Abstract: Visualization of spatio-temporal information has been a challenge for cartography for decades. The earliest approaches focused on static visualizations, several of them with great success (Friendly 2002, Monmonier 1990, Tufte 2006). With the digital age dynamic and animated maps have become possible. Much work has gone into the design and study of perception of both of these map types (Midtbø 2001a, Midtbø et al. 2007, Fabrikant et al. 2008, Harrower et al. 2000). Both static and animated visualizations have their distinct qualities. Static maps are able to provide the user with unlimited viewing time of the information, allowing the level of detail to be high. On the other hand, static maps do not have the intuitiveness of visualizing temporal information due to their inherent static nature. Animated maps are often more intuitive in their representation of temporal information. Displaying frames of information in rapid succession is perceived as more intuitive representation of the temporal information. However, the fact that the frames have a very limited viewing time often hinders the user from perceiving and gaining knowledge from the information (Harrower 2009).

There has been a sharp distinction between animated and static maps in cartography. Evaluation of either two has been following this distinction and often compared animated against static maps. In this article we propose moving beyond the sharp distinction of animated and static maps by combining the qualities of both in one new representation method. We term this concept; semistatic animations. The core idea of the concept is to make all information visually available to the user at any given time of the animation. This allows the user to look both back and forth in the animation while it is playing without interaction.

A proof-of-concept implementation has been made using weather map animations. In order to assess the perceptual performance of the concept a web experiment has been conducted. Realizing that the maps do not necessarily support all usage scenarios a task oriented approach was applied on the experiment. In total the experiment included 240 participants.
Results from the experiment revealed that the semistatic concept significantly increases the performance on several of the tasks compared to the equivalent traditional animated map. However for some of the tasks the semistatic approach did not improve the performance, or worsened it. This illustrates the importance of evaluating not only on a general level but delve further in different user tasks. The results obtained additionally motivates for further investigation of the semistatic concept as well as user behavior.
RESPONSE TO REFEREE’S COMMENTS

I would like to thank the referees for their efforts and valuable and very helpful comments. The comments have raised the quality of my article considerably. Below I go through each of the comments received from the initial submission and explain how I have addressed them. I have made an effort in addressing all of the comments as complete as possible. The referees’ comments are highlighted with italics and indented for clear separation.

The term semio-static maps is not clearly explained.

The background for the term “semistatic animations” is made clearer in the abstract and throughout the paper. Specifically the combination of static and animated representations is emphasized more.

It look that it is similar / same as the small multiples (already discussed by Bertin, cultivated by Tufte) or even to diagram maps.

The similarities as well as the differences are made clearer throughout the paper. In particular the abstract, section 2.1 and section 5 has been rewritten and includes more thorough discussion on this similarity.

section 1.1, bulleted list: would say (dis)appearance instead of disappearance

Yes. This is better.

page 4, line 24: we do not believe.......arguments please

The 4th paragraph in section 1.1 “animation challenges” is rewritten. Better discussion as well as arguments are included.

page 4, line 34: compare with visual hierarchy!

The 5th paragraph in section 1.1 “animation challenges” includes thoughts on visual hierarchy.

page 5, line 35: ...possible means... thought we know that interactivity is a must for animation

Section 1.2 “interactivity” is removed. Discussion on interactivity and animations is now made clearer and included in the section 1.1 “animation challenges”
The hypothesis is rephrased and made clearer. Real life examples included. Moved under section 1.1 “animation challenges”.

Section 1.3 I guess you forget in case of television that animations are often accompanied by a narrative of weatherperson

Section 1.3 was found unnecessary and is removed. Some examples included in section 1.1 “animation challenges”

Areas is much better term for this. Is corrected.

Section 5 is rewritten and includes a discussion on the limitations and issues with the proposed designs.

The terms used to differentiate between the two different versions have been revised throughout the paper. These are now “symbolic weather map” and “temperature map” which are both special cases of a general weather map.

Figure 2. I assume (a) is on of four snapshots showing Fredag, but how does is work in (b), here it seems to be Lordag. Unclear to me how it works. How does it link to time - what is time scale of history bar, Why do you stil have days above?

Both figure 2 and 3 is revised. The legend is in English and an “explanation box” is included in the figure to highlight the differences. This is also included explicitly in the text.

Beginning of section 2.2 is rewritten. The differences between the two versions are made clearer. The possibilities are made clearer and more explicit.
Figure 3 / same comments as for figure 2. How can people read the small history bars / it shows trend, almost impossible to retrieve values. Could think of symbols indicating trend: temp goes up equal or down.

The intentions of the design are made clearer. Alternative designs are deliberately not included as they were not part of the experiment. Some suggestions for future work are included.

Section 4
what are those typical tasks / third task seems most simple

The tasks and the intentions behind them are made clearer in the beginning of section 3 “experimental evaluation”.

structure test: line 55; why present task?/questions after seeing animation; then everything seems to be memory based?

A discussion on this as well as some alternative methods that was rejected is included in the 4th and 5th paragraph of section 3 “experimental evaluation”.

conclusion: you start with discussion on pictogram/symbol design. how does that follow from test?

Section 5 is rewritten. Discussion on issues with the design as well as the limitation of the web experiment is included and made clearer.

The temporal legend. how much was this feature really used? Is that derived from test?

This is not derived from the test. Section 5 now includes clearer discussion on limitation of test and suggestions for better/more granular results.

page 21 line 15. What is you conclusion 'promising' based on, comparing with animation? are there other maps that do same. diagram maps do exist with also hold the history of a time series (many climate maps have a similar approach). Why not compare with those solutions.

Section 5 now deals more properly with the aims of the experiment and suggestions for future work - including comparison against more traditional, static approaches.

In fact you semi-static maps seems to be diagram maps with small multiple incorporated. This has to be clarified.

This has been made clearer throughout the paper. See in particular section 2.1 and section 5
Semistatic animation - Integrating past, present and future in map animations.

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ABSTRACT

Visualization of spatio-temporal information has been a challenge for cartography for decades. The earliest approaches focused on static visualizations, several of them with great success (Friendly, 2002; Monmonier, 1990; Tufte, 2006). With the digital age dynamic and animated maps have become possible. Much work has gone in to the design and study of perception of both of these map types (Midtbø 2001; Midtbø et al. 2007; Fabrikant et al. 2008; Harrower et al. 2000) Several very effective animated maps have been developed and rigorously evaluated.

Both static and animated visualizations have their distinct qualities. Static maps are able to provide the user with unlimited viewing time of the information, allowing the level of detail to be high. On the other hand, static maps do not have the intuitiveness of visualizing temporal information due to their inherent static nature. Animated maps are often more intuitive in their representation of temporal information. Displaying frames of information in rapid succession is perceived as more intuitive representation of the temporal information. However, the fact that the frames have a very limited viewing time often hinders the user from perceiving and gaining knowledge from the information (Harrower 2009).

There has been a sharp distinction between animated and static maps in cartography. Evaluation of either two has been following this distinction and often compared animated against static maps. In this article we propose moving beyond the sharp distinction of animated and static maps by combining the qualities of both in one new representation method. To emphasize the concept’s qualities from both static and animated maps we call this concept; semistatic animations. The core idea of the concept is to make all information visually available to the user at any given time of the animation. This allows the user to look both back and forth in the animation while it is playing without interaction. The design draws inspiration from both static multiple map displays and diagram maps - qualities from both of these are integrated in an animated representation.
A proof-of-concept implementation has been made using weather map animations. In order to assess the perceptual performance of the concept a web experiment has been conducted. Realizing that the maps do not necessarily support all usage scenarios a task oriented approach was applied on the experiment. In total the experiment included 240 participants. Results from the experiment revealed that the semistatic concept significantly increases the performance on several of the tasks compared to the equivalent traditional animated map. However for some of the tasks the semistatic approach did not improve the performance, or worsened it. This illustrates the importance of evaluating not only on a general level but delve further in different user tasks. The results obtained additionally motivates for further investigation of the semistatic concept as well as user behaviour.

1 BACKGROUND
Visualizing temporal and spatial information has been a concern to cartography for decades. Throughout history there have been several different attempts including both static and animated solutions. There are several examples of success of 2-dimensional static visualizations including Minard's famous graphic of Napoleons march, which dates back to 1869 (Friendly, 2002). With the advances of technology, animated representations have become a possibility. The earliest examples of using animations as a means for representing spatio-temporal data dates back to the thirties (Peterson, 1999). Despite these early efforts and examples, cartographic animations have not gained a lot of attention until the recent ten to fifteen years. Enormous advances in the capability of computers as well as the ease of distribution through the internet are believed to be two of the major factors for this. With today's ease of access to information, computer capabilities and very easy distribution through the internet, “everyone” can very easily make map animations. Thus, cartographic animations are now common not only in the scientific community but more often in the general society. The use of cartographic animations is diverse. Examples range from the discussion on use for teaching and learning, to data exploration tools (Ogao & Kraak 2002; Acevedo 1997; Blok et al. 1999; Papliatseyeu et al. 2009; Harrower et al. 2000; Slocum et al. 2000; Harrower 2001). Thus the application areas are not only bound to mere display of a spatio-temporal phenomenon, but also comprise diverse tasks which we hypothesize have different needs in the cartographic design. There are, however, several unresolved issues with animations which need to be addressed. Often, animations are compared with their static counterparts in order to assess the performance of each. The comparison is often related to the question of which is better; the animated or the static representation. The results from these comparisons have not been unanimous (Tversky et al. 2002; Midtbø & Larsen 2005; Fabrikant & Goldsberry 2005; Griffin et al. 2006; Hegarty et al. 2003; Price 2004; Slocum et al. 2004). Based on this a finite answer cannot be made to the question; which is better. Among others Fabrikant et al. (2008) presents an interesting argument in this discussion. The discussion revolves around the comparisons made between animated and static representations and that they are not informational or computationally equivalent and cannot be compared directly with each other. For instance can the animated representation have additional information displayed when an object is moving from A to B, while the static counterpart can only have one frame of information. In addition animations often have interaction possibilities, such as pause, play, rewind and similar. This is of course highly recommended in a real-life animation (Harrower 2003), however, in order to compare against a static counterpart the representations should be both informational and computational equivalent. Although this can be highly problematic in some experimental setups, we believe animations and static representations have both similar and different qualities. The question of which is better is most certainly dependent on the task and the context for the usage scenario (Harrower 2003). In this article we will try to move beyond the discussion on static vs. animated maps and suggest a concept which combines qualities from both.


1.1 **Animation Challenges**

There are several issues associated with animations that have been identified and discussed. These issues are primarily concerned with the concept of animation itself and not relating or comparing with static representations. Harrower (2003) and Dodge et al. (2008) discuss some of the most notable issues. These are:

- (Dis)appearance
- Attention
- Confidence
- Complexity

Cartographic animations have often a large number of elements that change. These elements may only be displayed for a limited amount of time. This is often due to the phenomenon represented only occurred for a particular time period.

The user can then miss the information that is displayed. For instance if the user blinks he might miss important information if it is only displayed within this time window. Other examples can be typical user tasks such as comparison between a subset of the elements in the animation which can lead the user not perceiving the other elements. It is obvious that the two issues of disappearance and attention are interlinked and interdependent.

MacEachren (2004) argues that the ability for users to perceive non-dynamic elements decrease with animations. This in combination with the issue of disappearance makes the risk of losing information high for the user of animations. Several solutions to the problem have been suggested by Harrower (2003): Looping the animation so the user can watch it several times, pause the animation and play at a slower rate. All of these solutions require that the user is able to watch and/or interact with the animation. We believe that there are still some situations where this is either not wanted of the user or possible. There are several examples of such; for instance large screen monitors in public spaces such as airports, shopping centres and similar where it is very hard to achieve user interaction. Situations where the user has a very limited time to view the animation, for instance when glancing rapidly on a television or computer screen – it is not wanted from the user to interact or watch the animation several times. Added interactivity can in addition, add an unwanted cognitive load to the user (Fabrikant et al. 2008; Tversky et al. 2002; Hegarty et al. 2003; Griffin et al. 2006). On the other hand experiments have shown that map users become frustrated with maps they cannot control (Monmonier & Gluck 1994; Koussoulakou & Kraak 1992). This suggests that there is not a unanimous agreement on whether interactivity in animations is supporting their performance. We have intentionally left interactivity out of this project in an effort to explicitly address the issue of disappearance and present alternative solutions not interfering with the pace nor the user of the animation.
Attention is tightly related to the issue of disappearance (Dodge, McDerby & Turner, 2008). However, the user’s attention is not related only to disappearance. Animations and maps in general often try to emphasize a certain phenomenon. In order to succeed with this the user needs to pay attention to the phenomenon in question. This is often solved by taking advantage of a visual hierarchy in the design to emphasize or dampen the attention of certain parts of the animation. In addition or in combination to visual hierarchies the use of attention grabbing colours, blinking and even sound queues are also being used to attract the user’s attention. However the use of dynamic variables as a means for “attention grabbing” may cause more irritation to the user than actual attention and should be used cautiously. If several elements are competing for the user’s attention he/she may end up with dividing his/her attention between several elements in the animation. This is commonly referred to as split attention (Dodge, McDerby & Turner, 2008; Rensink, O'Regan & Clark, 1997). Split attention may in turns cause disappearance. The user needs, for instance, to divide his attention between several elements and potentially miss the information in the non-attended elements. We hypothesize that the issue of disappearance caused by split-attention is dependent on the spatial position of the elements as well as, of course, the temporal position. An example of this is the temporal legend which could be positioned at the top of the animation and be an animated linear bar. The user would almost certainly need to divide his attention between the symbols or elements within the map and the temporal legend in order to both get the spatial information as well as the temporal. Later we explicitly address this issue and propose solutions to it.

Results exist that suggests the confidence of information obtained or learned by animations is low (Rieber & Parmley, 1995; J. B. Morrison, 2000; M Hegarty, 2004). This is especially noticeable for children (Cutler, 1998) and is believed to be due to more experience interpreting static representations than animated representations. Interpretations of animated representations vary with the learning or experience the user has with animations. Harrower (2003) suggests incorporating guided introductions or similar tutorials in order for the user to learn the interface as well as the specifics of the animation. The user will then not be unfamiliar with the animation and can direct his attention toward the information rather than the interface itself.

The complexity of the map should be of particular focus when designing animated maps. Harrower (2003) argues that animated maps often becomes too complex and ends up not communicating well with the user. This is mostly due to the changing nature of an animation compared to a static map. To keep both the information as well as its representation as simple as possible, Harrower (2003) suggests favouring aggregated information and data filtering. In this article we employ these strategies in the symbol designs as will be further described later.

1.2 SEMISTATIC ANIMATIONS
Semistatic animations address the previously mentioned challenges by expanding the symbology to include both past, present and future information during the whole animation. Every frame of the animation then visualizes the complete information contained in the animation.

Several challenges occur when implementing the semistatic concept. The symbology of the information, the structure of the information and the time span of the animation all affects the potential of implementing a semistatic approach in an animation. Currently a simple implementation has been made to illustrate and evaluate the concept. This implementation covers non-moving points where the information is of either a textual or a numeric type, both one dimensional. Details on the implementation are covered in later sections.

Information represented with points is the current focus of exploration. Implementing the semistatic concept for lines and areas are believed to be possible but is left out of the scope of this project.
Symbolic weather and temperature forecast both have the properties of interest and are suitable for the proof of concept. Both symbolic weather and temperature are represented with a discreet spatial point, the attributes vary in one dimension, for instance as a textual description for symbolic weather and a number for temperature. This simplifies the implementation of the semistatic concept. Multi dimensional data can be for instance wind forecast, where the attributes of wind are both direction and magnitude. Although represented with one spatial point, the extended complexity of multi-dimensional data makes implementation of the semistatic concept challenging.

The essential visual component of the proof of concept implementation is the history view. The history view is an extension of the traditional point symbol in animations, to include the past and future information for that particular point and shares similarities to the earlier work by Midtbø (2007). A conceptual sketch of the history view can be found in figure 1. Including the information history for a point opens for easy inclusion of a temporal legend embedded in the component. Examples of this are an expanding time bar or a circular clock like metaphor depending on the design of the history view and the prospective users (Midtbø, 2001a). The history view is hypothesized to address the challenge of disappearance in particular by visually including all information associated with the particular point. Embedding a temporal legend within the history view is hypothesized to leverage the split attention caused by traditional temporal legends. This will inevitably lead to redundant representation of the temporal reference and can be argued to contribute to more split attention. It is believed that the visual proximity of the focus point of the viewer (i.e. a point) and the embedded temporal legend will attract the viewer’s attention more than the peripheral perception of the other elements in the map. The hypothesis is supported by removing the traditional top or bottom main temporal legend which inevitably resides further away from the focus point of the viewer which requires the viewer to actively move the focus point to perceive the temporal reference. Adding interactivity to the animation could meet several of the mentioned challenges. However, as argued for earlier, this is not always suitable.

FIGURE 1: Essential elements of the history view symbols implemented and used

2 PROOF OF CONCEPT IMPLEMENTATION

A proof of concept has been implemented to illustrate the main parts of the semistatic concept. The implemented animations focus on the special case of weather maps. Two different animations have been made, one temperature map and one symbolic weather map. The temperature map focusing solely on the numeric data and the symbolic weather map on the nominal or textual description, such as sun, rain, cloudy etc. This differentiation was chosen to avoid complexity in the animations and to isolate the different approaches during evaluation.

Weather map animations are commonly used in television, where all users must simultaneously watch the animation without any interactivity. Thus, the chance that some of the viewers loose information is large, whether that is due to disappearance or split attention.

In addition to use in television, similar map animations can be found on the internet. The internet provides possibilities of user interaction in far greater way than broadcast mediums will ever do. However, the added interaction may not always suit the needs of the user. A user may require that the animation provides all information in a very short time and may not want to engage in interactivity with the animation and finally the user can be distracted by the added interactivity (Fabrikant et al. 2008).
The proof of concept animations focus on one particular case and is further divided in symbolic weather and temperature map animations. There are distinct differences between symbolic weather and temperature maps. Temperature maps aim at communicating numeric information, while symbolic weather maps aim at nominal information. In traditional weather maps both are presented using symbols; temperature as a number and symbolic weather as a pictogram. With a semistatic approach the different information types can fulfil their potential better. The following will shed light on some of these potential visualizations and discuss the different implemented animations.

2.1 Symbolic Weather Map Animation

The symbolic weather map animation depicts the weather forecast for several different locations during a defined period of time. The different locations are major cities or other important locations. Each location has its own forecast and its own symbol. The symbols used follow the conventions of a standard symbolic weather map and are pictograms which are strongly associated with the forecast information.

Figure 2 shows snapshots of the traditional and the semistatic implementations of the symbolic weather animation. Both animations include a temporal legend on the top of the map. The temporal legend in the semistatic animation is not animated and does not indicate itself the temporal information as the integrated temporal legends are intended to communicate this. The temporal legend in the semistatic animation acts as such only to communicate the temporal scale, not the current time of the animation.

The temporal legend in the traditional animation depicts the time by increasing the fill in the legend rectangle. This is chosen as it is one of the most common ways to visualize time in animations (Harrower 2009; Midtbø et al. 2007; Midtbø 2001a; Midtbø 2001b). The temporal legend in the semistatic animation is not animated and thus, does not represent the time other than the temporal scale of the animation. This is deliberately chosen as the symbols within the map represent this information. The temporal legend is also deliberately included in the semistatic version to maintain similarity to the traditional version for the experimental evaluation.

FIGURE 2: Snapshots of the symbolic weather map animation. Traditional version to the left and semistatic version to the right. Both stopped at “Friday”.

The symbol at each location in the semistatic animation is an extension of the traditional animation. The current weather information is visualized similarly to the traditional version with a large pictogram. To include all of the information that is related to the location the symbol is extended with a small temporal time bar. The time bar represents the current time by filling the rectangle. In addition the previous, current and future pictograms are positioned in miniature according to their temporal location. This allows the user to visually move back and forth in time without the need to interact with the animation. It is evident that the temporal legend is visualized several times across the map. The hypothesis is that this will aid the user better by limiting the possibilities of split attention. A concern may be that the visual disturbance caused by many moving objects may lead to more visual noise. To limit this effect the colour chosen for the animated time bar is deliberately light.
The strategy of displaying all information in one frame is inspired by and very similar to static multiple map displays (Fabrikant et al. 2008; Tufte 2001; Bertin 1983). The semistatic concept presented here shares much of the same goals as static multiple map displays, with the main goal being to visually represent the full historical information in one frame. There are however some differences. Static multiple map displays are often complete maps that are positioned according to their temporal reference. One of the earliest uses of this technique is perhaps the famous stop-motion photography of galloping horses by Muybridge (Encyclopedia Britannica, 2011). In relation to dynamic animations static multiple map displays can be seen as snapshots of key frames of an animation. The semistatic concept is different from small multiple map displays in that the actual map is not replicated and positioned in separate figures. In addition the past and future information is de-emphasized, but still visible in the symbols time bar, making them have a lower rank in the visual hierarchy of the map display. This makes it possible for the viewer to comprehend historical trends or discreet information without moving between different maps but keep the view on the same map, possibly limiting issues with re-orientation.

In addition to the inspiration from static multiple map displays, the concept proposed shares similar features to diagram maps as well as earlier works by Monmonier (1990) and Vasiliev (1997). The semistatic concept extends and adapts features from all of these map types and integrates it into an animated map.

2.2 TEMPERATURE MAP ANIMATION

The temperature map animation illustrates the temperature forecast for four days for several different locations. Temperature is numeric data which allows for easier use of standard information visualization techniques geared for numeric data (Spence, 2006; Ware, 2004).

The history view depicts the temperature forecast at the specific location for the whole forecast period. Figure 3 shows snapshots of the traditional and the semistatic temperature map animations respectively. The semistatic animation includes the above mentioned local temporal legend with the temperature forecast for the whole period as a graph. Values above zero are coloured red, values below are coloured blue to ease the perception of above and below zero and to provide a reference to the scale of the graph.

FIGURE 3: Snapshots of the symbolic weather map animation. Traditional version to the left and semistatic version to the right. Both stopped at “Friday”.

The graph visualization of the temperature forecast is hypothesized to primarily ease the perception of trends in the data set, for instance variance, increase or decrease. Perceiving trends in traditional animations requires the user to remember previously perceived temperatures in short term memory while viewing the rest of the animation. This can be difficult, but manageable for one location and a short time period - however trends for several locations during longer periods will be harder and potentially not feasible for the viewer. Trends over several locations during the animation can be relevant when the viewer is interested in moving across different locations for instance planning a car trip. In more generic applications this could be even more relevant, for instance in exploring phenomena where movement is dependent on both time and space.

3 EXPERIMENTAL EVALUATION

Performance of the semistatic animations compared to the traditional animation is strongly influenced by the tasks they are going to support. In this study three different tasks are chosen that motivates for different usage strategies. They are, however, not believed to be equally difficult nor produce the same results.

1. Trend on one location
2. Trend over space and time

3. Memory

The first task is testing the perception of *trend at one location* during the time period the animation spans. For instance this could be whether the temperature is rising or if the weather is getting worse, better or stable. The user’s cognitive memory as well as the user’s perception of time in the animation is crucial elements that affect the ability to solve the task. These abilities thus enable the user to make comparison in time for the information portrayed. Trend on one location can be made more complex by introducing variation of the location in relation to a particular time, thus a *trend over both space and time*. A typical user task could be to find out what the weather is going to be on a car trip which lasts several days and spans over several locations. The user’s perception of time is crucial and it is believed the effect of split attention may easily affect the user so much that he/she is not able to fulfil the task, and thus render the animation useless for this particular task.

The third and probably most common task is to remember the information for a specific location on a specific time. This task targets both split attention as well as the user’s cognitive memory. A typical task would be that the user wants to know the weather at a location on a specific day. We refer to this task as *memory task*. The general hypotheses for this study are:

1. Semistatic symbolic weather map animation performs better at all three tasks than the traditional symbolic weather map animation.
2. Semistatic temperature map performs better at trend on one location than the traditional temperature map animation and equally good for the memory and trend over space and time tasks.

In order to investigate these hypotheses a web-experiment was conducted. The experiment aimed at investigating participant’s answers to the specific tasks after watching the different animations. Each participant watched both the semistatic as well as the traditional map animation, each using different data sets and with alternating sequences to overcome a learning effect which could bias the results. Before each animation the participants were presented a task. After watching the animation a question relating to the task were presented and answered by the participant. This was done deliberately to avoid as much distracting elements as possible while viewing the animation. This could have had an influence on the experiment as the participants needed to rely partly on their short term memory in order to answer the question. This could affect the answers slightly for the two trend tasks, although both trend tasks are inherently requiring the participants to use their short term memory to an extent. The third task was designed to evaluate the memory effect, and could thus not be affected negatively by this.

An alternative would have been to display the question and receive answers before or during the animation or even a combination. This could have affected the bias due to reliance on memory. However, it would also have affected the viewing strategy of the participants and could possibly have affected the results worse than what the reliance on memory have.

In total 132 participants participated in the experiment relating to the symbolic weather map animations and 133 participants participated in the temperature map animations. The experiment was emailed to students at different faculties of engineering at the Norwegian University of Science and Technology in Norway. It is estimated that about 2000 students received the email, thus the response rate was quite low.
4 RESULTS AND ANALYSIS

The results from the web experiment were split into two separate categories; one for the symbolic weather map animation and one for the temperature map animation. For all results the data collected were primarily the participant’s answer to the questions. Each answer was coded as either correct or wrong in relation to the data set used. Thus the results lend good to chi-square hypothesis tests. The hypotheses revolved around the general research question of elaborating whether the semistatic animations performed better than the traditional animation or not. As mentioned earlier, this was further divided into different tasks. The statistical analysis reflects this by testing first semistatic vs. traditional regardless of task, then testing semistatic vs. traditional for each of the three different tasks defined. The following presents the results from the different hypothesis tests for the symbolic weather map animation and temperature map animation respectively.

4.1 SYMBOLIC WEATHER MAP ANIMATION

Figure 4a illustrates the distribution of correct and wrong answers regardless of task for the symbolic weather map animation. The chi-square test reveals that there is a significant difference between the correct and wrong answers for semistatic and traditional animation with a chi-square value of: 18.459 which reject the null hypothesis at a 99% confidence interval (table value: 6.635 with 1 degree of freedom). The difference between correct and wrong answers for the semistatic animation indicates that the semistatic animation performs far better in general than the traditional animation.

Figure 4: Answer distributions for the symbolic weather map animation: (a) Total distribution regardless of task. (b) Trend on one location. (c) Trend over space and time. (d) Memory task

4.1.1 TREND ON ONE LOCATION

The answer distribution for the trend on one location task is found in figure 4b. The hypotheses of the chi-square test were as follows:

H₀ Traditional symbolic weather map animation performs better than the semistatic animation on the task; trend on one location.

H₁ Semistatic symbolic weather map animation performs better than the traditional animation on the task; trend on one location.

Based on the answer distribution a chi-square test was calculated using standard statistical software. The test gave a chi-square value of 22.744. At a 99% confidence interval the chi-square table value is 6.635 with 1 degree of freedom. This rejects the null-hypothesis for the test with good margins.

Further interpretation of this result yields that there is a significant difference in the distribution of correct and wrong answers for the traditional and semistatic animation. The graphs of the answer distributions found in figure 4b illustrates that this is not an unreasonable interpretation.

Interestingly the answer distribution for the traditional animation is fairly balanced in terms of correct and wrong answers. This gives an indication that the data sets used and the tasks are sufficiently complex (i.e. not too easy nor hard). These results strengthen the initial hypothesis that semistatic animations are well suited for user tasks involving trend at one location. Whether this is due to leveraging split attention or better supporting cognitive memory limits is hard to investigate using these results in isolation. However, it is clear that the semistatic animation affects positively one or both of these challenges.
4.1.2 TRENDS OVER SPACE AND TIME

The trend over space and time task is considered to be the most complex task for users, because of the requirement to move the attention between different locations synchronized with the time. However, the hypotheses of the chi-square test were similar to the rest of the task, favouring the semistatic animation:

\[ H_0 \] Traditional symbolic weather map animation performs better than the semistatic animation on the task; trend over space and time.

\[ H_1 \] Semistatic symbolic weather map animation performs better than the traditional animation on the task; trend over space and time.

Figure 4c shows the answer distribution relating to the task and forms the basis for the chi-square test. The semistatic animation received more wrong than correct answers for the task. Additionally the traditional animation received more correct than wrong answers. Combined this indicates strongly that the semistatic animation is not suitable for trend over space and time tasks. However the traditional animation does not gain an overweight of correct answers, which can be interpreted as the task being too complex for both animation types, or even that the answers collected are the result of chance, and not significant.

The chi-square hypothesis test resulted in a value of 1.163. Lowering the confidence interval to 90% follows a table value of 2.706 with 1 degree of freedom. Even at this low confidence interval the null-hypothesis is accepted. Thus, the semistatic approach seems not to be suitable for the trend over space and time task.

These results were surprising as it was believed that adding the possibility of visually moving back and forth in time would better support this specific task. However the results indicate that the semistatic animation actually made the results worse. Further investigation is needed in order to elicit why this is affecting the performance. It is evident that the traditional animation is also not performing well at this task, with a slightly higher number of correct answers. This may indicate, as previously mentioned, that the task is too complex or is misinterpreted by the participants.

4.1.3 MEMORY TASK

The memory task was considered to be the easiest and most common task of the three. Thus, it was expected that both the traditional and the semistatic animations would perform quite well. However, it was additionally expected that the semistatic would perform the better of the two. The stated hypotheses for the chi-square test reflect this.

\[ H_0 \] Traditional symbolic weather map animation performs better than the semistatic animation on the memory task.

\[ H_1 \] Semistatic symbolic weather map animation performs better than the traditional animation on the memory task.

Distribution of the answers which forms the basis of the chi-square hypothesis test is illustrated in figure 4d. This illustrates that the semistatic animation receives far more correct than wrong answers. The traditional animation gains surprisingly a 50% balance of correct and wrong answers. This indicates that the memory task was not as easy as initially thought. In addition the distribution indicates that the semistatic animation aids very well the user’s abilities to solve the memory task.

The chi-square hypothesis test further strengthens these initial beliefs with a resulting value of 19.828. At a 99% confidence interval the chi-square table has a value of 6.635 with 1 degree of freedom. The null-hypothesis is thus rejected with good margins. From this we can conclude that the semistatic animation for memory task solving is far better than the traditional animation. We believe that this is mainly due to better support of the cognitive memory limit earlier mentioned, however this is hard to investigate further without additional, more comprehensive evaluations.
In general, the results from the symbolic weather map animation data shows that the semistatic animation is suitable and supports well both memory tasks at one location and trend on one location. Complex tasks like trend over both space and time seem difficult for the user for both animation types. Further investigations with both more participants and on other similar complex tasks should be conducted in order to further elicit the reasons for the problems for these tasks. It is also necessary to develop other methods which could support this class of complex tasks and evaluate their performance.

4.2 TEMPERATURE MAP ANIMATION

The answer distribution for the temperature map animations regardless of task is illustrated in figure 5. The chart shows that the semistatic animation gets the majority of correct answers, while the traditional animations get a smaller amount of correct answers. However the traditional animation still receives a larger number of correct than wrong answers. The hypotheses are similar to the analysis of temperature map as with the symbolic weather map:

\[ H_0 \] Traditional temperature map animation performs better than the semistatic animation in general.

\[ H_1 \] Semistatic temperature map animation performs better than the traditional animation in general.

The chi-square hypothesis test resulted in a value of 6.647. From the chi-square table at a 99% confidence interval this rejects the null-hypothesis with the table value of 6.635 with 1 degree of freedom - although with very small margins. This motivates for deeper investigations and supports the task driven approach taken in this analysis.

Figure 5: Answer distributions for the temperature map animation: (a) Total distribution regardless of task. (b) Trend on one location. (c) Trend over space and time. (d) Memory task

4.2.1 TREND ON ONE LOCATION

The trend on one location was initially perceived as the easiest for the semistatic animation due to the line graph in the history view. As figure 5b shows, the traditional animation seems to perform better than the semistatic. The charts additionally show that the differences between the answers are marginal for both the semistatic and the traditional animations. This indicates that the differences in answers could have happened by chance. Two hypotheses were defined to investigate this statistically with the chi-square hypothesis test:

\[ H_0 \] Traditional temperature map animation performs better than the semistatic animation on the task; trend on one location.

\[ H_1 \] Semistatic temperature map animation performs better than the traditional animation on the task; trend on one location.

The chi-square test gave a value of 0.72. This accepts the null-hypothesis for as low as 90% confidence interval, which means the there are no significant differences between the answers for the semistatic and the traditional animations. Based on these results it is difficult to conclude with which is better of the two. However, the low performance of the semistatic animation indicates that the design needs rethinking in order to perform better.
4.2.2  Trend over Space and Time

Figure 5c shows the answer distribution relating to the task; trend over space and time. The percentage of correct answers for the semistatic animation clearly outnumber the wrong answers and thus it performs very well on this task. However, the traditional animation performs also fairly well with about 70% correct answers. The chi-square reveals that there is actually a significant difference in the answer distribution on a 99% confidence interval (table value: 6.635 with 1 degree of freedom), with a value of 9.771. The hypotheses remain the same as previously and thus, a conclusion that the semistatic animation is affecting the answers can be made.

However, as the traditional animation performs fairly well it may be discussed whether this is “good enough” or whether smaller changes to the traditional animation may lead to equal results. The integration of the temporal legend in the semistatic animation is believed to have the most effect for this task. Visualization for the “history view” is a line graph, which do indicate trend on one location, however it is not believed that this is supporting better perception of trend over space - thus the integrated temporal legend is concluded to have the better effect.

4.2.3  Memory Task

The final task which was evaluated was the memory task on one location. Figure 5d shows the answer distribution for this task. The semistatic animation has a majority of correct compared to wrong answers. As well, the traditional animation has a majority of wrong compared to correct answers. Initially this shows that the semistatic animation is performing better at memory tasks. This is supported by the chi-square test which yields a value of 7.756. This rejects the null hypothesis at a 99% confidence interval (table value: 6.635 with 1 degree of freedom). Thus, the distribution is most likely a result of the different visual stimuli that participants were subject to. Whether this result is due to leveraging the issue of split attention or that the line graph is aiding cognitive memory is difficult to conclude with without further investigations. It is, however likely that the positive results is affected strongly by the integrated temporal legend. The line graph is primarily supporting trends and not absolute numbers, but could potentially be a visual reminder of the previous or forthcoming temperatures.

In general the results from the temperature animation indicates that the semistatic approach, primarily implemented using a line graph, is performing better at certain tasks than the traditional animation. In particular the semistatic approach seems to be better at memory tasks as well as trend over space and time. Trend on one location is, on the other hand, not very well supported by the semistatic approach - although this could be reasonable to assume from the line graphs included specifically for this task. It may be the integration of the temporal legend that is affecting the participants the most. Thus further investigations on the semistatic concept, specifically for numeric data should consider this and evaluate the performance without an aggregated history view such as the line graph.

5  Conclusions and Further Work

This article has presented a new concept of animation aiming at bridging the gap between static and animated maps. The main goal is to include all information of the animation in every frame to allow the user to visually move back and forth in time without any additional efforts. This has been achieved in static multiple maps displays before and to some degree in diagram maps. However both are geared towards static representations. The semistatic concept integrates qualities from both of these but differentiates with the design and most importantly by applying the technique on animated maps.
An issue with this approach, which should be investigated in further work, is the visual space used by the extended symbols. With high density information and large data sets, overlapping of the symbols can become an issue and it is most certainly a limit to how much history the symbols can include. This issue is similarly found in other symbol mapping techniques, such as diagram maps. The experimental evaluation presented here compared against the animated counterpart. Further work should emphasize on evaluating the semistatic concept against the static counterparts where small multiple map displays and diagram maps are the most natural to foresee.

The integrated and animated temporal legend is of concern to the symbol design. Our hypothesis is that the element relieves the user of the need to split his attention between a traditional legend often positioned at the top or bottom of the animation and the symbols within the animation. Integrating the legend within every symbol inevitably leads to a large number of animated objects which may cause a visual disturbance for the user. The experiment presented here did not aim at investigating this. Further work using more sophisticated methods of evaluation and investigation is needed in order to elicit the effect the temporal legend has on the user. Especially interesting is to what extent the user is actually using the main temporal legend in the traditional animation and the main vs. the integrated temporal legend in the semistatic animation. We are currently in the process of analyzing eye-tracking data using the same experimental setup in order to investigate this issue as well as other properties of the semistatic concept.

A web experiment provides indications of the performance of the animations under evaluation. This research method does not provide us methods for investigating why the different animations perform as they do. Using eye-tracking as an experimental methodology can more easily provide us with insight to answer why the user is answering the tasks as he does. However, map animations as a stimulus in eye-tracking experiments have rarely been employed due to the difficulties of analyzing the data. We are currently trying to overcome this issue by applying space-time analysis methods on eye-tracking data in combination with animated maps.

The results from the web experiment indicate that the semistatic concept increase the performance of several of the tasks tested. This argues in favour of the concept and especially motivates for further work. The pictogram symbols proved to increase the performance of the symbolic weather maps tested in the experiment. Especially noticeable is that the performance for the tasks coincided with our initial beliefs. We believe the most important tasks for weather map animations are trend on one location and memory task - for these two tasks the semistatic approach increased performance tremendously. However, the semistatic concept is not intended to be applied only to weather map animations. Further work is needed to investigate other application domains where the semistatic concept may be suitable. The results documented here gives an indication that domains which already utilizes animations and where the user tasks is focused on either memory or trend on one location should be very suitable for adopting and implementing the semistatic concept.
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Non-colour figure

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Traditional

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