted with labels in the figure together with explanations. Color (label 1 in figure 4) has been used to differentiate the different floors. A qualitative color scale has been selected with similar hues as the well-known London Underground Tube Map. Qualitative color scales have been proven to have a strong selective property and thus leans well to perceiving differences (Brewer 1996; Spence 2007). Visual overlap of the lines was implemented to separate the floors and create a visual hierarchy reflecting the vertical hierarchy of floors – label 2 in figure 4 illustrates this concept. When verifying the currently used floor plan map and the IndoorTube map against the actual building, it was discovered that one of the wings in the building was actually not aligned vertically with the rest of the building. These floors were labeled as *sub floors* in the building. This was very confusing for staff and patients and was not captured at all by the currently used floor plan map. The sub floors were included in the IndoorTube map which is demonstrated in label 3 in figure 4. The strategy was to connect the sub floor tubes with thin lines that would indicate that the following tubes are connected differently than the rest of the floors. In retrospect, the visualization of sub floors need further work to be more intuitive and successful. However, compared to the currently used floor plan there is a clear advantage in that the IndoorTube map is able to visualize the sub floors at all. The original tube map has a geographical advantage in that stations on metro lines are at the same location for all lines passing through it. This is not the case with rooms on different floors. Rooms can be, and often are, at the same location, however, it is also very common that room location differs between floors, and thus, is not vertically aligned. To more precisely indicate the room location, the IndoorTube visualizes rooms with a pushpin metaphor illustrated in label 4 in figure 4. The pushpins are attached to the correct side of the tube relative to the location in the corridor and share color-coding with the respective floor; the topology of the different rooms in each floor is also preserved. Staircase and elevators connect floors together, which is identical to connecting stations in transportation networks. Label 5 in figure 4 shows how elevators and stairs are symbolized differently, yet sharing a similar visual expression, and also how the symbols visually connect different floors. A legend was included to explain the basic concepts of the map, which is shown in label 6 in figure 4. The topological accuracy was considered important in the map design and hypothesized to be a crucial factor to the navigational ability. On the other hand, the metric accuracy was adjusted several places to accommodate for better visual expression and higher aesthetics while still retaining the cardinal directions and structure of the building.

One of the key differences, and strengths, of the IndoorTube map is its ability to display all floors, together with their individual room layouts, *simultaneously* in one map. This is a fundamental difference from the vast majority of other maps of multi-storey indoor environments, and has not been subject of wayfinding evaluation before.

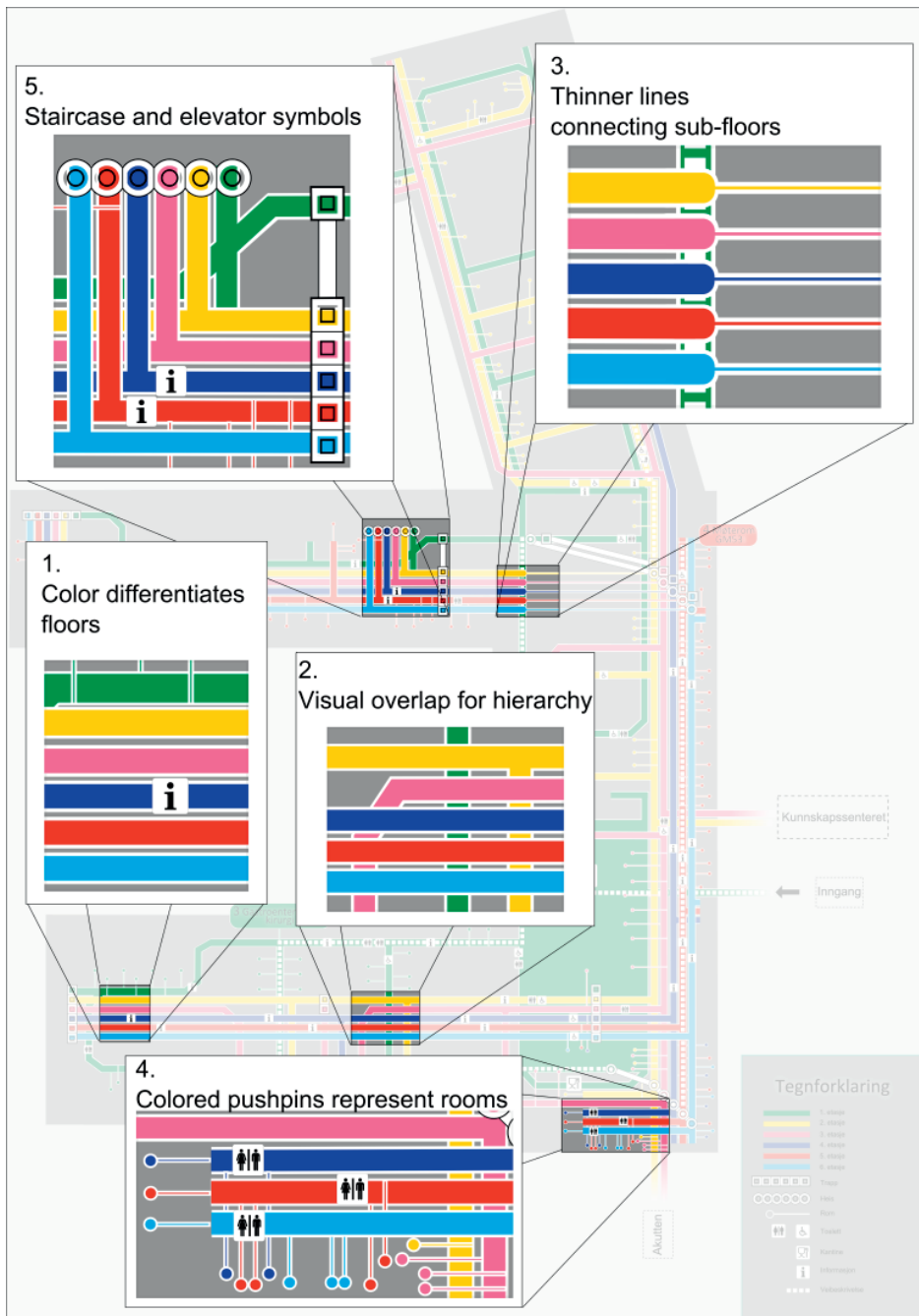


Figure 4: The IndoorTube map with labels highlighting the basic concepts. A larger, high resolution version can be found at: <http://issuu.com/alexanno/docs/indoortubegastrosenteret>

Facilitating wayfinding

An experiment was designed and conducted to investigate the wayfinding capabilities of the IndoorTube map compared to the currently used floor plan map at the hospital. The experiment compared the wayfinding performance, in terms of time, between the IndoorTube map and the floor plan map. 30 subjects were recruited primarily from the student population at the Norwegian University of Science and Technology. The subjects were selected based on self-reported age, gender, navigational abilities and familiarity with the building in question to balance the different variables. The average age of the selected subjects was 25. There were 13 females and 17 male subjects. These were balanced across three groups: 1) control group, not using maps, 2) IndoorTube group 3) current floor plan map group. The experimental procedure was: 1) sign consent form 2) hand out paper copies of map and list with navigation targets to the subject 3) Subjects were asked to start, the experimenter followed each subject while he/she was navigating, and timed them. The time did not include pauses when reaching the navigation targets. 4) A short informal interview ended the experiment.

The navigation task consisted of finding the way to four different locations in the building in the specified order. Each location was named with a name familiar to the environment so signs would match the location name. A suggested route was indicated on the maps available to the floor plan map group and the IndoorTube group, the control group had to rely solely on the location names. The four target locations were spread out both horizontally and vertically. Figure 2 and figure 3 details the location of each of the target locations. Several pictures of the environment can be found in figure 1. As can be seen, the first target is close to the main entrance, the second target is on the second floor, the third target is back down on the first floor and the fourth target is on the fifth floor. The order and the horizontal and vertical variation were all hypothesized to require the user to understand the maps and the environment and also challenge the vertical comprehension of the environment in relation to the maps. The suggested route was rarely followed by the participants during the experiment, although it was believed to be the most efficient route with only 15 turns and the use of 3 elevator rides, 0 stairs and in total travelling 6 floors.

Figure 1 depicts several pictures of the environment in which the experiment was held. The main entrance includes several boards and screens with information which are highlighted in the image. Two elevators were intended to use in the suggested route, both of which were easily accessible. The staircase is located in a central location of the entrance, but was not intended to be used in the suggested route. During the design and surveying of the building, a wing of the building was discovered to actually be vertically located as sub-floors so every floor was adjusted to half floors. Target locations in the navigation task were kept outside of the sub-floors. The stimuli available to the participants, in addition to the environment, were the list of target locations and maps. The floor plan map group was given a collection of floor plan maps, one map on one sheet of paper, which are all depicted in figure 1. The IndoorTube group was given one IndoorTube map printed on one sheet of paper which is depicted in figure 3. Full size digital representations of the maps can be found at the web address given in the figure captions.

The time used by the different subjects laid the foundation for analysis. Other types of performance metrics which could be measured were discussed during the design of the experiment. Characteristics of the actual route the participants choose would provide a rich data set to analyze. In particular the number of turns made, the Euclidean length, the speed/pace, and route variations compared to the suggested route were considered as potential metrics. Route characteristics would provide more information on the selections made by the participants and could potentially reveal, or at least give indications as to how the different

maps were understood and used. Further, the behavior of the participants in terms of metrics such as number of times looking at the map, number of times looking at particular objects in the environment or the time used to look at the map or objects could also be interesting to include in the study of map performance and comparison. However, these types of metrics all require a fair amount of additional effort, compared to simple timing of the participants. Several of the metrics would also greatly benefit by introducing automated and precise measurement technologies, where tracking systems, such as accurate positioning systems, and mobile eye-tracking technologies easily comes to mind. Unfortunately, the limited amount of resources available to the project reported here together with the prototypical nature of the conducted experiment hindered metrics beyond timing the participants. Future studies expanding upon the reported results could greatly benefit by introducing more accurate and comprehensive measurement techniques.

Table 1 details the sample size, mean completion time and standard deviation for the three different groups. Subjects in the IndoorTube used on average the least time to complete the navigation task. As table 1 show, the standard deviations are fairly high which indicates that the results are not conclusive. A one-way analysis of variance (ANOVA) was performed to test the hypothesis whether the time used in the different groups were significantly different. Significantly different results should indicate that the maps used in the different groups had a significant impact on the navigation task. The means and standard deviations used in the ANOVA are presented in table 1. The analysis of variance yielded no significant difference between either of the groups with respect to the map type including the control group with $F(2,00) = 0.155$, $p > .05$. Based on this result the IndoorTube map can be said to be as good as the currently used floor plan map. However, neither the currently used floor plan map nor the IndoorTube map can be said to be better than the control group, which was not given any map. The result was surprising as it was expected that wayfinding with a map would have an effect on the total time used. On the other hand, the subjects in the control group could have used the maps already in the hospital building, such as those in the entrance area or information screens, which were close to identical as the map given to the floor plan map group. However, even if the control group had been so severely biased that they could be theoretically equal to the floor plan group, there were still no evidence that suggested a significant difference between the group using the floor plan maps and the group using the IndoorTube map. One could experiment with the idea that neither of the groups using maps (floor plan and IndoorTube) used the available maps at all and relied solely on the environment, which would, theoretically, render the three groups equal in terms of actual stimuli. However, even though no quantitative measurements were made which would prove this event did not occur, it was observed frequently by the experimenter that participants in the map groups used the map and thus can be assumed to be affected by the respective maps.

The population in this experiment is limited, with 30 subjects, all fairly young, compared to the average hospital user. The size of the population can lead to noise in the data set coming from unforeseen bias. In addition, the sample population consists mainly of students, which does not necessarily represent the general hospital user which could also affect the generalizability of the analysis.

| Group | Sample size | Mean (seconds) | Standard deviation |
|------------------|-------------|----------------|--------------------|
| Control group | 6 | 8,197 | 1,120 |
| Floor plan group | 12 | 7,298 | 1,642 |
| IndoorTube group | 12 | 6,848 | 1,096 |

Table 1: Average completion times for the three different groups together with standard deviation and sample size.

In addition to the quantitative analysis, a short, informal, interview was held with the subjects in the floor plan map group and the IndoorTube group. The interview revealed that subjects which used the IndoorTube map was positive to the idea and concept, but found it a bit too abstract and unfamiliar. Moreover they suggested improvements to make it less schematic and with a higher metrical accuracy. Several participants reported that they found the IndoorTube easier to use after having used it for a while, which could indicate that there is an issue of familiarity with the map which is the biggest issue. Subjects in both the IndoorTube group and the floor plan map group found the idea of presenting several floors simultaneously in a map very attractive and liked the idea. The participants from the floor plan map group were in general familiar with the floor plan map concept and had little problems using it for navigation. However, some stated that: *“they don’t connect to the architecture”* and *“it’s about time something new is made”*.

Conclusion

Navigating complex multi-storey buildings like hospitals are challenging and in many situations a problem for the patients and visitors. Current map solutions are mostly based on different styles of floor plan maps – often based on CAD drawings. Floor plan maps have the disadvantage of requiring one map for each floor. In an effort to find alternative map designs, which could accommodate wayfinding equally well or better than the current solution; an implementation of the IndoorTube concept has been made. The IndoorTube map is capable of including several floors simultaneously which is hypothesized to accommodate better wayfinding tasks and the spatial awareness of the building. Results from a user experiment indicate that the wayfinding performance of subjects is not affected by the currently used floor plan map, or the proposed IndoorTube map – compared with not using a map at all. From interviews with the subjects, it is, however, evident that the familiarity with the floor plan map concept has an effect on the ease of use and thereby, most likely, also the wayfinding performance. The IndoorTube map is considered to be too schematic and should be developed to be more metrical accurate which most likely would allow it to be more intuitive. Moreover, subjects also requests new map types for indoor environments. The potential of multi-floor maps is both appreciated and needed for better wayfinding aids in the hospital environment, however, care on metrical accuracy, familiarity, and ease of use is needed for its success. The reported results indicate that other use cases of the IndoorTube design may have greater success comparing to floor plan maps. Future research should investigate in particular the appropriateness of using IndoorTube maps for real-time spatial awareness tasks specifically targeting “at-a-glance” displays. Examples of this may be in hospitals for real-time monitoring and tracking of human resources, patients and equipment. Such monitoring may be visualized easily in an IndoorTube map on a large, non-interactive screen – which can facilitate rapid comprehension of the information. Results from 3D analysis of interior environments may also benefit from being visualized following the design principles of the IndoorTube. In the case of real-time monitoring and 3D analysis, a significant difference from the wayfinding task is the users assumed knowledge of the

environment. Wayfinding tasks assume little prior knowledge to the environment. The reported experiment demonstrates that the design principles of the IndoorTube can facilitate wayfinding, and that alternatives are requested, but at the same time the IndoorTube principle does not excel at facilitating wayfinding. Exploration of tasks in which the IndoorTube excels compared to today's standard interior maps are needed – where real-time monitoring and 3D visual analysis are hypothesized to currently be very good candidates.

References

- Agrawala, Maneesh, and Chris Stolte. 2000. "A Design and Implementation for Effective Computer-generated Route Maps." *AAAI Symposium on Smart Graphics*: 0–4. <http://www.aaai.org/Papers/Symposia/Spring/2000/SS-00-04/SS00-04-010.pdf>.
- Allison, D. 2007. "Hospital as City: Employing Urban Design Strategies for Effective Wayfinding." *Health Facilities Management*. <http://www.ncbi.nlm.nih.gov/pubmed/17621859>.
- Bing Mall Maps. 2011. "Bing Mall Maps." http://www.bing.com/community/site_blogs/b/maps/archive/2010/12/07/bing-s-new-mall-maps-get-in-get-out-and-the-avoid-the-crowds.aspx.
- Brewer, Cynthia A. 1996. "Guidelines for Selecting Colors for Diverging Schemes on Maps." *Cartographic Journal, The* 33 (2) (December 1): 79–86. doi:10.1179/000870496787757221. <http://openurl.ingenta.com/content/xref?genre=article&issn=0008-7041&volume=33&issue=2&spage=79>.
- Ciavarella, Carmine, and Fabio Paterno. 2004. "The Design of a Handheld, Location-aware Guide for Indoor Environments." *Personal and Ubiquitous Computing* 8 (2): 82–91. doi:10.1007/s00779-004-0265-z. <http://www.springerlink.com/index/HQT5F0HK18WRM8CU.pdf>.
- Cooper, R. 2010. "Successful Signage: How Hospitals Have Solved Wayfinding Challenges." *Health Facilities Management*. <http://trid.trb.org/view.aspx?id=859366>.
- Evans, Gary W. 1980. "Environmental Cognition." *Psychological Bulletin* 88 (2): 259–287.
- Floorplanmapper. 2012. "Floorplanmapper." <http://floorplanmapper.com/>.
- Garland, Ken. 1994. *Mr. Beck's Underground Map: a History*. Capital Transport Publishing. <http://www.worldcat.org/isbn/1854141686>.
- Google Maps. 2011. "Google Maps." <http://maps.google.com/>.
- Hölscher, Christoph, Tobias Meilinger, Georg Vrachliotis, and Martin Brösamle. 2005. "Finding the Way Inside : Linking Architectural Design Analysis and Cognitive Processes." In *SC'04 Proceedings of the 4th International Conference on Spatial Cognition: Reasoning, Action, Interaction*, 1–23. doi:10.1007/978-3-540-32255-9_1.
- Hölscher, Christoph, Tobias Meilinger, Georg Vrachliotis, Martin Brösamle, and Markus Knauff. 2006. "Up the down Staircase: Wayfinding Strategies in Multi-level Buildings." *Environmental Psychology* 26 (26) (December): 284–299. doi:10.1016/j.jenvp.2006.09.002. <http://linkinghub.elsevier.com/retrieve/pii/S0272494406000582>.

- Jiang, Ching-Fen, and Yuan-Shyi Li. 2007. "Virtual Hospital--a Computer-aided Platform to Evaluate the Sense of Direction." In *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference, 2007*:2361–4. doi:10.1109/IEMBS.2007.4352801. <http://www.ncbi.nlm.nih.gov/pubmed/18002467>.
- Jung, WR, Scott Bell, Anastasia Petrenko, and Anton Sizo. 2012. "Potential Risks of WiFi-based Indoor Positioning and Progress on Improving Localization Functionality." ... *International Workshop on Indoor ...* <http://dl.acm.org/citation.cfm?id=2442621>.
- Klippel, A. 2003. "Wayfinding Choremes: Conceptualizing Wayfinding and Route Direction Elements". University of Bremen. <http://scholar.google.com/scholar?q=klippel+wayfinding+choremes&hl=en&lr=#1>.
- Klippel, Alexander, Christian Freksa, and Stephan Winter. 2006. "You-Are-Here Maps in Emergencies The Danger of Getting Lost." *Journal of Spatial Science* (August 2012): 117–131. <http://www.ingentaconnect.com/content/spatial/jss/2006/00000051/00000001/art00010>.
- Klippel, Alexander, Stephen Hirtle, and Clare Davies. 2010. "You-are-here Maps: Creating Spatial Awareness Through Map-like Representations." *Spatial Cognition and Computation* 10 (June 2011): 82–93. <http://www.cognitivegiscience.psu.edu/pdfs/klippel2010you-are-here.pdf>.
- Kritsotakis, Manolis, Maria Michou, Emmanouil Nikoloudakis, Antonis Bikakis, Theodore Patkos, Grigoris Antoniou, and Dimitris Plexousakis. 2008. "C-ngine: A Contextual Navigation Guide for Indoor Environments." *Ambient Intelligence*: 258–275. <http://www.springerlink.com/index/Q364M540U1112206.pdf>.
- Kwan, M.P., and J. Lee. 2004. "Geovisualization of Human Activity Patterns Using 3D GIS: a Time-geographic Approach." *Spatially Integrated Social Science* 27. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.115.6873&rep=rep1&type=pdf>.
- Lee, D.T. 1982. "Medial Axis Transformation of a Planar Shape." *Pattern Analysis and Machine Intelligence, IEEE ...* 3 (4). http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4767267.
- Lee, Jiyeong. 2004. "A Spatial Access-Oriented Implementation of a 3-D GIS Topological Data Model for Urban Entities." *GeoInformatica* 8 (3) (September): 237–264. doi:10.1023/B:GEIN.0000034820.93914.d0. <http://link.springer.com/10.1023/B:GEIN.0000034820.93914.d0>.
- Lyardet, Fernando, D Szeto, and Erwin Aitenbichler. 2008. "Context-aware Indoor Navigation." *Ambient Intelligence*: 290–307. <http://www.springerlink.com/index/t018q3657qp01504.pdf>.
- Lynch, K. 1992. *The Image of the City*. MIT Press. http://books.google.com/books?hl=en&lr=&id=_phRPWsSpAgC&oi=fnd&pg=PA1&dq=kevin+lynch+image+of+the+city&ots=jFC69c1Coi&sig=y8ORvszEJFer05sNpGavyCHcKD4.
- Meilinger, Tobias, Christoph Hölscher, Simon J Büchner, and Martin Brösamle. 2007. "How Much Information Do You Need ? Schematic Maps in Wayfinding and Self Localisation the Start to the Goal This Is a Feasible Approach . In a Second Step It Is Also Possible To." In *SC'06 Proceedings of the 2006 International Conference on Spatial Cognition V: Reasoning, Action, Interaction*, 381–400. doi:10.1007/978-3-540-75666-8_22.

- Moar, Ian, and Gordon H. Bower. 1983. "Inconsistency in Spatial Knowledge." *Memory & Cognition* 11 (2) (March): 107–13. <http://www.ncbi.nlm.nih.gov/pubmed/6865743>.
- My Way. 2011. "My Way Airports De Paris." <https://market.android.com/details?id=fr.aeroportsdeparis.myway>.
- Nossum, Alexander Salveson. 2011. "IndoorTubes A Novel Design for Indoor Maps." *Cartography and Geographic Information Science* 38 (2) (January): 192–200. doi:10.1559/15230406382192. <http://www.tandfonline.com/doi/abs/10.1559/15230406382192>.
- OpenStreetMap. 2012. "Indoor Mapping - OpenStreetMap." http://wiki.openstreetmap.org/wiki/Indoor_Mapping.
- Point Inside. 2011. "Point Inside Shopping and Travel." <https://market.android.com/details?id=com.pointinside.android.app>.
- Radoczky, Verena. 2007. "How to Design a Pedestrian Navigation System for Indoor and Outdoor Environments." In *Location Based Services and TeleCartography*, 301–316. Springer. doi:10.1007/978-3-540-36728-4_23. http://dx.doi.org/10.1007/978-3-540-36728-4_23.
- Raubal, Martin, and M Egenhofer. 1998. "Comparing the Complexity of Wayfinding Tasks in Built Environments." *Environment and Planning B* 25 (6): 895–913. <http://www.spatial.maine.edu/~max/wayfinding.pdf>.
- Raubal, Martin, M Egenhofer, and D Pfoser. 1997. "Structuring Space with Image Schemata: Wayfinding in Airports as a Case Study." *Spatial Information Theory*. <http://www.springerlink.com/index/e47vq08255l45pk2.pdf>.
- Spence, Robert. 2007. *Information Visualization: Design for Interaction*. Prentice Hall. <http://www.amazon.co.uk/Information-Visualization-Prof-Robert-Spence/dp/0132065509>.
- Wallgrün, JO. 2005. "Autonomous Construction of Hierarchical Voronoi-based Route Graph Representations." *Spatial Cognition IV. Reasoning, Action, Interaction*: 413–433. http://link.springer.com/chapter/10.1007/978-3-540-32255-9_23.
- Wei, Ting, and Scott Bell. 2012. "Impact of Indoor Location Information Reliability on Users' Trust of an Indoor Positioning System": 258–269.

Paper XXX

Developing a Framework for Describing and Comparing Indoor Maps

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Abstract. Traditionally, research on cartography has primarily been focused on visualization of outdoor environments. Recently, however, indoor cartography has increasingly attracted attention both from the academic world and from commercial enterprises. Indoor cartography calls for markedly different visualization strategies. Frameworks for describing map communication and use exist for general maps. But so far, no such framework exists for indoor maps. This article presents and discusses several map types for indoor spaces found in the literature and commercial products. The different characteristics of each one are identified and described. On this basis, a framework for indoor maps is developed and presented. Arbitrary indoor maps can be described by their properties using the framework. This allows indoor maps to be compared and described using a common platform.

Keywords: Indoor cartography, descriptive model, visualization

1. Why indoor cartography?

Cartography has evolved for centuries and improved the way maps are depicted and communicated. A rich variety of cartographic standards and practices may be found in the research literature on map types and use cases (Dorling & Fairbairn 1997; MacEachren 2004; Kraak & Ormeling 1996; Robinson et al. 1995). These standards and practices are almost exclusively focused on outdoor environments. Examples of maps which benefit from recent advantages in cartography are abundant, ranging from aerial maps (Google Maps 2011; Yahoo! Maps 2011; Bing Maps 2011), to street view maps (Schöning et al. 2008; Weber et al. 2010; Riedl et al. 2007; Google Earth Election Guide 2006; Bell et al. 2007). Maps of indoor environments have received scant attention compared to outdoor environments. One of the exceptions to this is the literature on you-are-here-maps for emergency purposes, where there has been extensive work on symbolization and visualization (Klippel et al. 2006; Klippel et al. 2010).

The complexity of buildings, together with the increasing deployment of indoor positioning technology, provides forceful motivation for improving the cartography of indoor maps. Given the pace at which indoor positioning technology is being deployed, it is natural to assume that in the near future this technology will be as ubiquitous as wireless internet is today. Hitherto, most research on map applications in in-door environments has focused mainly on the use of indoor positioning systems, rather than indoor cartography as such (Ciavarella & Paterno 2004; Mautz 2009; Yang et al. 2007; Curran et al. 2011; Dahl & Svanæs 2007; Schrooyen et al. 2006; Huang et al. 2009). This is the point of departure for the present article.

In the following, we will discuss some of the different types of indoor maps currently found in the literature. From this discussion, several characteristics can be identified which helps describe and differentiate maps. The characteristics are combined with inspiration from several already existing frameworks that describes general map use (MacEachren & Fraser 1994), qualities of conceptual models (Krogstie 2012) and qualities of maps (Nossum & Krogstie 2009). On the basis of this an outline of a framework specifically tailored for indoor maps is proposed.

1.1. Designing indoor maps

Indoor environments pose some unique challenges to the cartographer. Information density is often higher indoors than outdoors. Orientation and navigation is also different (Lawton 1996; Wolbers & Hegarty 2010). Landmarks can change frequently and generic north-south orientation can be hard to maintain for the user. The main challenge, however, is the added dimension introduced by multi-storey buildings. So far, few researchers have taken up the challenge of visualizing or facilitating several different floors when mapping the indoor spaces of a multi-storey building. In the following, we discuss some design issues of visualization and user interaction in such maps.

We start by considering some relevant map types found in current cartographical applications. Table 1 lists a selection of these from the literature and commercial products. Each map type is loosely categorized as either floor plan maps, 3D/virtual reality, or novel designs, providing some structure for the following discussion.

| Map type | Category | Example of use |
|----------------------------|--------------------|-------------------------------|
| Architectural floor plan | Floor plan maps | Engineering, Emergency |
| Abstract floor plan | Floor plan maps | Airports, malls, universities |
| 3D models | 3D/Virtual reality | Engineering, presentations, |
| Virtual reality | 3D/Virtual reality | Prototypes, presentations |
| Augmented reality | Novel designs | Research projects |
| First person photo reality | Novel designs | Google Art/Business project, |

Table 1. Types of indoor maps and their categories.

The floor plan map is probably the most common type of indoor maps. In table 1, we distinguish between architecturally styled floor plans and abstract floor plans. Examples of these are shown in figure 1a and 1b, respectively. Architectural floor plans are rich in detail and are readily available for most buildings. This type of maps is commonly used for emergency maps where work on indoor specific symbolization can also be found (Klippel et al. 2006; Klippel et al. 2010; Seppänen et al. 2007; Seppänen & Virrantaus 2010). The level of detail can in many situations be too high, making such maps aesthetically unsuitable as consumer products. Abstract floor plans deal with these issues by redesigning or remaking architectural floor plans in order to optimize certain features. Figure 1b shows an example of an abstract floor plan where the amount of detail is dramatically reduced and the use of colors and symbols is aimed at consumer users. Both types of floor plans lack the possibility of displaying several floors at once. Some applications implement a makeshift solution by adding a perspective view of several floor plans on top of each other, which requires more screen/document size. Recently, web map solutions including indoor maps have appeared which allow the user to zoom through layered floors in a manner similar to changing the map scale. This obviously requires support for user interactivity in the system.

3D models of buildings and their interior are often found in presentations of architectural designs. 3D solutions are typically navigated by way of complex interfaces which allow the user to orbit or fly around in the model, as if present inside the mapped space. The level of detail can be very high and the different floors can to some degree be presented simultaneously. This makes the abstraction level of a 3D model lower than floor plan maps or other more abstract visualizations.

Virtual reality solutions are similar to 3D models but often incorporate a more in-person feel or game-like experience to the navigation. As in 3D models, the level of detail can be very high and the level of abstraction is generally low. Because of this, 3D models and virtual reality solutions are considered poorly suited to providing an overview of the environment.

Augmented reality (AR) systems are relatively new in the consumer market and are still mostly found in research projects. AR allows the system to overlay information on top of an image of the real world, usually a video stream. The method relies heavily on interaction with the user, as the user's movements often control what is displayed. The level of abstraction is very low, like in 3D and virtual reality solutions.

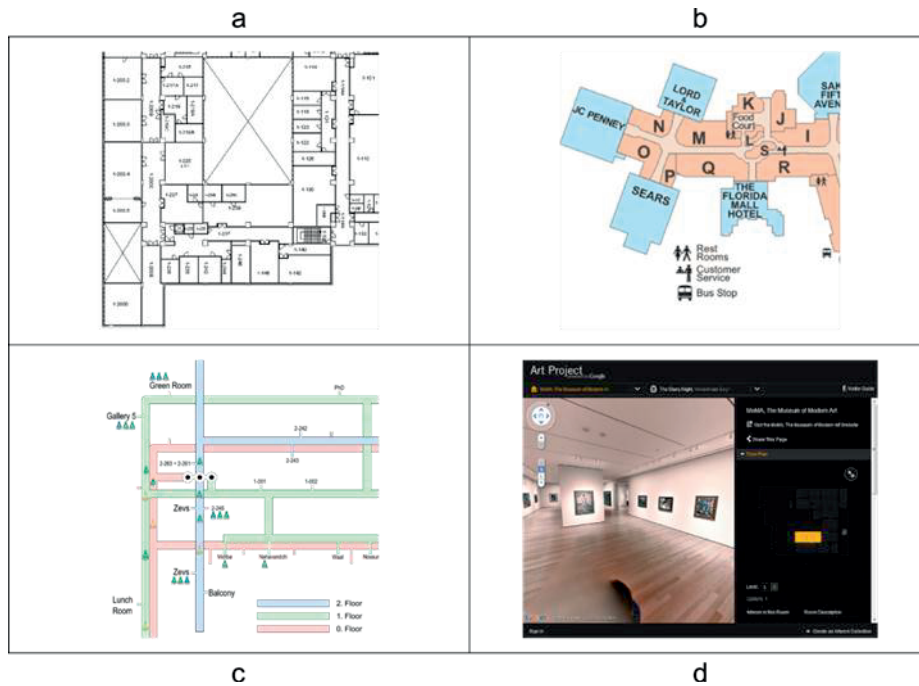


Figure 1. A selection of different indoor maps: a) architectural floor plan map b) abstract floor plan map c) IndoorTube and d) first person photo reality

First person photo reality can be said to be a sibling of Google's Street View (Google Street View 2011) but has been discussed earlier in the literature (Radoczky 2007; Fisher & Unwin 2001). The visualization essentially navigates within spherical photos of the interior of a building, providing solutions similar to those of virtual reality and augmented reality. One disadvantage of this approach is that the images can become outdated very fast. For instance, if essential landmarks change, walls are painted, etc. On the other hand, the level of detail can be very high. In addition to static images, additional information can be overlaid where appropriate – by analogy with augmented reality systems. Figure 1d shows an example of this kind of system.

IndoorTubes is a proposed map type that incorporates several floors in one single visualization (Nossum 2011a). The design is inspired by Beck's metro

map design of the London underground (Garland 1994). Floors are represented similarly to under-ground lines, corridors correspond to metro lines, rooms to stations, and elevators/stairs to connected stations where metro lines cross. This simplification of the geography gives a compact view of several floors, and potentially a complete building, in one map. It is hypothesized that the method is very good at visualizing real time activity inside buildings, especially in high intensive work situations, such as for instance hospitals. Figure 1c shows an example of the IndoorTube design.

From the examples presented above, several important differences, functionalities and use cases of indoor maps emerge. However, so far there are no common guiding principles or frameworks for categorizing or comparing different indoor maps. The technology for indoor maps is mature and indoor maps are in high demand. A framework for the description and development of indoor maps is therefore to be desired.

2. Developing a Framework for Describing Indoor Maps

The wide variety of indoor maps is apparent from the different characteristics found in the previous sections. Capturing and describing this variation is difficult and requires a common framework for describing indoor map features. For outdoor maps, some corresponding frameworks for describing and comparing different characteristics have already been developed. An influential one is the map use cube by MacEachren & Fraser (1994). The cube represents a three-dimensional way of describing maps, using interaction, audience and data relation as the main characteristics. SEQUAL is another framework that aims at describing quality of conceptual models in computer science (Krogstie 2012). MAPQUAL (Nossum & Krogstie 2009) is an extension to SEQUAL which approach maps as a specialized form of conceptual models and tailors the framework to describe the quality of maps in general. The following presents an initial step in developing a framework based on the ideas of MacEachren & Fraser (1994), the ideas of SEQUAL and MAPQUAL, and the characteristics found from the previous presentation of indoor maps

Seven dimensions have been selected for the initial version of the framework. They are visualized in a kiviati diagram (Chambers et al. 1983) to allow a visual interface while easily supporting extensions to the framework. Figure 2 shows the kiviati diagram of the framework. Figure 3 illustrates how two maps can be described and compared in the framework. In the following, we will present and discuss each of these seven dimensions.

2.1. Privacy

The intended privacy of a map affects its cartography. This characteristic has been previously identified as the audience dimension by MacEachren & Fraser 1994 in their work on the map use cube. The map privacy is equally important for indoor maps as it is for general maps. An indoor map can be used, for example, on a mobile device for seeing where your friends are inside a building, which would then be in a private context. On the other hand, an indoor map can be used on a large screen, displaying discount coupons for stores inside a shopping mall – and thus intended in a public context. The privacy dimension is defined as a continuous dimension which allows maps to be placed between the extremes of fully public and completely private. One could for instance imagine a semi-public map if the map is positioned publicly, but in a restricted area – such as a hospital ward.

2.2. Semantic accuracy

The quality of a map is not a simple function of whether it is a semantically correct depiction of the real world or not. Sacrificing semantic accuracy over, for instance, aesthetical qualities may be a good choice if the user does not require a high semantic accuracy map, but prefers other characteristics. There are also situations where high accuracy can occur without sacrificing other characteristics. MacEachren & Fraser 1994 identified accuracy as one of the dimensions for describing map use. (Krogstie 2012) identified semantic quality and several facets of it for conceptual models. Drawing on this, the framework includes a dimension describing the semantic accuracy of indoor maps. This dimension is continuous between low and high semantic accuracy. Semantic accuracy is considered to be as important for indoor maps as it is for other kinds of maps. The information density is typically high in indoor environments and potentially higher than for outdoor environments. Considering what information to include and what to exclude in indoor maps is crucial. For example accurate semantic metrical information is sometimes not necessary. One example that focuses on topological accuracy at the expense of metrical semantic accuracy is the Indoor-Tube map (Nossum 2011a).

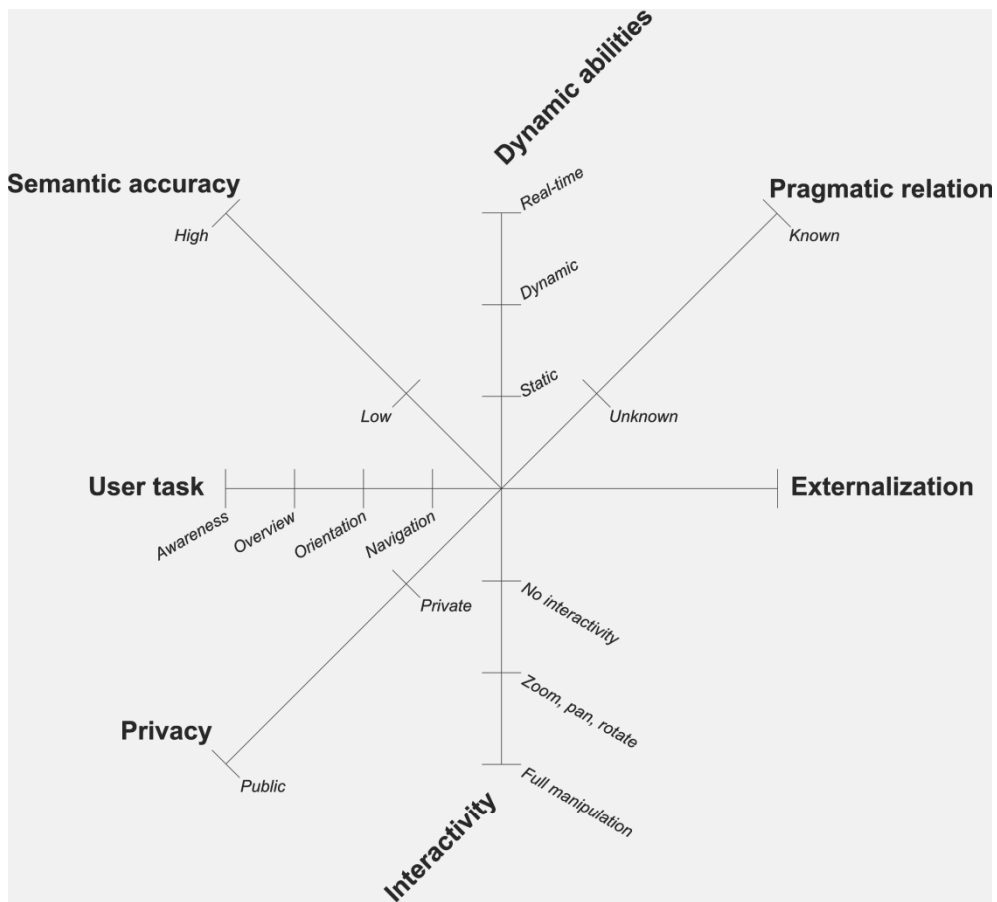


Fig. 2. The framework visualized as a kiviati diagram.

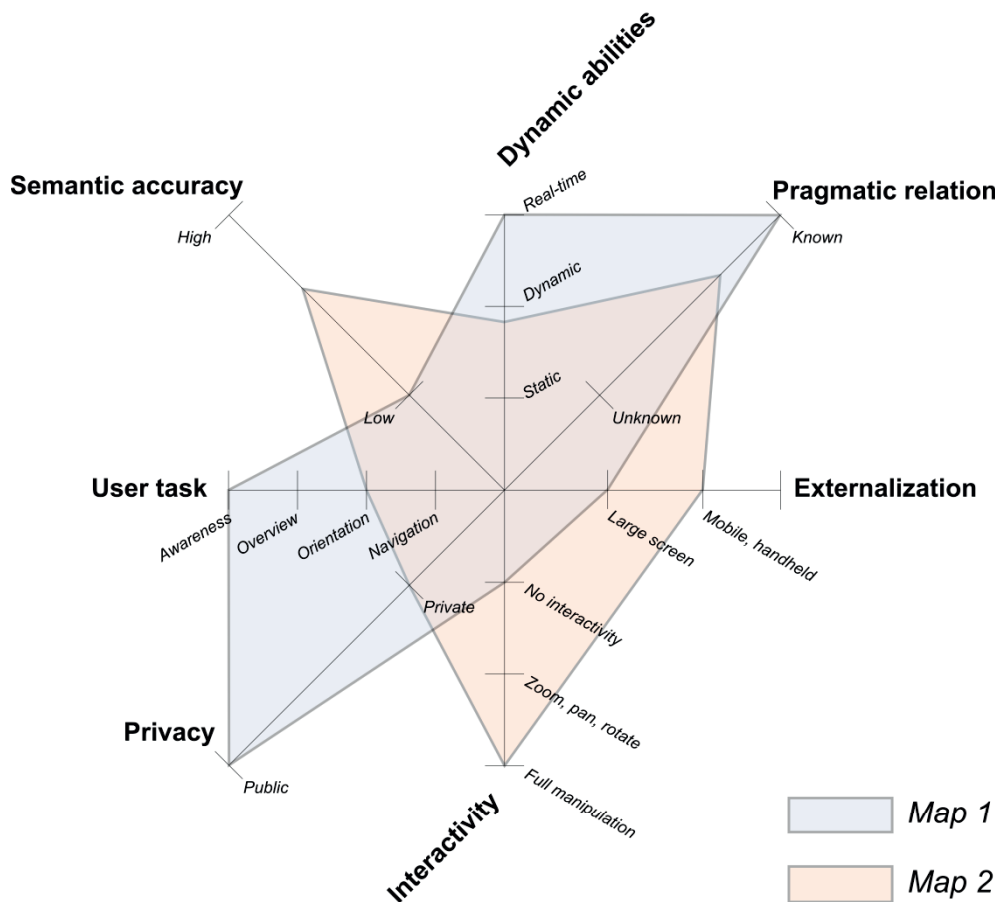


Fig. 3. Example use of the framework describing and comparing two different indoor maps.

2.3. Pragmatic relation

A common use for maps is to explore the unknown, for instance to get an overview of different stores in a shopping mall. An opposite example is provided by maps that present known territory to their users. This could be for example “you are here” maps in shopping malls. In either case, the users’ degree of familiarity with the mapped space affects the use and design of a map. MacEachren & Fraser 1994 identifies this characteristic as the data relation dimension in the map use cube. In the quality frameworks (Krogstie 2012; Nossum & Krogstie 2009) a pragmatic quality is described. Both are equally important for indoor maps. In the proposed framework a dimension termed “pragmatic relation” is included that aims at capturing the relation-ship between the map and the user’s previous knowledge of content in the map. The dimension is defined as a continuous scale from

unknown to known, and thus also captures maps and users that lay in between.

2.4. Dynamic abilities

Maps have historically been printed and have had little or no dynamicity. In recent times, digital technology has enabled more dynamic abilities in maps, with movie-like animations and computer generated web animations (Kraak 2007; Harrower 2009; Nossum 2011b). The internet and increasingly faster communication have made it possible to include real time information in maps (Field & O'Brien 2010; Field et al. 2011). Map developers today need to consider the different possibilities of dynamic abilities that the map should have. Many situations require static maps, while others require real time maps. The level of dynamic abilities affects the design and the functionality of a map. In indoor environments this is equally or even more important. The dimension in the framework is described by three characteristics: static, dynamic and real time. These characteristics outline the dimension and should not be considered limiting. Users of the framework are able to include other appropriate characterizations to suit their specific needs. Static maps have no possibilities of change, while dynamic maps can reflect change and real time maps are able to immediately reflect a change in the data set. The level of dynamic abilities of the map does not make the map better or worse, but reflects one characteristic of the map. A map's dynamic abilities are related to the interactivity provided in the map which inevitably will affect the dynamic abilities, such as a GIS client. However the dynamic abilities are not necessarily dependent on interactivity, as is the case in non-interactive animations. The two dimensions are intentionally separated to facilitate a more precise description of maps within the two dimensions.

2.5. Interactivity

Interactivity concerns user input and user interaction. MacEachren & Fraser 1994 includes this in the map use cube as a continuous scale ranging from low to high in-teractivity. The interactivity dimension in the framework for indoor maps uses the same scale but also includes three distinct characteristics that are commonly found in indoor maps. Interactivity differs from the dynamic ability which does not require any user interaction. In computer science, and in particular the field of human computer interaction (HCI), interactivity has been subject for extensive research (Svanæs 2000; Card et al. 1986; Sharp et al. 2007). In modern maps, the degree of interactivity is crucial to both the design and the success of the map. This is similarly true for indoor maps. However, a high degree of interactivity will not necessarily result in a better map. In the framework, interactivity has

been described using three characteristics: no interactivity, zoom/pan/rotate and full manipulation. These three characteristics outline a scale of interactivity. Full manipulation is intended to comprise maps that enable the user to add features or information to the map as well as view the map. Zoom, pan and rotate describe maps that have the typical pan, zoom, “click for more”, rotate and similar viewing functionality. There exist maps that lie in between the defined properties which the kiviati diagram supports by its continuous scale.

2.6. Externalization

The manner of which maps are externalized will inevitably affect the resulting quality of the map as well as it affects greatly design considerations. The externalization is regarded equally important for traditional maps as for the specific case of indoor maps. Historically, maps have been physically externalized, typically on paper. In modern times, paper maps are equally important, however, the addition of digital maps has opened up a large span of possibilities, not possible with paper. Indoor maps are commonly found printed as you-are-here maps for emergency purposes. Other, more novel approaches seem to focus largely on digital externalization.

There are several important aspects related to the externalization. Available size is one that sets constraints on how much information can be displayed and how it is displayed. In connection with size, resolution is equally important. Printer technology is able to produce maps with very high resolutions and in general higher than digital displays. On the other hand are technological properties of the externalization. Mobile devices have seen an enormous development in the last decade. The capabilities varies greatly from examples such as; multi touch screens, GPS, Near Field Communication, 3G/4G, WiFi and accelerometers, just to mention a few. The range of sensors, size, resolution and other capabilities of the externalization affects the quality of the indoor map. Externalization is included in kiviati diagram as a dimension without a scale or ordering to accommodate the vast variety of differences in map externalizations. Users of the framework will need to consider which properties that are of most importance to the evaluation or comparison in question which can then be included on the dimensions as properties of the externalization.

2.7. User task

A map is typically designed with one particular main user task in mind. To outline the user task classification, the framework includes a set of four generic tasks that can aid in describing user tasks across different maps made for different purposes. These four tasks are: Awareness, overview, orientation and navigation. It is emphasized that these four tasks are intended to

outline the user task dimension, but does not restrict the addition of several specific user tasks if wanted by the user of the framework.

Navigation can range from; mentally finding a route from one point to another – to an interactive map offering specific guidance on almost every move that the user should make. The latter is well known from GPS navigation devices.

In pure orientation tasks the user needs to cognitively adapt the map to the physical environment (Lawton 1996). For indoor environments, an additional complexity is introduced by the different floors of multi-storey buildings. Several well-known techniques from cartography and psychology are available to facilitate orientation in maps, even on indoor maps and environments (Wolbers & Hegarty 2010; Xu et al. 2010; Walton & Worboys 1989). Almost regardless of the primary user task of a map, care should be taken to facilitate proper orientation support. The framework focuses mainly on the primary user task, however, orientation is kept as a characteristic to include maps that solely focus on orientation as its primary task.

In indoor environments, maps that provide overview are commonly found in shopping malls, airports and similar public indoor spaces. The quality of these varies tremendously, illustrating a need for maps that provide the user with a general overview of a certain environment. Most of the examples found today are on a physical platform, typically printed or painted on walls, although more examples are found as digital versions either on large screens or mobile devices.

The last user task described in the framework is awareness. This task is inspired by future promises of real time indoor maps, in particular in hospital environments (Nossum 2011a). Providing awareness of a situation in maps is particularly important in crisis maps (Seppänen et al. 2007; Seppänen & Virrantaus 2010; Klippel et al. 2006; Klippel et al. 2010). In crisis maps, the information changes rapidly, often combined with limited viewing time. Providing awareness through a map requires careful decisions on the map design which can be significantly different than for other user tasks.

3. Conclusions and Future Work

Seeking better ways to describe and compare indoor maps cartographically, we have proposed a framework with seven dimensions of characteristics of indoor maps.

The framework presented here extends on earlier frameworks for both conceptual models and map use (Krogstie 2012; Nossum & Krogstie 2009;

MacEachren & Fraser 1994) and is also inspired by commercially available indoor map types as well as map types from the research literature.

This kind of framework relies on continuous contribution from an active scientific field. Novelty in cartographic solutions for indoor maps need to continuously be included in the framework. In future work to be reported elsewhere, the capabilities of this framework will be put to the test through empirical and theoretical evaluations. In the current state the proposed framework sets out a direction and acts as a starting point for putting quantifiable quality of indoor maps on the agenda. The work pre-sented here is one step in that direction.

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References

- Bell, D.G. et al., 2007. NASA World Wind: Opensource GIS for Mission Operations. In *2007 IEEE Aerospace Conference*. IEEE, pp. 1-9.
- Bing Maps, 2011. bing maps. Available at: <http://www.bing.com/maps/> [Accessed September 14, 2011].
- Card, S.K., Moran, T.P. & Newell, A., 1986. *The Psychology of Human-Computer Interaction*, Lawrence Erlbaum Associates.
- Chambers, J.M. et al., 1983. *Graphical Methods for Data Analysis (Wadsworth & Brooks/Cole Statistics/Probability Series)*, Duxbury Press.
- Ciavarella, C. & Paterno, F., 2004. The design of a handheld, location-aware guide for indoor environments. *Personal and Ubiquitous Computing*, 8(2), pp.82-91.
- Curran, K. et al., 2011. An evaluation of indoor location determination technologies. *Journal of Location Based Services*, 5(2), pp.1-18.
- Dahl, Y. & Svanæs, D., 2007. A comparison of location and token-based interaction techniques for point-of-care access to medical information. *Personal and Ubiquitous Computing*, 12(6), pp.459-478.
- DiBiase, D., 1990. Visualization in the earth sciences. *Earth and Mineral Sciences*.
- Dorling, D.D. & Fairbairn, D.D., 1997. *Mapping: Ways of Representing the World (Insights Into Human Geography)*, Prentice Hall.
- Field, K. & O'Brien, J., 2010. Cartoblogography: Experiments in Using and Organising the Spatial Context of Micro-blogging. *Transactions in GIS*, 14, pp.5-23.

- Field, K., O'Brien, J. & Cartwright, W., 2011. EXPLORING CARTOGRAPHIC DESIGN IN SOCIAL-NETWORK MAP MASHUPS. In *Proceedings of the 25th International Cartographic Conference*. p. ONLINE.
- Fisher, P. & Unwin, D., 2001. *Virtual Reality in Geography (Geographic Information Systems Workshop)*, CRC Press.
- Garland, K., 1994. *Mr. Beck's Underground Map: a history*, Capital Transport Publishing.
- Google Earth Election Guide, 2006. Google Earth Election Guide. Available at: http://www.google.com/press/pressrel/earth_election_guide.html [Accessed September 7, 2011].
- Google Maps, 2011. Google Maps. Available at: <http://maps.google.com/> [Accessed September 14, 2011].
- Google Street View, 2011. Google Street View. Available at: www.google.com/streetview.
- Harrower, M., 2009. Cartographic Animation. *International Encyclopedia of Human Geography*, pp.408 - 413.
- Huang, H., Gartner, G. & Ortag, F., 2009. *Cartography in Central and Eastern Europe* G. Gartner & F. Ortag, eds., Berlin, Heidelberg: Springer Berlin Heidelberg.
- Klippel, A., Freksa, C. & Winter, S., 2006. You-Are-Here Maps in Emergencies The Danger of Getting Lost. *Journal of Spatial Science*, pp.117-131.
- Klippel, A., Hirtle, S. & Davies, C., 2010. You-are-here maps: Creating spatial awareness through map-like representations. *Spatial Cognition and Computation*, 10(June 2011), pp.82-93.
- Kraak, M.-J., 2007. Cartography and the use of animation. In W. Cartwright, M. Peterson, & G. Gartner, eds. *Multimedia Cartography*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 317-326.
- Kraak, M.-J. & Ormeling, P.F., 1996. *Cartography: Visualization of Spatial Data*, Prentice Hall.
- Krogstie, J., 2012. *Model-Based Development and Evolution of Information Systems: A Quality Approach*, Springer.
- Lawton, C.A., 1996. Strategies for indoor wayfinding: The role of orientation. *Journal of Environmental Psychology*, 16(2), pp.137-145.
- MacEachren, A.M., 2004. *How Maps Work: Representation, Visualization and Design*, Guilford Press.
- MacEachren, A.M. & Fraser, D.R., 1994. *Visualization in Modern Cartography*, Pergamon.
- Mautz, R., 2009. Overview of Current Indoor Positioning Systems. *Geodesy and Cartography*, 35(1), pp.18-22.

- Nossum, A.S., 2011a. IndoorTubes A Novel Design for Indoor Maps. *Cartography and Geographic Information Science*, 38(2), pp.193-201.
- Nossum, A.S., 2011b. Semistatic animations - integrating past, present and future in animations. *Cartographic Journal The*.
- Nossum, A.S. & Krogstie, J., 2009. Integrated quality of models and quality of maps. In *Enterprise, Business-Process and Information*. pp. 264-276.
- Radoczky, V., 2007. How to design a pedestrian navigation system for indoor and outdoor environments. In *Location Based Services and TeleCartography*. Springer, pp. 301-316.
- Riedl, A. et al., 2007. *Multimedia Cartography* W. Cartwright, M. P. Peterson, & G. Gartner, eds., Berlin, Heidelberg: Springer Berlin Heidelberg.
- Robinson, A.H. et al., 1995. *Elements of Cartography*, John Wiley & Sons.
- Schrooyen, F. et al., 2006. Real Time Location System over WiFi in a Healthcare Environment. *Journal on Information Technology in Healthcare*, 4(6), pp.401-416.
- Schöning, J. et al., 2008. Improving interaction with virtual globes through spatial thinking. In *Proceedings of the 13th international conference on Intelligent user interfaces - IUI '08*. New York, New York, USA: ACM Press, p. 129.
- Seppänen, H., Krisp, J.M. & Virrantaus, K., 2007. Expanding the situation picture for the decision maker with geographical information. In *Proceedings of the 23th International Cartographic Conference*. p. CD-ROM.
- Seppänen, H. & Virrantaus, K., 2010. The role of GI-supported methods in crisis management. *International Journal of Digital Earth*, 3(4), pp.340-354.
- Sharp, H., Rogers, Y. & Preece, J., 2007. *Interaction Design: Beyond Human-Computer Interaction*, Wiley.
- Svanæs, D., 2000. *Understanding interactivity: Steps to a phenomenology of human-computer interaction*, Norges teknisk-naturvitenskapelige universitet.
- Walton, L. & Worboys, M., 1989. Indoor Spatial Theory.
- Weber, A. et al., 2010. Cartography Meets Gaming: Navigating Globes, Block Diagrams and 2D Maps with Gamepads and Joysticks. *Cartographic Journal, The*, 47(1), p.9.
- Wolbers, T. & Hegarty, M., 2010. What determines our navigational abilities? *Trends in cognitive sciences*, 14(3), pp.138-46.
- Xu, J. et al., 2010. Persistent posterior and transient anterior medial temporal lobe activity during navigation. *NeuroImage*, 52(4), pp.1666-1654.
- Yahoo! Maps, 2011. Yahoo! Maps. Available at: <http://maps.yahoo.com/> [Accessed September 14, 2011].
- Yang, B. et al., 2007. Indoor positioning performance of Galileo signal. In *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*.

Appendix

A1. High resolution of IndoorTube Gastroenteret

<http://issuu.com/alexanno/docs/indoortubegastroenteret>

