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The Role of Map Animation for Geographic Visualization

Mark Harrower, and Sara Fabrikant

Department of Geography, University of Wisconsin – Madison

Department of Geography, University of Zurich

4.1 Introduction

Many of today's significant research challenges, such as resource management and environmental monitoring, depend upon capturing, analysing and representing dynamic geographic processes. The ability to recognize and track changes in complex physical systems is essential to developing an understanding of how these systems work (Yattaw, 1999). For thousands of years cartographers have been perfecting the representation of dynamic spatio-temporal phenomena with static, spatial representations in the form of two-dimensional maps (Bertin, 1983). As early as the 1930s, cartographers also experimented with adding the time dimension to congruently representing dynamic geographic processes with animated map displays. Dynamic cartographic representations, such as cartographic movies (Tobler, 1970), two- and three-dimensional computer animations (Moellering, 1976, 1980), as well as interactive map animations and simulations, have become increasingly popular since personal computers with growing graphic-processing power have become cheaper, faster and more user-friendly (Peterson, 1995). Even though real-time three-dimensional landscape fly-throughs and interactive map animations of various spatial diffusion processes have become widespread with dissemination through the Internet, it still seems that the cartographic community has only been scratching the surface of dynamic displays (Campbell and Egbert, 1990; Fabrikant and Josselin, 2003) and there is the very real risk that mapping technology is outpacing cartographic theory. This chapter explores the role of animation in geographic visualization and outlines the challenges, both conceptual and technical, in the creation and use of animated maps today.

Geographic Visualization Edited by Martin Dodge, Mary McDerby and Martin Turner

Animation has it roots in the Latin word *animare*, in English, 'bring to life'. Animation is not to be confused with film or video movies. Animations are defined as sequences of static graphic depictions (frames), the graphic content of which, when shown in rapid succession (typically 24–30 frames per second), begins moving in a fluid motion. The use of animated maps spans the spectrum of disseminating spatial knowledge to a wide audience (e.g. animated weather map loops on television) to data exploration for knowledge discovery by experts (e.g. highly interactive exploratory spatial data analysis tools for scientists). Animated maps have become increasingly popular in recent years because they congruently represent the passage of time with changing graphic displays (or maps). With Google Earth or similar virtual-globe interfaces that can render rich, immersive three-dimensional maps in real-time, the dynamic change of one's point of view or geometric perspective on a three-dimensional landscape has become as easy as one mouse click. However, this technology goes beyond just virtually exploring the surface of the Earth: expert users of animated maps can now explore 'attribute space' using the same kind of techniques developed to explore 'geographic space', for example, when cycling through different themes of a geographic dataset, or by moving along a timeline that represents ordered data values of a certain variable of interest.

An example of this is Peterson's (1995, pp. 50–51) non-temporal animation[1] depicting the percentage of births to mothers under the age of 20 for the United States. The first frame in the animation is a two-class map and the last frame is a seven-class map. The legend is represented as a histogram with bars indicating the number of observations in each category.

Regardless of the map-use goal, unlike static maps that do not change, the individual frames of an animated map are on-screen briefly and there is little time to examine fine details (Monmonier, 1994; Harrower, 2003). In other words, there are obvious cognitive and perceptual limits that must be understood and used to inform map design. We believe that exceeding these limits – which is easy to do with today's massive and complex dataset coupled with powerful computer graphic cards – is likely to leave the user frustrated or unsure of what they have seen. Since our visual memory has limits (Marr, 1982) we will simply not see the finer details in the animation, and only the most general patterns and clusters will be noticed (Dorling, 1992). Basic map-reading tasks, such as comparing colours on a map with those on a legend, become significantly more difficult when the map is constantly changing and thus 'the compression of time as well as space in dynamic cartography poses new problems requiring the recasting, if not rethinking, or the principles of map generalization' (Monmonier, 1996, p. 96).

Their fleeting nature combined with the problem of split attention suggests, then, that the primary utility of animated maps is to not to emphasize specific rates for specific places, but rather to highlight the net effect of the frames when run rapidly in sequence and to gain an overall perspective of the data (Dorling, 1992). According to Ogao and Kraak (2002, p. 23), 'animations enable one to deal with real world processes as a whole rather than as instances of time. This ability, therefore, makes them intuitively effective in conveying dynamic environment phenomena'. Unlike static maps, animated maps seem especially suited to emphasizing the change between moments (Peterson, 1995) and static maps are often insufficient for the task of representing time because they do not directly represent – or foster hypotheses about – geographic behaviours or processes. Because animated maps can

[1] Examples of non-temporal map animations are available on the web at: http://maps.unomaha.edu/books/IACart/book.html#ANI

explicitly incorporate time they are (potentially) better suited to this task and cartographers have long-sought to exploit the potential of animated maps over the past 50 years (Campbell and Egbert, 1990; Harrower, 2004).

In the foreword to *Interactive and Animated Cartography*, Mark Monmonier extols: 'In rescuing both makers and users of maps from the straitjacket of ossified single-map solutions, interactive mapping promises a cartographic revolution as sweeping in its effects as the replacement of copyists by printers in the late fifteenth and early sixteenth centuries' (Peterson, 1995, p. ix). Although the 'promises' of this revolution have been at times slow to materialize, there is justifiable enthusiasm for animated and interactive mapping systems. Moreover, the concurrent and rapid maturation in the last 15 years of (i) animated mapping software, (ii) widespread and powerful computers, (iii) fast Internet connections and (iv) an explosion of rich temporal-spatio data – and tools for viewing those data – has allowed animated mapping to flourish (e.g. NASA World Wind, Google Earth). Unfortunately, academic theories and field-validated best practice have not kept pace with these technological changes, and as a research community we are still learning how to get the most out of our animated maps and, quite simply, know when or how to best use them. Animated maps do not replace static maps, nor are they are not intrinsically better or worse than static maps; they are simply different. Like any form of representation (words, images, numerical formulas), animated maps are better suited to some knowledge construction tasks than others. Understanding what those tasks are is one of the key research challenges for geovisualization (MacEachren and Kraak, 2001; Slocum *et al.*, 2001).

Research into the cognitive aspects of map animations would help to shed light on how users understand and process information from these dynamic representations. The construction of sound theoretical foundations for the effective representation of spatio-temporal phenomena and the adequate depiction of fundamental spatial concepts and relationships, including people's understanding thereof, is not new to GIScience and geovisualization, but due to wider usage of GIS tools outside of geography, it has gained new importance in the past few years.

Preliminary research has shown that animation can reveal subtle space–time patterns that are not evident in static representations, even to expert users who are highly familiar with the data (MacEachren *et al.*, 1998). A good example of the power of animated maps to stimulate new knowledge is provided by Dorling and Openshaw (1992). In their investigation of leukaemia rates in northern England, previously unrecognized hotspots (localized in both space and time) emerged from an animated map of these data. The cancer hotspot in a specific area lasted only a few years and had been missed in previous (i.e. static) analysis because the temporal component of the data had been collapsed, thus 'grossly diluting situations such as these by amalgamating years of low incidence with a pocket of activity' (Dorling and Openshaw, 1992, p. 647). The animation also revealed a second unexpected process, which they described as a 'peculiar oscillation' between leukemia cases in Manchester and Newcastle with an approximately five-year periodicity. Fresh insights such as these provide a useful starting point for more formal spatial analysis.

Wood (1992) chastises cartographers for trying to distil time out of the map and states that 'time remains the hidden dimension' in cartography.

> But the map *does* encode time, and *to the same degree* that it encodes space; and it invokes a temporal code that empowers it to signify in the temporal dimension (Wood, 1992, p. 126).

Timeless maps are problematic because they portray the world in an 'eternal present' and eliminate the concept of process. Langran (1992, p. 22) suggests that historically cartographers actively avoided dealing with time by mapping mostly static things with static maps 'thereby shifting the burden of dealing with the temporal phenomena to the map user'. Being constrained by static display technology (e.g. paper), the majority of Western maps traditionally have emphasized space over time and, thus, are more often used to represent states rather than processes. However, with the rise of geographic visualization (for experts) and highly interactive web maps (for the public), representing time has become routine in cartography. An active group of researchers have called for – and begun to develop – empirically validated theories and practices upon which to create a robust understanding of 'temporal cartography'.

4.2 Types of time

One of the primary reasons for making animated maps is to show spatial processes. As Dorling and Openshaw (1992, p. 643) note:

> It is self-evident that two-dimensional still images are a very good way (if not the only way) of showing two-dimensional still information. However, when the underlying patterns (and processes) start to change dynamically, these images rapidly begin to fail to show the changes taking place.

Time and change, however, are broad concepts and, just as there are different types of attribute data (e.g. categorical data, numerical data), there are different types of time. More importantly, much as there are different graphic 'rules' for different kinds of spatial data (e.g. sequential colour schemes match with numerical data series, qualitative colour schemes with categorical data), there is reason to believe that different types of time require different graphic approaches, although further work is needed in this area to elucidate what these might be.

One of the first geographers to move beyond simple linear concepts of time was Isard (1970), who characterized four types of time: universe time which is absolute and linear, cyclic time such as diurnal patterns, ordinal time which records the relative ordering of events, and time as distance in which the spatial dimension is used to represent time. Frank (1994) identifies three basic kinds of time: linear, cyclic and branching. Linear time depends upon the scale of measurement. Linear time measured at the ordinal scale is the sequence of events, whereas linear time measured numerically is duration. Duration can be continuous or discontinuous. Cyclic time expresses the idea of repetition or recurrence in the sequence of events that can occur in either a regular or irregular manner. Branching time is used to describe future possibilities. The further into the future one goes, the greater the number of possible temporal paths. In complementary work, Haggett (1990) describes four types of temporal change in geography: constants, trends, cycles and shifts. Constants (i.e. no change) and trends (i.e. linear change) are long-term changes. Cycles describe recurring patterns and shifts describe sudden changes (not necessarily recurring).

While there is no agreed upon list of the 'basic' kinds of geographic time, there are commonalities within these frameworks: Isard, Frank and Haggert all include the concepts of *linear time* and *cyclic time* in their respective typologies. These are perhaps the 'core' ideas of time in geography and, as we discuss below, are reflected in widespread use of both cyclic

and linear temporal legends (Edsall *et al.*, 1997; Esdall and Sidney, 2005) and ontologies of space–time (Hornsby and Egenhofer, 2000).

4.3 The nature of animated maps

In cartography, two basic animations types are known: temporal animation and non-temporal animation (Dransch, 1997). Temporal animation deals with the depiction of dynamic events in chronological order and depicts actual passage of time in the world. In a temporal animation, 'world time' (e.g. days, centuries) is typically proportionally scaled to 'animation time' (e.g. typically seconds). For example, a population growth animation based on decennial census data is mapped such that 10 years of world time represent a constant time unit in the animation (temporal scale). Examples of temporal animations are population growth, diffusion processes of diseases, commodities and the like, or wild fire spreads and glacier movements.

Non-temporal animations use animation time to show attribute changes of a dynamic phenomenon. The morphing technique is a good example of a non-temporal animation. For instance, animation time is utilized to show a phenomenon's transformation from an orthographic two-dimensional map depiction (e.g. 'god's eye' view) into a perspective three-dimensional view. Other very popular non-temporal animation examples are fly-bys or fly-throughs of three-dimensional terrain, where the viewer's perspective changes over time (e.g. animation of camera motion).

Figure 4.1 demonstrates the flexibility and variety of animated maps that can be found today. The photo-realistic fly-over map (upper left) takes viewers on a high-speed flight

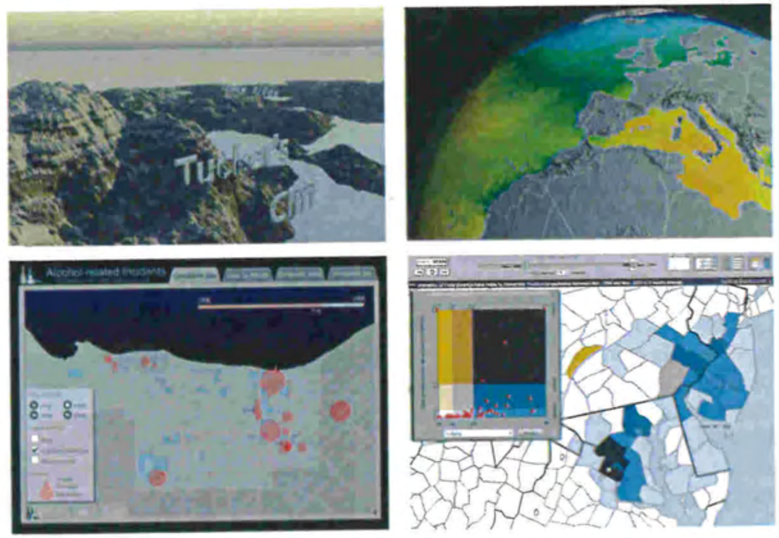


Figure 4.1 Four types of animated maps (clockwise from top left): 'Fly-over' animated map (Harrower and Sheesley, 2005), animation of sea surface temperatures (NASA/Goddard Space Flight Center Scientific Visualization Studio, 2006), Ballotbank.com (Heyman, 2007) and UW-Madison alcohol-related incidents (Liu and Qi, 2003)

over a fractal-generated landscape (which mimics natural forms), annotated with three-dimensional text placed directly on the landscape. Unlike static two-dimensional maps, few rules have been established in how to most effectively label three-dimensional immersive maps (Maass, Jobst and Döllner, 2007), including issues such as text size, placement, label density and text behaviour (e.g. should the three-dimensional text 'track' the user, always presenting an orthogonal face?). The MODIS sea surface temperature animation (upper right) highlights the importance of the Gulf Stream in the North Atlantic by using four years of high-resolution space–time data that captures subtle behaviours not easily seen in static snapshots. This animation demonstrates that a well-designed map can successfully present gigabytes of raw satellite data without overwhelming the reader, in part because individual data points (pixels) merge to form a coherent larger picture (i.e. distinct ocean currents, seasonality and overall north–south gradient). Ballotbank.com (lower right) can create animated bivariate choropleth maps that allow for both temporal and attribute focusing (both forms of information filtering) as well as on-the-fly temporal aggregation, allowing uses to adjust the 'temporal granularity' of the animation: often what one sees in an animation is a product of the ways in which the data are presented, especially the temporal and spatial resolution of the data, and the look of the animation can vary dramatically by changing either (Harrower, 2002). Thus, allowing the user to make these kinds of adjustments to the map themselves is both useful and ethical. The map of alcohol-related incidents (lower left) employs *temporal re-expression* controls, allowing users to animate through the data by composite hour of day, day of the week and month to see how patterns of drinking behaviour change as the basic unit of time changes.

4.3.1 Characteristics of animated maps

Animated maps, sometimes called movie maps or change maps, are primarily used to depict geographic change and processes. Static maps present all of their information simultaneously; animated maps present information over time. Thus, animated maps have an additional representational dimension that can be used to display information. Increasing the running time of an animation increases the total amount of data that can be represented, but at a cost to the user. As the length of the animation increases so too does the difficulty of remembering each frame of the animation. Put another way, although the amount of data that can be represented within an animation is virtually unlimited, there is a finite amount of information the user can distil from the animation and store in their short-term visual memory. As a result, animated maps are typically less than a minute in duration. They are more analogous to television commercials than feature-length films. One practical reason for this is the limitations of visual working memory (Sweller, 1988). Another reason is that animated maps are temporal abstractions. As condensed forms of knowledge, animated maps are intentionally scaled-down representations of the world.

Just as static maps have a spatial scale, temporal animated maps have a temporal scale. This can be expressed as the ratio between real-world time and movie time. For example, five years of data shown in a 10 s animation would have a temporal scale of 1:157 million. Although it is possible to build animated maps that vary their temporal scale as they play – to focus on important moments, or blur-out others – most animated maps keep a constant temporal scale. Additional aspects of the map include its temporal granularity/resolution

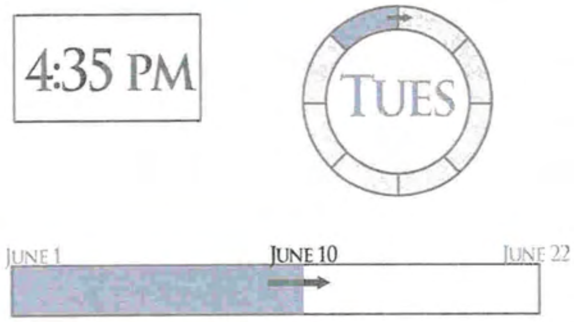


Figure 4.2 The three most common kinds of temporal legend – digital clock, cyclical and bar. The graphical cyclic and bar legend can communicate at a glance both the specific instance and the relation of that moment to the whole (source: M. Harrower)

(the finest temporal unit resolvable) and pace (the amount of change per unit time). Pace should not to be confused with frames-per-second (fps): an animation can have a high frame rate (30 fps) and display little or no change (slow pace). Perceptually, true animation occurs when the individual frames of the map/movie no longer are discernable as discrete images. This occurs above roughly 24 fps – the standard frame rate of celluloid film – although frames rates as low as five fps can generate a passable animation effect. Higher frame rates yield smoother looking animations, although modest computers will have trouble playing movies at high frame rates, especially if the map is a large raster file.

The passage of time or the temporal scale is typically visualized along side the map animation through a 'temporal legend'. Figure 4.2 shows three different kinds of temporal legend: digital clock, cyclical time wheel and linear bar. The advantage of graphical temporal legends, such as the time wheel and linear bar, is that they can communicate at a glance both the current moment (e.g. 4:35 p.m.) and the relation of that moment to the entire dataset (e.g. halfway through the animation). Because it is often assumed that these kinds of legends support different map-reading tasks, designers often include more than one on a single map. Cyclic legends, for example, can foster understanding of repeated cycles (e.g. diurnal or seasonal), while linear bars may emphasize overall change from beginning to end.

By making a temporal legend interactive, the reader can directly manipulate the playback direction and pace of the movie, or jump to a new moment in the animation (known as non-linear navigation). This has become a common interface action in digital music and video players and many map readers now expect to be able to directly interact with temporal legends to control the map. One unresolved problem with legend design is split attention: because animated maps, by their very nature, change constantly, the moment the reader must focus on the temporal legend they are no longer focusing on the map and may miss important cues or information. If they pause the animation to look at the legend, they lose the animation effect. The more the reader must shift their attention between the map and the legend, the greater the potential for disorientation or misunderstanding. Proposed but untested solutions to the problem of split attention include (1) audio temporal legends and (2) embedded temporal legends that are visually superimposed onto the map itself.

In their suggestions for improving animated maps, Johnson and Nelson (1998) suggested giving the subjects the freedom to have direct control over the animated sequence. Moreover, Andrienko, Andrienko and Gatalsky (2000) claim that the greatest understanding may be achieved when the animation is under user control and the geospatial data can be explored in a variety of ways.

Temporal tense is an issue explored by Wood (1992, p. 126): '[t]ense is the direction in which the map points, the direction of its reference in time'. Building on basic linguistic concepts of present, past and future, Wood demonstrates that *all* maps possess 'temporal codes'. These temporal codes allow us to construct a temporal topology for geographic data. Like its spatial counterpart, the concept of temporal topology allows the relationship between temporal entities to be understood and encoded. The development of temporal analytical capabilities in GIS such as temporal queries requires basic topological structures in both time and space (e.g. an object is both *to the left of* and *older than* another object; Peuquet, 1994).

4.4 Potential pitfalls of map animation

While there are some representational tasks for which animation seems especially well-suited (e.g. showing motion), equally there are some representational tasks for which animation is poorly suited. For example, animating changes in property ownership of a neighbourhood over the past 10 years is unwise because these changes are discrete events that can be conceptualized as happening without time. Although buying property is a complex human process, the actual cadastral change is applied at an instant of time (e.g. noon on 1 January 2007). Creating a linear temporal animation of this event might be ineffective (Goldsberry, 2004), and certainly would be boring since the animation would depict long periods of no change, punctuated by periods of instantaneous change that might easily be missed (*Nothing. Nothing. Nothing. Something. Nothing.*). Put another way, important changes often occur over very short time intervals, and thus a static map with ownership names and dates, or even a simple data table, is likely to be a better choice for the tasking of retrieving dates.

Choropleth maps are seldom created with more than 10 data classes, seven data classes being the often-cited upper limit for good map design (Slocum *et al.*, 2005). These limits derive from psychological studies performed a half century ago (Miller, 1956) that revealed that most individuals can process seven (plus or minus 2) 'chunks' of information at once. Probably class limits are even lower for animated maps considering the increased human memory load required to remember earlier map frames when looking at later ones in the animation sequence (Goldsberry, Fabrikant and Kyriakidis, 2004; Harrower, 2003). Does this mean that animated maps should contain no more than seven frames? Clearly not, as people are capable of working with and understanding animations composed of thousands of individual frames, but the question remains: what are the cognitive limits to the complexity of animated maps? In other words, at what point do animated maps become too data-rich for the user? What forms the basic mental chunks of an animated map? How can the size of these chunks be increased? Although answers to these questions are few, we suspect it is driven in part by the length of the animation (i.e. running time), the complexity of the spatial patterns depicted (i.e. spatial heterogeneity) and the complexity of the patterns of change (i.e. temporal heterogeneity).

4.4.1 Cognitively adequate animation design

We still know very little about how effective novel interactive graphical data depictions and geovisualization tools are for knowledge discovery, learning and sense-making of dynamic, multidimensional processes. Cognitive scientists have attempted to tackle the fundamental research question of how externalised visual representations (e.g. statistical graphs, organizational charts, maps, animations etc.) interact with people's internal visualization capabilities (Tversky, 1981; Hegarty, 1992). Experimental research in psychology suggests that static graphics can facilitate comprehension, learning, memorization, communication of complex phenomena and inference from the depiction of dynamic processes (Hegarty, 1992; Hegarty, Kriz and Cate, 2003). However, in a series of publications surveying the cognitive literature on research on animated graphics (that did not include map animations), Tversky and colleagues claim they failed to find benefits to animation for conveying complex processes (Bétrancourt, Morrison and Tversky, 2000; Bétrancourt and Tversky, 2000; Morrison, Tversky and Betrancourt, 2000; Tversky, Morrison and Bétrancourt, 2002). In the cartographic literature, results on animation experiments are not conclusive in part because they depend on how 'success' is measured. For example, in think-aloud experiments comparing passive, interactive and inference-based animations for knowledge discovery (e.g. differing in their interactivity levels), Ogao (2002) found that animations did play a crucial role in facilitating the visualization of geospatial data. Different animation types are used at specific levels of the exploratory process, with passive animation being useful at earlier observatory stages of the exploration process, and inference-based animation playing a crucial role at later stages of discovery, such as in the interpretation and explanation of the phenomenon under study. Similarly, participants in a study by Slocum *et al.* (2004) suggested in a qualitative assessment that map animations and small multiples are best used for different tasks, the former being more useful for inspecting the overall trend in a time series dataset, the latter for comparisons of various stages at different time steps.

In studies reviewed by Tversky and colleagues, typical 'success' measures are either response time, also known as *completion time* (a measure of efficiency) or *accuracy of response* (a measure of quality). In some experiments comparing map animations with static small multiple displays participants answer more quickly, but not more accurately, with animations (Koussoulakou and Kraak, 1992); in other experiments they take longer, and answer fewer questions more accurately (Cutler, 1998), or the time it takes to answer the question does not matter for accuracy at all (Griffin *et al.*, 2006).

There is a fundamental problem with these kinds of comparative studies. To precisely identify differences in the measures of interest, the designs of the animation and the small multiples to be compared require tight experimental control to the extent that it might make a comparison meaningless. Animations are inherently different from small multiples. Making an animation equivalent in information content to a small multiple display to achieve good experimental control may actually mean degrading its potential power. Animations are not simply a sequence of small multiples. Good animations are specifically designed to achieve more than just the sum of their display pieces.

As mentioned earlier, there are many design issues to consider for the construction of potentially useful map animations. Dynamic geographic phenomena may not only change in position or behaviour over time, but also in their visual properties (e.g. attributes). Moreover, the observer or camera location may change in position, distance and angle in relationship to the observed event. Lighting conditions that illuminate the scene and dynamic events may also change over time (e.g. light type, position, distance, angles, colour attributes). The speed with which an animation is viewed is crucial (Griffin *et al.*, 2006) and whether the viewing order of the frames in an animation is predefined (i.e. without any interaction mechanisms) (Hegarty, Kriz and Cate, 2003). The effectiveness of a small multiple displays on the other hand depends mostly on the appropriate number and choice of the small multiples, that is, how many and which of the key events (macro steps) are selected to discretely represent the continuous, dynamic process. Well-designed small multiple displays depict the most thematically relevant (pre-selected) key events, and unlike non-interactive animations allow viewers to inspect the display in their own pace and viewing order.

Figure 4.3 shows a test participant's eye movement patterns overlaid on an identical small multiple map display, but during two different data exploration tasks. The graduated circles show eye fixation durations (the larger the circle, the longer the fixation) and the connecting lines represent rapid eye movements between fixations, called *saccades*. In Figure 4.3(a) the task is to gain an overall impression of the small multiple display, and to verbally describe the patterns that are discovered during its visual exploration. When animating the gaze tracks, one can see that the viewer is not exploring the display in the implied sequence of the small multiple arrangement, but going back and forth between the maps several times or jumping between different rows of maps.

In Figure 4.3(b) the task was to specifically compare two maps within the display. The significantly different viewing behaviour from Figure 4.3(a) suggests that small multiple displays will never be informationally equivalent to non-interactive animations as Tversky, Morrison and Bétrancourt (2002) are implying. When map use contexts require a user to compare items in a time-series (across time, space or attribute) the non-interactive animations (locking a viewer into a pre-defined sequence) will always add cognitive load, as the viewer will have to wait and remember the relevant information until the respective comparative displays comes into view (see Figure 4.4).

The small multiple map display on the other hand allows the user to freely interact with the data in the viewing sequence they deem necessary for the task. In other words, the experimental data (Figure 4.3) suggests that non-interactive animations should be made interactive to be informationally equivalent to small multiple map displays.

Two animation types depicted in Figure 4.4 dynamically depict the same information shown in the static small multiple map display (see Figure 4.3). Figure 4.4(a) represents a frame of a non-interactive animation, only containing a start button, while the interactive animation depicted in Figure 4.4(b) allows a viewer to start and stop the animation at any time and change its display speed and movement direction.

The great power of carefully designed animations, however, are their ability to display micro steps in complex systems that might be missed in small multiple displays (Slocum *et al.*, 2001; Jones *et al.*, 2004). The apprehension of micro steps is directly related to the perception of apparent motion problem. As Griffin *et al.* (2006) note, this is still an unsolved issue in animation research. The perception of apparent motion (i.e. being able to visually interpolate fluid motion from discrete jumps in position between images) depends on (1) the relationship between the duration of a frame in the animation being displayed, (2) the frame rate in the animation (how many frames are displayed per unit time) and (3) the distance of an object moving across the screen. Rensink, O'Regan and Clark (1997) have demonstrated that observers have great difficulty noticing even large changes between two successive scenes in an animation when blank images are shown in between scenes (e.g. simulating a flicker). This *change-blindness* effect operates even when viewers know that

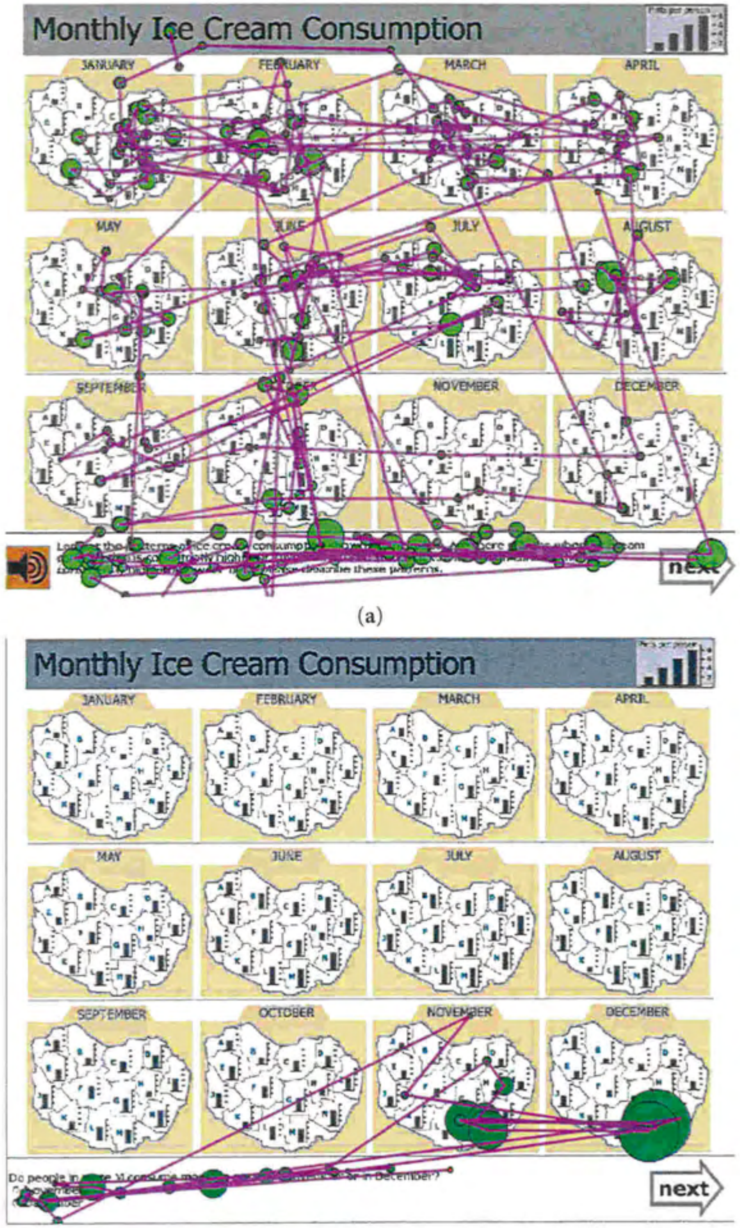
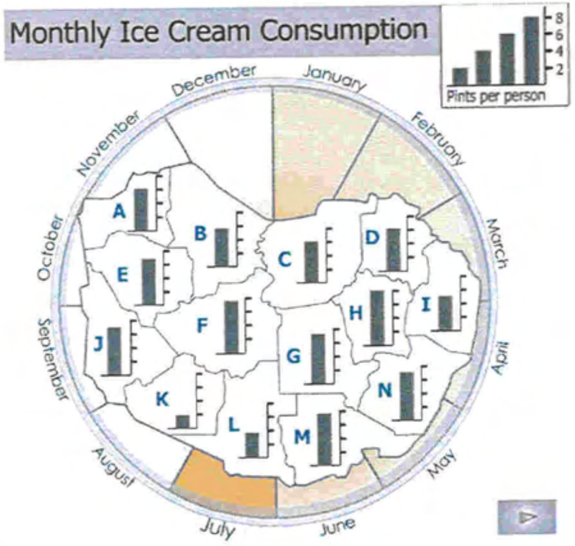
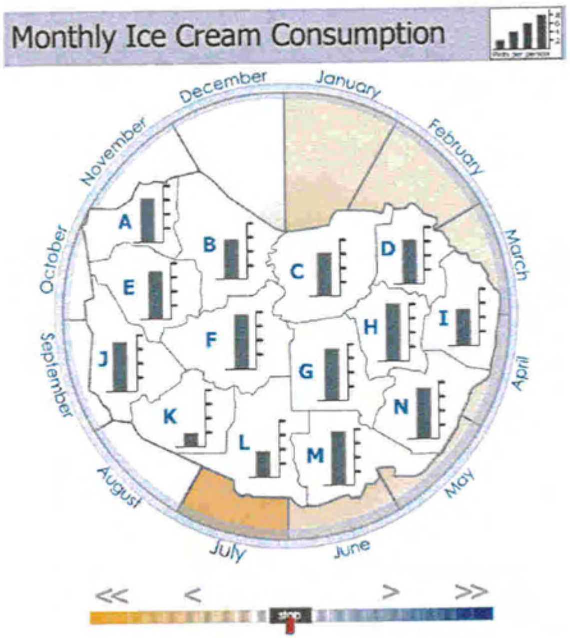


Figure 4.3 Task-dependent viewing behaviour of two identical small multiple map display stimuli (source: S. I. Fabrikant)



(a)



(b)

Figure 4.4 Frames from a non-interactive (a) and (b) interactive animation (source: S. I. Fabrikant)

they will occur. Rensink (2002) suggests that only about four to five items can be attended to at any moment in time in animated scenes. Visual transitions in dynamic scenes can be controlled through dynamic design variables, as for example proposed by Lasseter (1987) and DiBiase *et al.* (1992), and these variables could potentially mitigate the change blindness effect. These key design issues need to be carefully considered such that thematically relevant items are made perceptually salient in the animation (Fabrikant and Goldsberry, 2005).

Animation sceptics like to cite Lowe's (1999, 2003, 2004b) experiments on complex interactive weather map animations as examples of animation failures. Lowe (1999) found that participants tended to extract information based on perceptual salience rather than thematic relevance. He additionally suggests potential reasons why animation failed, such as the participant's lack of relevant domain expertise, the complexity of the depicted system and more importantly the manner in which the system was depicted. This begs the question of whether better graphic design principles for animation may make relevant thematic information more perceptually salient, and thus overcome the suggested drawbacks of animation? The level of user manipulation or human–display interaction is one such element of display design.

However, Lowe (2004a) suggests that simply providing user control (e.g. interaction capabilities) to an animation does not always result in the desired learning improvements. He found that participants neglected the animations' dynamic aspects, perhaps because of available user controls. Most of the time participants either stopped the animation and investigated still frames, or the animation was being viewed in a stepwise fashion, one frame at a time. This raises additional research questions such as what kinds of interaction controls are needed for dynamic map displays, and how these controls should be designed such that they are more efficiently used.

4.5 Conclusions

As mentioned earlier, we do not believe it to be a question of whether animations are superior to static maps or not, but as geovisualization designers we are rather interested in finding out how animations work, identifying when they are successful, and why (Fabrikant, 2005). Although Tversky and collaborators emphasize that sound graphic principles must be employed to construct successful static graphics, they do not elaborate which ones. The same authors further suggest that research on static graphics has shown that only carefully designed and appropriate graphics prove to be beneficial for conveying complex phenomena, but they do not offer specific design guidelines. As geovisualization designers we assert that design issues must be carefully considered not only for static graphics, but also especially for dynamic graphics, considering that animated graphics add an additional information dimension (e.g. that of time or change). Ad-hoc design decisions of graphic test stimuli, due to lack in graphic design training, may be an additional reason why animations might have failed in past research. Research in cartography suggests that traditional graphic design principles may only partially transfer into the dynamic realm, and therefore design for animation needs special attention (Harrower, 2003). To systematically evaluate the effectiveness of interactive and dynamic geographic visualization displays for knowledge discovery, learning and knowledge construction, Fabrikant (2005) proposes a research agenda and sketches a series of empirical experiments aimed at developing cognitively adequate dynamic map displays (see sample test stimuli shown in Figures 4.3 and 4.4). The proposed empirical studies adhere to experimental design standards in cognitive science, but are additionally grounded on a solid dynamic design framework borrowed from cartography, computer graphics and cinematography. The goal is to investigate how dynamic visual variables (DiBiase *et al.*, 1992) and levels of interactivity affect people's knowledge construction processes from dynamic displays as compared with static displays.

In order to realize the full potential of animated maps within GIScience – and more broadly, within society – we need to better understand for what kinds of representational tasks they are well suited (and just as importantly not well suited) and how variations in the design of animated maps impact our ability to communicate and learn. By doing so we will broaden the cartographic toolkit available to GIScientists.

In a broader context, better understanding of the human cognitive processes involved in making inferences and extracting knowledge from highly interactive graphic displays is fundamental for facilitating sense-making of multidimensional dynamic geographic phenomena. Better understanding will lead to greater efficiency in the complex decision-making required to solve pressing environmental problems and societal needs.

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