Issues of Change Detection in Animated Choropleth Maps

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Abstract

One primary utility of animated maps is their ability to depict change over time and space; unfortunately, recent research suggests that humans frequently fail to perceive changes within dynamic graphics. However, different types of dynamic graphics include different manifestations of change. For example, an animated proportional-symbol map possesses different change properties than an animated choropleth map. This article examines issues of change on animated choropleth maps. We identify relevant limitations of the human visual system that pertain to animated map reading, including change blindness and foveal versus peripheral attention, and introduce methods to quantify the magnitude of change that separates individual scenes within choropleth animations. These methods are useful for measuring and describing changes that confront users of animated choropleth maps. We also characterize the transitional behaviours of enumeration units and discuss the influences of data classification and other cartographic controls on change within animated choropleth maps.

Keywords: animation, choropleth maps, magnitude of change, change blindness, perception, cognition, change characterization

Résumé

Une des principales utilités des cartes animées est qu'elles permettent de suivre les changements en fonction du temps et de l'espace. Malheureusement, selon de récentes recherches, il arrive souvent que les humains ne perçoivent pas ces changements dans les graphiques dynamiques. De plus, chaque type de graphique dynamique inclut des manifestations différentes de l'évolution. Par exemple, les propriétés d'une carte animée avec symboles proportionnels sont différentes de celles d'une carte choroplèthe animée. Dans l'article, on examine les problèmes liés au changement dans les cartes choroplèthes animées. On définit les limitations pertinentes des systèmes visuels humains qui sont associées à la lecture de cartes animées, y compris la cécité au changement et l'attention fovéale/périphérique, et on présente des méthodes pour quantifier la magnitude du changement qui sépare des scènes individuelles dans des animations choroplèthes. Ces méthodes sont utiles pour mesurer et décrire les changements auxquels se heurtent les utilisateurs de cartes choroplèthes animées. On caractérise aussi les comportements transitionnels des unités de dénombrement et on parle des effets de la classification des données et d'autres mesures cartographiques sur les changements apportés aux cartes choroplèthes animées.

Mots clés : animation, cartes choroplèthes, magnitude du changement, cécité au changement, perception, cognition, caractérisation du changement

1. Introduction

Animation enables cartographers to produce maps that communicate changes in space, time, and attribute simultaneously. Although conventional cartography has focused mostly on static map production, recent technological developments have enabled cartographers to extend map-making into a more interactive and dynamic enterprise. Unfortunately, it seems that cartographic animation's potential has not yet been fully realized. In fact, many recent studies have uncovered fascinating issues that may limit the functionality of animated maps. Many of these issues have more to do with the limitations of human perception than with our technological capabilities: ''When it comes to animated maps, the bottleneck is no longer the hardware, the software, or the data – it is the limited visual and cognitive processing capabilities of the map reader'' (Harrower 2007, 349). With this in mind, it is imperative that we investigate how different types of animated maps operate and how they challenge the visual and cognitive processing capabilities of map readers.

According to the congruence principle of graphics, a well-designed animation should enable us to visualize dynamic geographic processes more effectively (Tversky, Bauer Morrison, and Betrancourt 2002). However, research in cartography (MacEachren 1995) and psychology (Morrison, Betrancourt, and Tversky 2000) has revealed that human beings have difficulty understanding animations. This difficulty is partly due to the fleeting nature of dynamic displays: as a dynamic display changes over time, display elements may appear, disappear, move, or morph in various ways. Animations are thus more challenging to read than static displays and require readers to complete additional visual tasks. With respect to thematic map animations, we believe that changes are manifested differently depending on the type of thematic map being animated. Different thematic maps rely on different visual variables; when they are animated, therefore, they signify change in different ways. For example, readers of animated proportional symbol maps must notice, attend to, comprehend, and recall changes in the size of symbols; readers of animated choropleth maps are faced with multiple enumeration units that may shift in visual variables including hue, value, saturation, and spacing (see Figure 1). Before we can make effective animated thematic maps, we need to better understand how these maps behave, how their transition behaviours signify change, and the cognitive processes that hinder or help in the perception of animated maps.

As a step in that direction, this article focuses on the transitional behaviours of animated choropleth maps. We focus on choropleth mapping because it is ''arguably the most commonly used method of thematic mapping'' (Slocum and others 2008, 251) and, consequently, animated choropleth maps are increasingly prevalent in our culture. We characterize change on animated choropleth maps by identifying the elements of choroplethic change and by presenting methods to quantify the magnitude of change between adjacent scenes in a choropleth map animation. By definition, a choropleth map – from the Greek *choros* (place) and *plethos* (magnitude) – is a thematic map in which enumeration units are shaded or patterned in proportion to a statistical variable. The primary objective is to symbolize the magnitudes of the statistics as they occur within the boundaries of the unit areas (Robinson, Sale, and Morrison 1978). Since many geographic measurements are aggregated to enumeration units such as counties, states, or other political areas, choropleth mapping is very popular. To construct a choropleth map, data for enumeration units are typically grouped into classes, and a tone, hue, or pattern is assigned to each class

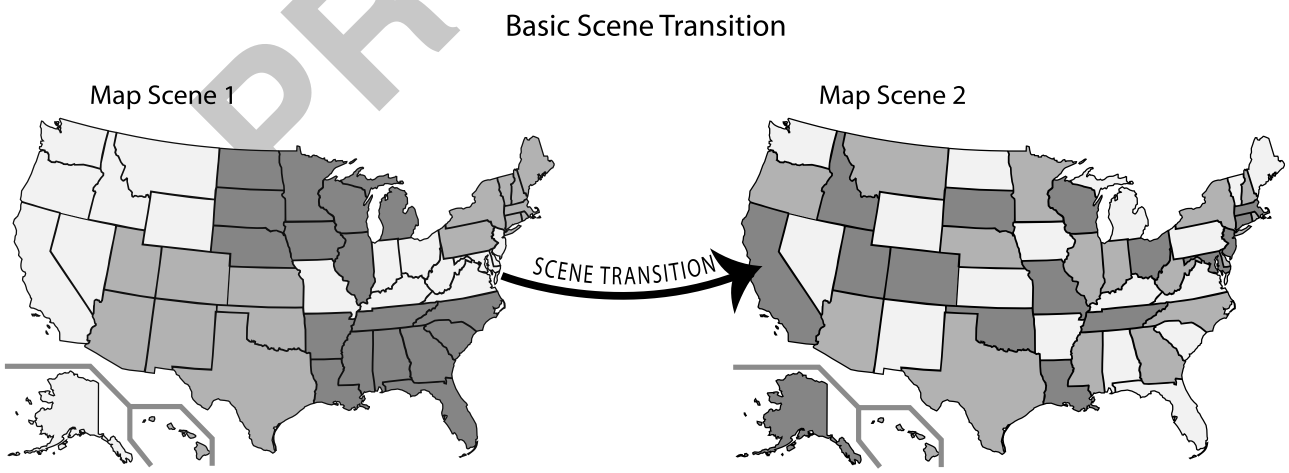

Figure 1. Animated choropleth maps include transitions characterized by shifts in the fill appearances of individual enumeration units. These transitions signify change in the mapped variable.

(Slocum and others 2008). Animated choropleth maps are dynamic thematic maps in which static choropleth map frames are sequentially arranged in order to depict multiple samples of geographic information. Commonly, animated choropleth maps depict time-series data, and the sequencing of map frames is intended to mimic the passage of time. As a result, animated choropleth displays are characterized by shifts in tones, hues, or patterns over both space and time.

In this article we examine transition behaviours of animated choropleth maps, focusing on one particular reason that animated choropleth maps are difficult to read: change blindness. Because change blindness is specific to detecting (or not detecting) changes in an animation, it is directly related to the cartographic variable *magnitude of change* (MOC). In the cartographic context MOC was first defined as the amount of change in position and attributes of entities between scenes (DiBiase and others 1992). To date, however, we have seen no conclusive discussion of the link between cartographic MOC and change blindness. This lack is due in part to differences in the goals of visual perception and animated cartography research, but it is also due to the absence of methods to quantify MOC in animated maps.

Because of the limitations of human perception, people can comprehend only so much change at any given time. Therefore, one critical component in investigations of change perception is a metric designed to quantify the magnitude of the graphical change that confronts an observer. Such expressions of graphical differences are useful to help identify empirically the thresholds or points at which observers' processing abilities become overwhelmed. These metrics have been used in non-cartographic investigations to demonstrate effectively that performance does indeed depend on the magnitude of the change (Williams and Simons 2000). However, since thematic maps are unique visual stimuli, signifying geographic meaning via various cartographic techniques, it is important that we explore the specific transitional natures of animated thematic maps. To address these cartographic issues, we introduce expressions capable of quantifying the amount of change between adjacent scenes in choropleth map animations. Our rationale is that the magnitude of changes during animation transitions is a key element in the perception of animated choropleth maps.

This article addresses perceptual issues related to animated cartography. We begin with a review and assessment of the role of change blindness in the general visual perception literature and its applicability to the field of animated cartography. Drawing on this review and assessment, we then propose several methods for quantifying magnitude of change in animated maps – a necessary step in comparing the transitional complexity of multiple animations. We conclude by identifying research challenges in visual change detection with animated choropleth maps, with particular attention to the effect of magnitude of change on inducing change blindness.

2. Visual Perception and Animated Choropleth Maps

This section ties together research in visual perception and animation in a discussion of challenges to reading animated choropleth maps. We review the existing, though relatively limited, research in animated cartography and the more abundant literature on visual perception to examine why and how change blindness and simultaneous change events cause difficulties and to explore techniques for limiting these difficulties.

2.1 THE NATURE OF DYNAMIC VISUAL DISPLAYS

Previous cartographic research has addressed difficulties with animated maps (MacEachren 1995; Harrower 2003; Fabrikant and others 2008), some have even warned about the potential for change blindness; Alan MacEachren (1995) asserts that because of the perceptual power of animation, we should expect a decrease in map readers' ability to notice differences in non-dynamic visual variables on animated maps. Unfortunately, map animations rely on change signals created by transitions in non-dynamic visual variables. For example, animated choropleth maps represent change in an enumeration unit via a shift in colour hue or lightness; an animated proportional symbol map relies on changes in size to imply changes in attribute. Transitions in non-dynamic visual variables are critical signals in thematic map animations, but observers may fail to receive them; observers attending to one portion of a map display are likely to miss simultaneous changes occurring elsewhere.

Imagine a hypothetical animated (time-series) choropleth map of population density in the United States. A user attending to the western portions of the map may perceive changes in that vicinity but be unable to notice simultaneous changes occurring in the north-east portion because of the viewing distance between locations. Challenges of disappearance and split attention make it difficult to perceive multiple changes simultaneously (Morrison and others 2000; Tversky and others 2002). In fact, several researchers have demonstrated that conscious perception requires attention (see Simons and Chabris 1999 for a review of this literature), and it is more difficult to attend to multiple locations. Cartographic researchers argue that good design can help confront the perceptual challenges of dynamic maps (Fabrikant and Goldsberry 2005; Fabrikant and others 2008; Harrower 2003), but at this point our knowledge of whether and how design variables can help alleviate problems such as change blindness is limited.

2.1.1 Why We Animate

The primary utility of animated maps is their ability to depict change over time and space (Harrower 2007). Many geographic processes are temporally continuous, and animation allows cartographers to create displays that mimic this dynamic process. Map animation is especially adept at depicting geographic time-series data such as hurricane data or population changes (Tobler 1970), whereas static depictions of time-series data are limited to ''snapshot'' strategies such as small multiples, which rely on a sequence of individual non-dynamic graphics to convey the passage of time.

As a map-making technique, computer animation is relatively new. Unlike other established cartographic techniques, cartographic animation is, for the most part, untested and misunderstood, and its potential is debatable. In general, animation has its share of critics; as technologies enable advancements in cartographic techniques, it is not unusual for the new techniques to be met with doubt and scepticism – as have many other cartographic innovations. For example, in the past there have been debates over the use of colour and of digital media. Clearly, in these cases, the doubts and scepticism instigated important research – for instance, Cynthia Brewer's extensive work with colour (1992, 1996, 1997) – that benefited the discipline. In the context of animation, some recent publications have expressed doubts about animations (Tversky and others 2002) while others have argued that more research is necessary (Fabrikant and others 2008). In either case, it is obvious that there remain many unanswered questions about how animation can become a more effective map-making technique.

2.1.2 Effectiveness of Animations

Recent research questions the overall effectiveness of animation for knowledge construction. Barbara Tversky and others (2002), in their review of the findings of several noteworthy animation experiments, insist that successful animations must adhere to both the congruence principle and the apprehension principle. These authors conclude that the benefits of animation are hard to find, if they exist at all. They endorse the use of cleverly schematized static diagrams instead of animation; curiously, they note that ''interactivity may be the key to overcoming the drawbacks of animation'' (Tversky and others 2002, 258). Previous cartographic research has already noted that users become frustrated with cartographic movies that they cannot control (Harrower 2003); an evaluation of animation versus traditional paper graphics that allows users to interact with the static graphics but not with the animated graphics might introduce a significant bias in favour of the former.

2.2 VISUAL PERCEPTION AND CHANGE BLINDNESS

Interpretation of animated choropleth maps involves assessing patterns over time; it requires the ability to notice that changes have taken place, where those changes are located, and how much change has happened (i.e., how much the new value differs from the previous value). Unfortunately, successful assessment of change is made more difficult by issues with change blindness, or the inability to recognize even substantial changes in a visual scene. References to this problem have begun to appear in the cartographic literature (e.g., Fabrikant and others 2008; Harrower 2007); however, the focus has been on only a few aspects of change blindness, such as the flicker paradigm. This section reviews several other relevant issues and discusses their impact on interpretation of animated choropleth maps. While the existing literature provides relevant background and context for examining the general perception of dynamic displays, most of the studies were clearly not conducted within the cartographic domain and can only provide suggestions regarding perceptual problems specific to animated choropleth maps. Throughout the review we will return to this issue, and we will identify several areas in need of cartography-specific research.

2.2.1 Change Blindness

Change blindness is a phenomenon whereby individuals fail to notice change that occurs in a visual stimulus (Simons and Rensink 2005). In an animated choropleth map, this means that a map reader would miss changes in the value or class of some enumeration units across time steps in an animated choropleth map or changes to other non-mapped elements on the map (e.g., a temporal legend). While most people believe that they are able to detect any substantial change that occurs in their visual field, this is not always the case (Levin and others 2000). According to numerous studies in the visual perception literature, missed changes may be minor or substantial; one-time or repeated; and expected or unanticipated (for a review see Rensink, O'Regan, and Clark 1997).

Change blindness can be induced in many ways – for instance, if change occurs during a saccade, or shift of eye gaze (Grimes 1996); if a brief blank or flicker – as short as 67 milliseconds – is introduced between images (Pashler 1988); if the image is too complex (Pylyshyn and Storm 1988); or if the change does not draw sufficient attention from the viewer for some other reason (Rensink and others 1997; Simons, Franconeri, and Reimer 2000). This plethora of causes for change blindness is discouraging when we consider that

- animated map readers *need* to shift eye gaze to examine the map;
- transitions between frames in the animation often introduce some amount of flicker;

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- the enumeration units used on the animation may be small or complex; and
- many dynamic map displays are created for exploratory analysis, which makes it difficult or impossible to direct attention to important changes.

Given there are so many causes of change blindness, that substantial changes can be missed, and that many causes of change blindness are related to natural eye movements, how is it that we notice any change in animations at all? The difference is *focused attention*. Without focused attention, changes to the visual stimulus overwrite the individual's memory of the stimulus pattern (Rensink and others 1997); if the change signal is too weak, the change will be missed. Attention requires a motion or change signal that is unique and strong enough to overcome any background noise in an animation (Klein, Kingstone, and Pontefract 1992). In a choropleth map, this means that a change in class for any specific enumeration unit must be substantial enough that the map reader can tell the difference between the classes *and* that the change must be more perceptually salient than other changes in the map's background information (e.g., objects that appear and disappear because of lack of data, dates changing in a temporal legend). Since the objectives of geovisualization include drawing attention to information relevant for decision making and clarifying patterns that would otherwise not be noticed (Swienty and others 2008), understanding change cues and how attention is drawn to areas of change on an animated choropleth map is of particular importance.

2.2.2 Foveal vs. Peripheral Attention

To be detected, change must occur somewhere within our visual field, either in our central visual field (foveal vision field, roughly a 2° field) or within the surrounding peripheral vision field. While it is possible to attend to changes in both foveal and peripheral vision, changes in peripheral vision require a stronger change signal; Nagy, Sanchez, and Hughes (1990) have suggested that changes occurring in peripheral vision may need to be bolder (e.g., greater hue or lightness difference) or occur over a larger area than those occurring in foveal vision if they are to present a signal equivalent to those of changes occurring in foveal vision. Typically our foveal area is much smaller than the screen space allotted for an animated map, so we rely on both foveal *and* peripheral vision to assess the overall patterns of an animation. This raises the interesting question of how we can signal change effectively so that the patterns of the map become apparent to the reader, or how we can otherwise direct a map reader's attention. To draw attention to relevant change patterns in animated maps, Mark Harrower (2003) has suggested several techniques that would help moderate change blindness due to flicker: giving greater control to the map reader through the use of looping, permitting frame-by-frame control or adjustment to the speed of the animation, and using "attention-grabbing" techniques such as voice-overs, sound prompts, or dynamic map symbols. While these techniques are effective for traditional animations, it is not clear whether they also aid in problems of data exploration, in which animation is a vehicle for discovering spatial relationships that are not already known.

2.2.3 Smooth vs. Abrupt Changes between Scenes

Discussions of animated choropleth maps and change blindness in cartographic research most often relate to the *flicker paradigm* (e.g., Fabrikant and others 2008; Harrower 2007), wherein the change signal can be blocked by the brief appearance of a blank screen, or flicker, between scenes. To avoid this problem, it has been suggested that we consider smooth transitions (or "tweens") between display frames (e.g., Fabrikant and others 2008) to draw attention to the change. To date, there is no concrete evidence that smooth transitions relieve the problems associated with flicker or abrupt changes between scenes in a map animation. In fact, Simons and others (2000) suggest that smooth transitions may hinder the detection of change signals. In their study, many participants viewing a 12-second animation failed to detect signals for colour change or for addition or deletion of objects unless the area in question was being directly attended to. Though 12 seconds is longer than the typical transition between scenes in an animated map, this finding still raises concerns about the rate and magnitude of change necessary to present a signal strong enough to draw attention; is there a threshold for successful detection of change in animated choropleth maps?

Since map displays are typically more complex than the stimuli used in the studies mentioned above, we must also consider the relationship between the strength of the signal and the background noise provided by surrounding enumeration units. Hans-Christoph Nothdurft (2006) suggests that target salience affects the ability to search for and identify change; bright targets surrounded by dim features are more salient than dim targets surrounded by bright features. Separating signal from noise in cartographic animations is difficult, because we cannot simply delete data from patterns that the cartographer deems irrelevant (e.g., by removing all data from a particular region because "there isn't anything interesting happening there"). As the complexity or noise of a map display increases – for instance, using smaller, but more, enumeration units or patterns that are more "random" in appearance – we would expect the relative saliency of any individual location to decrease as the location blends into the noise of the background.

2.2.4 Visual Variables for Choropleth Maps

In addition to issues of foveation, transitions between scenes in an animation, and signal-to-noise ratios, we must also consider the role of visual variable selection in change blindness. Animated choropleth maps rely primarily on hue, saturation, and lightness as visual variables. Whether or not colour changes draw sufficient attention is debatable. Some studies have found that equiluminant colour changes can draw attention (e.g., Lambert, Wells, and Kean 2003; Lu and Zhou 2005), while others have shown just the opposite (e.g., Theeuwes 1995). Findings with respect to lightness and saturation are equally unclear in terms of both their ability to draw attention and the conditions that are necessary for this to occur. Though Lambert and others (2003) found that peripheral luminance cues can draw attention, their studies were conducted in a controlled environment in which single visual cues appearing against a solid background, which is not reflective of the often noisy background of a choropleth map.

2.2.5 Attending to Multiple Locations

Working memory is considered to have a limited capacity for storing information. The original model for working memory capacity is George Miller's (1956) ''magical number seven, plus or minus two'' chunks of information. When change is occurring in various locations, no more than four or five locations can be attended to at a time (Pylyshyn and Storm 1988); yet many animated choropleth maps show change in more than five enumeration units at a time. Studies of map-reading ability with animated maps often restrict the number of regions that participants must attend to, and often these regions are pre-defined for participant so that they know where to focus their attention (e.g., Harrower 2007). However, cartographic animations are not always used to examine smaller trends within the greater map; individuals may be interested in examining the larger trends on the whole map. Since insufficient change signals often induce change blindness, studies that cue participants to change locations, or that provide specific task demands to guide a reader's scanning of the map, may give a false impression that change blindness is less prevalent for certain types of animated maps.

2.3 Dynamic Visual Variables and Magnitude of Change

David DiBiase and others (1992) have attempted to extend Jacques Bertin's (1983) set of visual variables into the dynamic domain to help us design effective animated maps. Bertin's visual variables have proved to be an immensely valuable contribution to cartography, so an effective extension of these variables could serve as a breakthrough for dynamic map design. In addition, DiBiase and others propose three dynamic variables: *duration*, *rate of change*, and *order*. Each of these variables treats display time as a controllable dimension of the map. ''In the same way that many different forms of static graphics can be constructed from a few visual variables, several types of animated maps can be created from the dynamic variables'' (DiBiase and others 1992, 206). Apart from DiBiase and others (1992), there have been few studies conducted on the use of dynamic visual variables. The following sections look at the relationship of dynamic visual variables to change blindness.

The dynamic variable rate of change (R) in an animation is equal to the magnitude of change (MOC) divided by the frame duration (D), expressed as $R = MOC/D$. MOC quantifies the amount of change between map frames; this translates to the magnitude of attribute and symbology change that occurs between adjacent frames in an animation, or the amount that the face of the map changes per unit of time during an animation. An animation with a high rate of change forces map readers to interpret more change in less time than an animation with a lower rate of change. Unfortunately, since DiBiase and others' mention of MOC in 1992, little research has expanded on their definition or examined potential quantification strategies.

We feel that the quantification and empirical study of MOC is a critical part of understanding why some animated choropleth maps may be difficult to read – and why some may be easier to read. Without standardized methods for quantifying change, we have little basis for empirical comparison of animations. The next section, therefore, proposes several methods for quantifying MOC in animated choropleth maps.

3. Quantifying Magnitude of Change

To improve understanding of change blindness on maps, cartographers first need methods to characterize changes in cartographic displays. These methods enable cartographers to understand and assess the potential for change blindness in animated choropleth maps. Although many statistical methods are available to characterize change between discrete time-series samples, few techniques are available to quantify graphical change within thematic map sequences. Since observers are confronted with the graphic dimensions of change, it is necessary to examine methods to measure visual changes between scenes (not between columns in a data table). A graphic measurement of change is also justified by previous research findings on specific human perceptual limitations (Miller 1956; Pylyshyn and Storm 1988). In this section we demonstrate two techniques – *basic magnitude of change* and *magnitude of rank change* – to quantify graphical change between choropleth map pairs. These techniques are applicable to both object-oriented (enumeration unit) and pixel-based measures.

3.1 MAGNITUDE OF CHANGE: CHANGES IN ENUMERATION UNITS

In a choropleth map, thematic statistics are represented by various fill appearances within a set of enumeration units. Consequently, changes within a sequence of choropleth maps are signified by *shifting* fill appearances. Magnitude of change (MOC) is defined as the amount of change in position and attributes between scenes. For animated choropleth maps, since enumeration units generally remain stationary, there is no change in position, and change in attributes is depicted by changes in an enumeration unit's fill appearance. For example, on a map of US presidential election results, New Hampshire's change in hue from red in 2000 to blue in 2004 signifies a change in attribute.

Based on our observations, we propose the following elements of change in choropleth maps:

- *Enumeration units* are the administrative areas that compose a choropleth map (e.g., counties, census tracts, countries, other areas).
- The *origin state* is the initial state in a choropleth pair; in a temporal transition, this is the earlier timestamp.
- The *destination state* is the end state in the transition; in a temporal transition, this is the later timestamp.
- *Class rank* corresponds to the rank value of each class. A three-class example would have values of 1, 2, and 3 (1 = lowest class, 3 = highest class).
- *Rank distance* is the difference in class rank between the origin state and the destination state.

3.1.1 Basic Magnitude of Change

Enumeration units exhibit one of two general transition behaviours between scenes of animated choropleth maps: either they *persist* or they *shift*. An enumeration unit is said to persist if its class rank remains constant between the origin state and the destination state; if its class rank differs between the origin and destination states, it is said to shift. Perhaps the simplest method to quantify MOC between choropleth scenes is to count the number of enumeration units that shift between the origin state and the destination state. We call this the *basic magnitude of change* (BMOC). The BMOC value will always be an integer, ranging from a minimum of zero to a maximum equal to the total number of enumeration units in the display.

In the BMOC approach we view change as a binary condition; each enumeration unit in the pair (E) is assigned a value of either 0 or 1, depending on its transition behaviour: $\triangle E_{ab} = 0$ if an enumeration unit persists, and $\triangle E_{ab} = 1$ if the enumeration unit shifts between the origin state and the destination state. The sum of all values of $\triangle \mathrm{E_{ab}}$ is equal to the total number of enumeration units that shift during a transition:

$$\text{Let } \Delta E_{ab} \text{ be an indicator value (01)} = \{0 \ \mathit{if}\ E_a = E_b \ 1 \ \mathit{if}\ E_a \neq E_b\}$$

$$\text{Enumeration Change } = \Sigma \Delta E_{ab}$$

Where

E = Enumeration Units 1 . . . n

a = rank value at origin state (lowest class = 1, second-lowest = 2, etc.)

b = rank value at destination state

The two-class "red-state, blue-state" map of US presidential elections provides a simple example. If we compare the 2000 and 2004 maps, our resulting BMOC value is 3 (see Figure 2).

By itself, the BMOC value fails to convey the proportion of the choropleth map that shifts value; we can correct for this by normalizing the result. By dividing the number of shifting units by the total number of enumeration units, we obtain the proportion of units that shift. The proportion is useful because it reveals the frequency of shifting versus persisting. For the example given above, the normalized BMOC would be 0.06 (three of 50 states, or 6%, changed class):

$$\text{Normalized BMOC } = \frac{\Sigma \Delta E_{ab}}{n}$$

Where n = total number of enumeration units

3.1.2 Magnitude of Rank Change

As Figure 3 shows, the change between classes becomes more complicated as the number of classes increases in the individual map frames. If there are more than two classes, not only does the number of potential transitional classes increase but individual enumeration units can potentially "jump" intermediate classes. In quantitative choropleth maps, these non-adjacent transitions indicate larger changes in attribute. Since by definition MOC is a measure of amount of change in position and attributes, we may want to account for the severity of change. We use the term *rank distance* to describe the severity of change between the origin state and the destination state. Each cartographic class or category is ranked from low to high, and for each pair of maps, rank distance for every enumeration unit is calculated as follows:

$$\text{Rank Distance } = |E_a - E_b|$$

Another expression of MOC, *magnitude of rank change* (MORC), quantifies this cumulative rank distance between the origin and destination states. After the

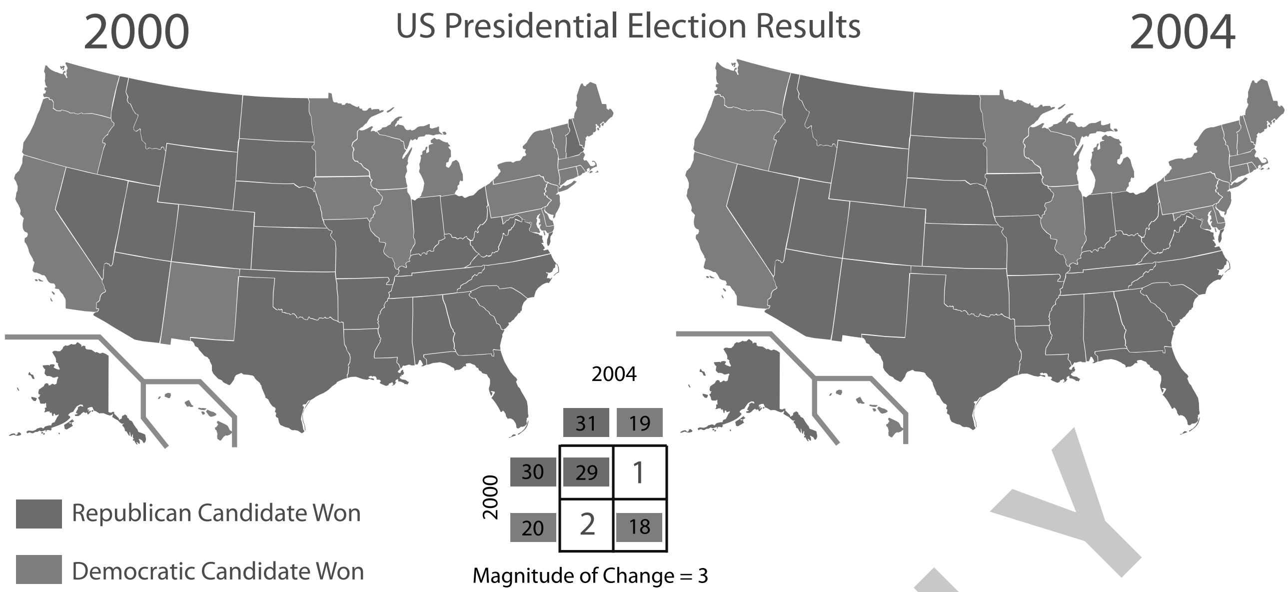

Figure 2. A simple method to calculate BMOC between a pair of choropleth maps; BMOC equals the total number of enumeration units that shift during the transition. In this example, New Mexico, Iowa, and New Hampshire shift, while the other 47 states persist. The sum of the shifting units is 3, so BMOC = 3.

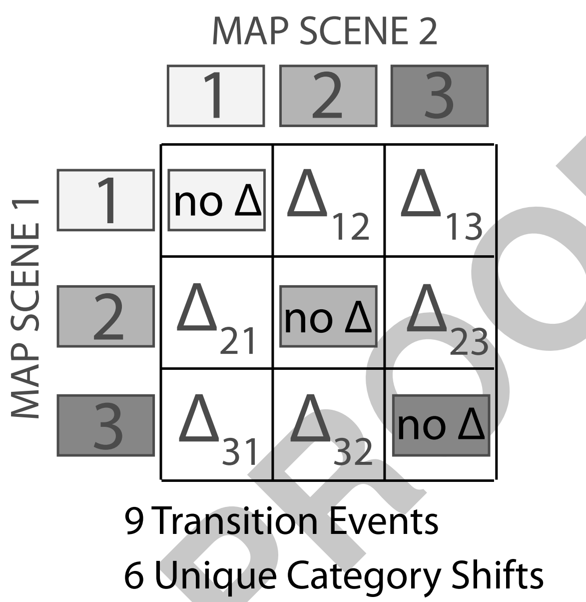

Figure 3. A change-characterization array for a pair of three-class choropleth maps. When choropleth map scenes include three classes, there are nine potential transition behaviours, six of them involving shifting and three involving persisting.

rank-distance value is computed for each enumeration unit, the sum score of n rank distances equals the MORC in the transition:

$$\text{MORC} = \Sigma|E_a - E_b|$$

Where

E = Enumeration Units 1 ... n

a = rank value at origin state (lowest class = 1, second-lowest = 2, etc.)

b = rank value at destination state

Dividing the MORC variable by the total number of enumeration units allows us to describe the mean rank change per enumeration unit:

$$\text{Normalized MORC} = \frac{(\Sigma|E_a - E_b|)}{n}$$

In other words, the MORC represents the total number of category "jumps" between a pair of choropleth maps. This value is equal to zero if the maps are identical and increases in value with increasing differences between the maps (see Figure 5).

3.2 MAGNITUDE OF CHANGE: PIXEL-BASED APPROACHES

Previous change-blindness research has used pixel-based approaches to quantify the amount of change that exists within stimuli. These values are usually reported in terms of the percentage of the display area that changes (e.g., Simons and others 2000). We can apply all the object-based MOC measures mentioned above on the pixel level. There are two ways that this information can be quantified: as percentage of change in the entire display area or as change within the map itself. Both of these measures rely on determining the pixel count for each colour region in the image and creating a change matrix to categorize the pixels that have changed value and how their value has changed.

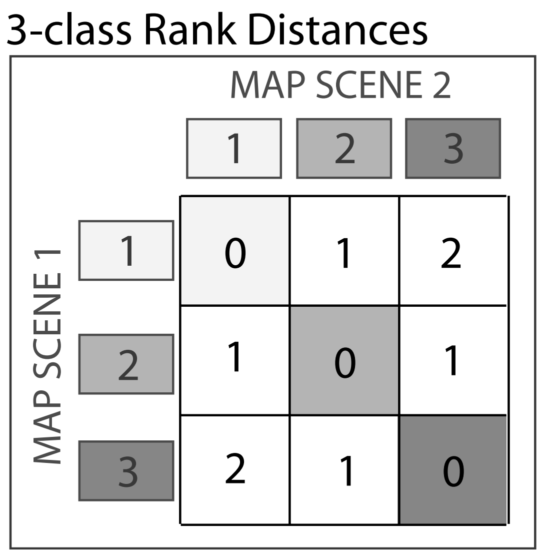

Figure 4. Values for the rank-distance variable shown within a cross-classification array. In a three-class example, every enumeration unit exhibits a rank distance equal to 0, 1, or 2 depending on its transition behaviour. Units that persist have a rank distance of 0; units that shift have rank distances of 1 or 2, depending on the severity of the shift.

Pixel-based metrics enable subsequent researchers to compare their stimuli and results with previous change-blindness studies not involving maps. Using the same images from the previous section, we can report the basic measure of percent change in display area (see Figure 6): between Scene 1 and Scene 2, 67% of the pixels in the map shift categories. This provides no details of the type of change that took place; MORC on the pixel level can also be calculated (see Figure 6).

4. Discussion: Challenges in Reading Animated Choropleth Maps

In animated choropleth maps, change is signified by a dynamic shift in the visual variable filling an enumeration unit. As scenes transition over time, a subset of enumeration units will change classes; this change is presented graphically to the reader via changes in the fills of polygons. The magnitude of the change can be measured by quantifying the shifting behaviour of individual enumeration units. As previous research in psychology has found, human perception is limited; for example, when change is occurring to various locations, no more than four or five locations can be attended to at a time (Pylyshyn and Storm 1988). By examining the transition behaviours of choropleth map scenes, we discover that multiple changes can often occur simultaneously in different portions of the display. Furthermore, animated choropleth maps often depict multiple types of change. To understand the theme of the map, it is not enough simply to note that an enumeration unit has changed over time: to fully understand a single change, the map reader must notice, process, and remember multiple graphic states for a single enumeration unit.

If an enumeration unit shifts from the low class (1) to the high class (3), this means something different than if a unit shifts from the middle class (2) to the low class (1). This phenomenon is represented by choropleth change maps, which demonstrate the spatiality and magnitude of transitional changes. When combined with change-characterization arrays, change maps offer a comprehensive static graphic summary of change between two independent states (see Figure 7). We propose that there are three levels of change detection in animated choropleth maps. In the first and coarsest level, readers notice change but fail to comprehend the nature of that change; in other words, we notice that something is different, but we are not sure what it is. In the intermediate level of change detection, which is applicable only to quantitative choropleth maps, we notice changes *and* notice whether the enumeration unit has increased or decreased in value. Finally, in advanced-level change detection we notice a change *and* recall the original state of the enumeration unit; this enables us to characterize the exact nature of the change (e.g., from low to high or from middle to high). The three levels of change detection are summarized in Figure 7.

Unlike other, more artistic forms of animation, choropleth map animations are bound to geographic data; as a result, cartographers designing these maps have limited control over where and when graphic changes occur. Therefore, it is important that cartographers be acutely aware of the influences they do have; some cartographic controls directly influence magnitude of change, and other controls influence rate of change. For example, by employing graphic interpolation (sometimes called *in-betweening*, or *tweening*), cartographers can elongate and smooth scene transitions; this increases the dynamic variable, duration (DiBiase and others 1992), thus reducing the rate of change during the transition (recalling that $R = \mathrm{MOC}/D$). In addition, cartographic classification influences both the rate and the magnitude of changes on animated choropleth maps. To date, however, little research has explored these links. One exception is a study by Mark Monmonier (1994), who demonstrates classification techniques capable of minimizing change between a pair or among a series of choropleth maps. Depending on the number of classes and the method used to divide the data into groups (e.g., quantiles, equal intervals), the frequency and the number of types of changes will vary considerably (Goldsberry 2004).

Previous research examining the issue of data classification for choropleth maps has suggested that static choropleth maps should contain no more than seven classes (Slocum and others 2008). This recommendation has been linked to the limitations of human memory and

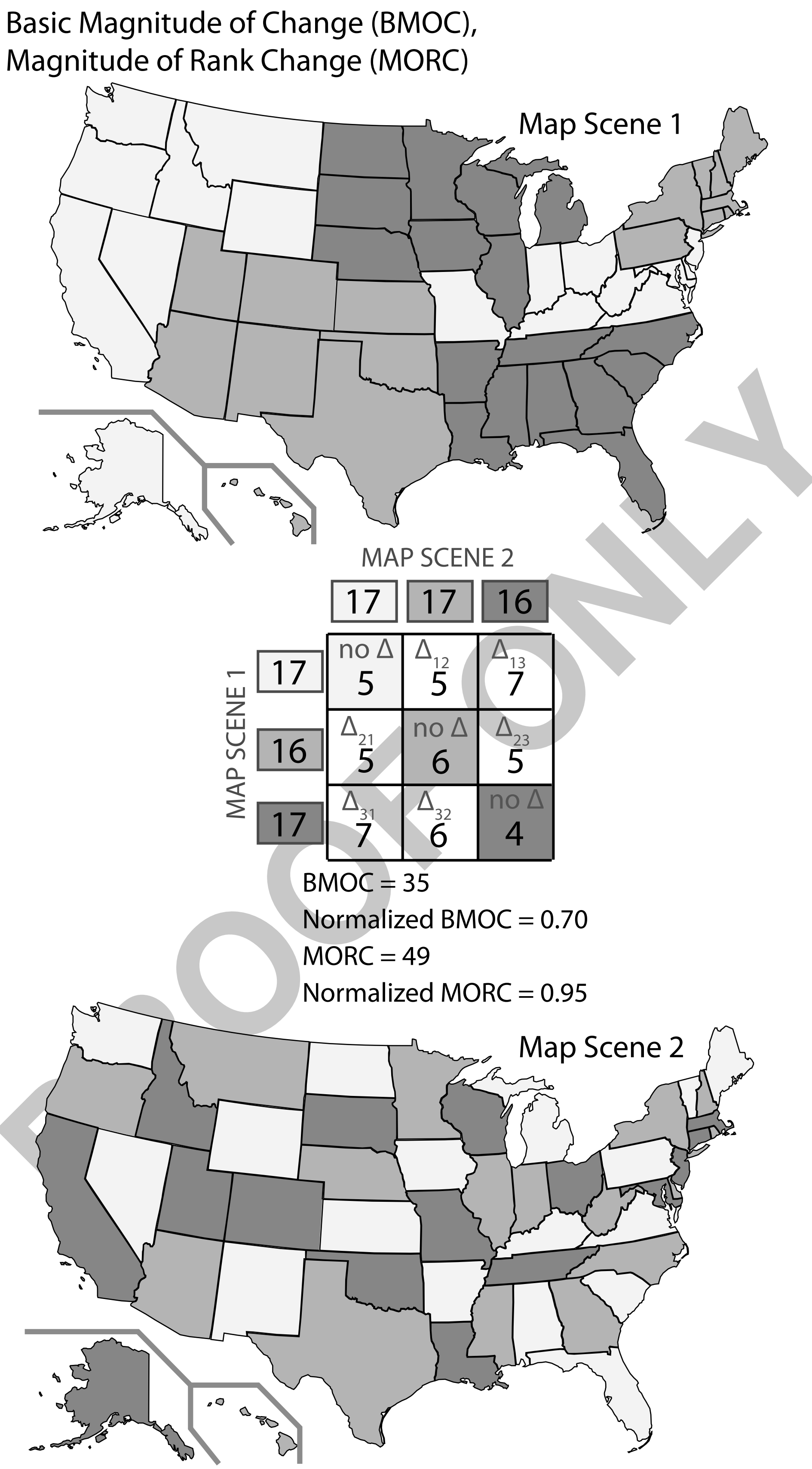

Figure 5. Summary of the four enumeration-unit-based calculations of MOC established in section 3.1. The BMOC value of 35 indicates that 35 of the 50 states shift during the scene transition. The normalized BMOC value indicates that 70% of the states shift. The MORC value of 49 indicates the absolute value of the total rank distance spanned during the scene transition, and the normalized MORC indicates that enumeration units on the map spanned an average rank distance of 0.95.

MAP SCENE 1 \ MAP SCENE 2	Light	Medium	Dark
Light	19,174	16,615	25,786
Medium	15,693	24,500	14,428
Dark	20,320	20,164	11,677

Figure 6. The results of a pixel-based change characterization. We calculated the same four expressions of MOC with pixels, rather than enumeration units, as the elemental components. In the above array, the values within the cells correspond to numbers of pixels.

the amount of information we are able to receive, process, and remember (Miller 1956). In fact, previous research has speculated that because of the increased perceptual burdens of the animated domain, animated choropleth maps should be even more constrained (Harrower 2003). Perhaps the constraining "magic number" for animated maps has less to do with the number of classes on the individual map frames than with the number of unique transitional behaviours presented to the reader via the dynamic display. We argue that choropleth map sequences include "hidden" classes that do not appear on conventional choropleth legends. For example, imagine an ordinal three-class legend containing classes named "low," "medium," and "high." Although each individual static frame may include only three classes, each enumeration unit on the map exhibits one of nine different transition behaviours at every scene change throughout the animation. Each individual enumeration unit may persist in one of the three classes or shift in any of six different ways. As time passes, each of these transition behaviours is signified differently on the map with different graphic transitions. The number of individual classes on the

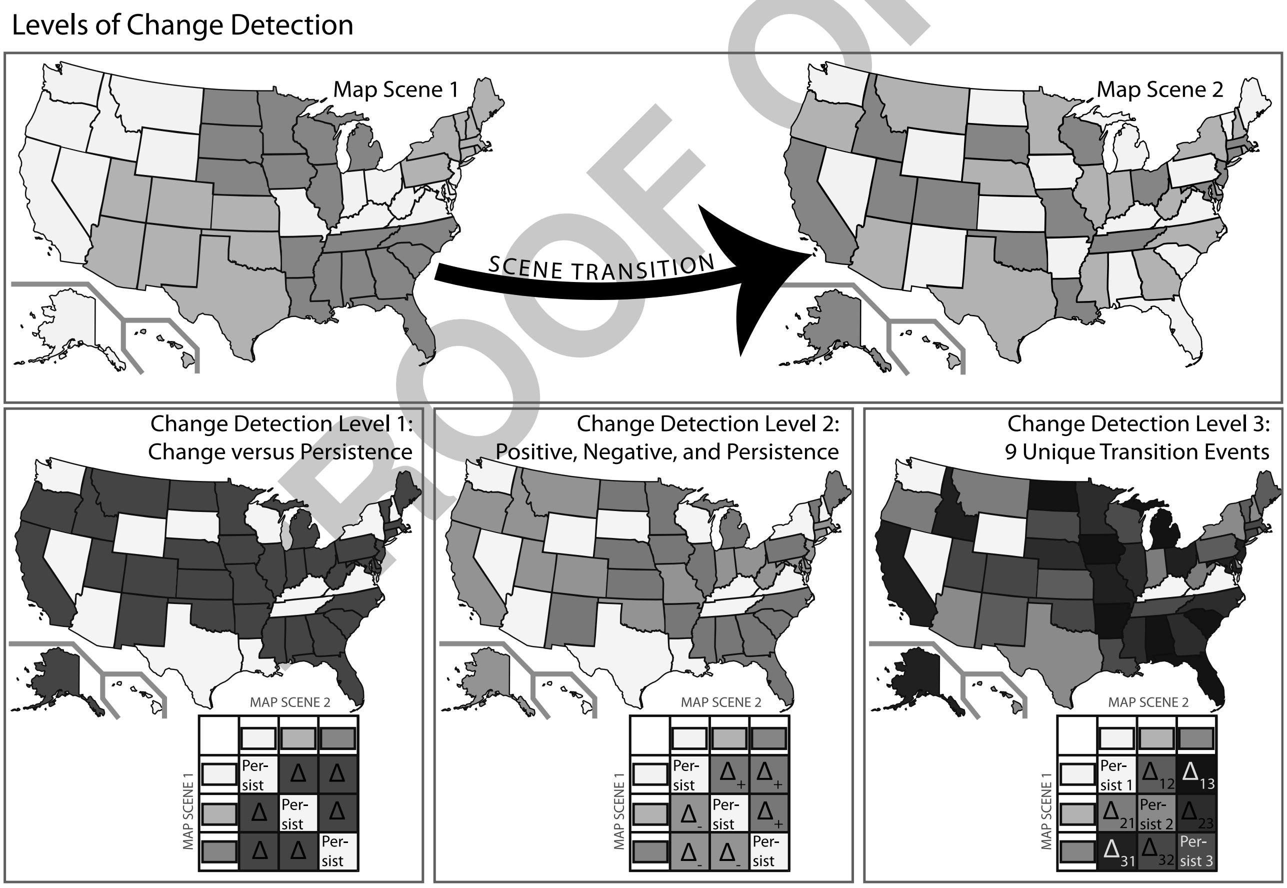

Figure 7. Changes in choropleth map animations can be detected at three levels. In a three-class animated sequence, readers may not comprehend the full meaning of each enumeration unit's transition behaviour (level 3), instead simply noting the presence or absence of simple changes (level 1). The change map presented at lower right demonstrates the full complexity of the transition; there are nine qualitatively different transition behaviours that occur throughout the display.

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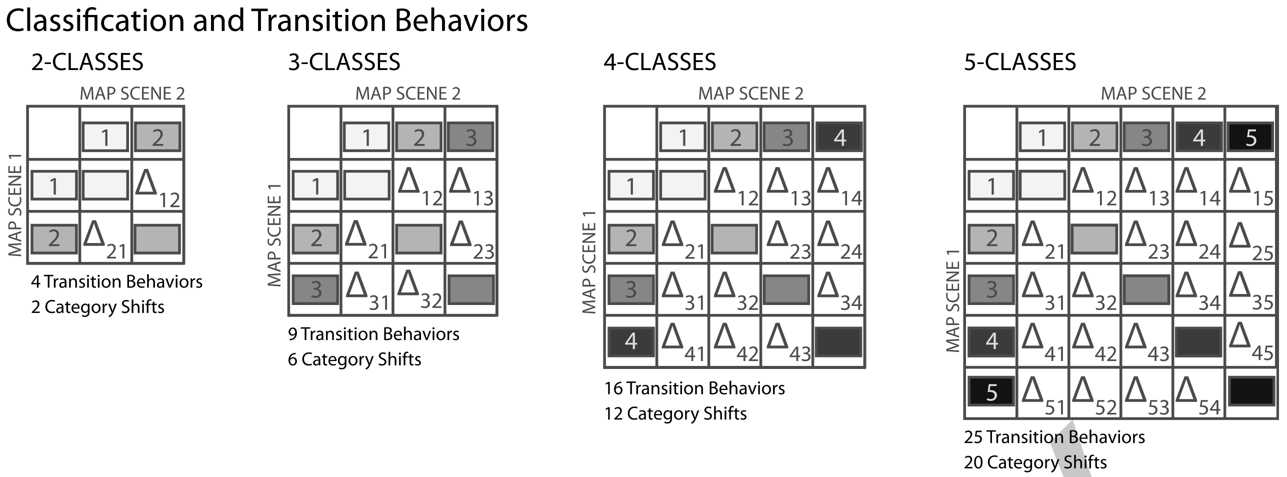

Figure 8. As the number of classes on individual map frames increases, the number of transition behaviours increases exponentially.

static frames of an animation is a poor reflection of the number of signs presented to readers as the animation unfolds.

As the number of classes on the static frames increases, the number of unique transition behaviours increases exponentially (see Figure 8). This ''exponential legend'' phenomenon is visually evident in the characterization arrays: a pair of three-class choropleth maps is characterized using an array containing nine elements, for example, while the arrays for an animation built with four unique classes contains 16 elements. This raises an important question about animated classification and choropleth maps: if designers wish to adhere to Miller's (1956) oft-cited magic-number-seven-rule, does this mean that their maps should contain no more than seven transitional events? If so, even a three-class approach to individual map frames is in violation. The arrays in Figure 8 offer compelling evidence in support of Harrower's (2003) suggestion that animated map frames should contain only two or three classes. If transitional behaviours are the limiting factor, then four- and five-class approaches to animated choropleth mapping will almost certainly overwhelm the human visual system or, at best, restrict the quantity and type of information that can successfully be assessed.

As the number of data classes in an animated choropleth map increases, the number of unique transition behaviours increases exponentially, and the magnitude of change between frames also increases. For any given data set, when we increase the number of data classes on individual frames, more enumeration units will shift during scene transitions, making the animation more difficult to read. In other words, the simplest way to minimize change and reduce the perceptual burden of animated choropleth maps is to reduce the number of data classes. Figure 9 demonstrates this phenomenon, showing not only the influence of the *number of classes* on transition behaviours but also how influential the *location of each class division* is. Just as in static choropleth mapping, it is imperative that cartographers select appropriate numbers of classes and methods for dividing those classes. In the case of animated choropleth maps, classification decisions influence the appearance of temporal as well as spatial patterns.

Whenever we classify data on maps, some changes in the underlying data are hidden and others are emphasized. Cartographers need to understand the interactions of the data, their classification scheme, and the resulting visualization presented to readers. Another option is not to classify the data at all (Harrower 2007). Classification has been proven to influence the perception of trends on static choropleth maps (Brewer and Pickle 2002), and this effect is amplified in the animated domain (Goldsberry 2004; Monmonier 1994). Although Harrower demonstrates the viability of unclassed choropleth animations, sometimes classification is required – for example, in choropleth maps of dominant political parties (e.g., the ''red-state, blue-state'' map), income groups, or other qualitative statistics. In these and other cases, time-series data have meaningful thresholds that continuous symbolization schemes fail to present to readers.

Animation enables cartographers to depict changes via dynamic displays, but the visual appearance of these changes depends on the nature of the geographic data as well as on cartographic design decisions. Just as in static map design, different design approaches emphasize some things while reducing the prominence of others; it is likely that these design variables influence the feasibility of different map tasks and facilitates different learning activities. For example, imagine the following three basic types of map-reading tasks, each with different interests and data needs: survey tasks, locally focused tasks, and globally

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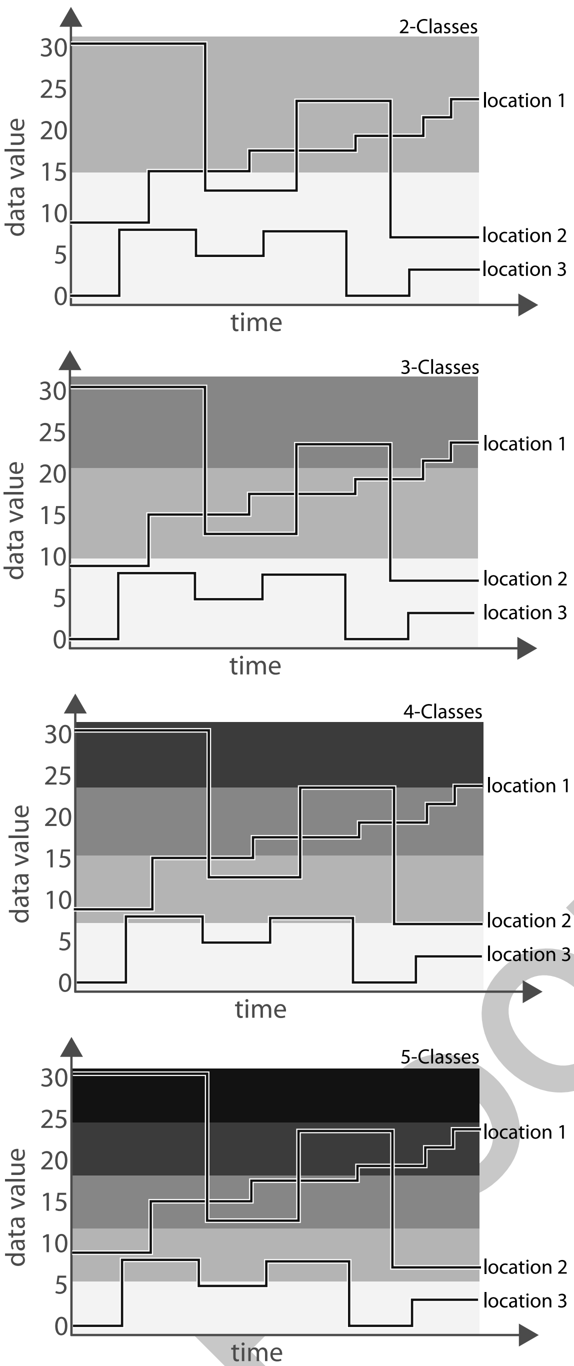

Figure 9. A greater number of data classes results in an increased amount of shifting behaviour in animated choropleth maps. Over time, an individual enumeration unit will shift more frequently and exhibit more different kinds of transition behaviours when more data classes are included on the map. This graphic is structured to extend ideas presented in previous research by Harrower (2007).

focused tasks. *Survey tasks* involve general trends for the entire mapped area; for instance, a survey reader would simply focus on general patterns of where change occurs (e.g., there was a lot of change in the north-east). Survey tasks may also include an ordinal assessment of change (e.g., values increased in the north-east). *Locally focused tasks* require readers to focus on a small number of specific regions and to concentrate their attention on detailed patterns of change for a small portion of the map. *Globally focused tasks* involve detailed information about the patterns of change for individual enumeration units or regions at numerous time stamps. These three types of tasks all have different data needs, and the same animated map design will likely not meet all their requirements. To make animated maps effective and easy to read, we need to take into account the purpose for which the map will be used – just as we do when designing static maps. When studying the effectiveness of animated maps, we need to take this factor into consideration in our experimental design: the effectiveness of any individual map designs will vary depending on the tasks at hand. Similarly, different types of thematic maps will exhibit unique transition behaviours; animated proportional symbol maps and animated choropleth maps present readers with different challenges. With this in mind, although readers of different forms of animated maps face conceptually similar difficulties, the measures introduced in this article will not translate directly to other forms of animated thematic maps.

5. Conclusion

Many geographic processes are temporally continuous; animation allows us to create dynamic maps that mimic the continuous nature of these processes. Unfortunately, for many complicated reasons, people have difficulty in reading these animated maps. In this article we have identified and examined several of the issues that cause difficulty in reading animated choropleth maps. These fit into two categories: general limitations of the human perceptual system and issues related to how we indicate change in animated maps. Animated choropleth maps present change via shifts in the fill appearances of individual enumeration units. In order to detect change on these maps, readers must notice, attend to, perceive, and recall multiple graphic states for potentially numerous individual enumeration units. The difficulty of these change-detection tasks increases as the number of data classes on the animation frames increases, because both the frequency of shifting and the number of unique shifting behaviours are directly related to the number of data classes and the method used to divide the data into classes. Although design variables such as tweening and interactivity may mitigate some of our difficulties with change detection on animated choropleth maps, the exact effects of these techniques on readability remain unknown. More research is needed to inform and enhance the design of animated choropleth maps.

We feel that there are three main questions with which we need to concern ourselves: What do animated choropleth maps facilitate? What do they *need* to facilitate? Where do these maps fail, and why? With respect to these broad questions, we see several specific research areas that we feel need to be addressed with empirical research:

1. **Size and number of enumeration units in relation to change blindness**. One unknown involves the number of enumeration units in a given animated choropleth map. For example, Americans commonly see choropleth maps of the United States at both the state level and the county level. At the state level, there are 50 enumeration units; at the county level, there are (according to the United States Census Bureau) 3141 enumeration units. If we consider each enumeration unit to be a unique symbol, what does this mean for the function, design, and readability of these maps? From an attentional standpoint, county-level maps are clearly more demanding than state-level maps. Because individual readers cannot keep track of 3141 unique symbols and their individual transitional behaviours through time, mental aggregation becomes an important part of the perception process. How does this process happen, and how does it influence the patterns that are identified in an animation? How many individual enumeration units can individuals focus attention on simultaneously? Do the sizes and shapes of enumeration units influence attentional capabilities?
2. **Map size and foveation distance**. Animated maps can be displayed on a variety of digital media and, thus, on a number of different screen sizes. Given that the foveal viewing area is roughly 2°, and that changes occurring in peripheral vision require stronger change signals in order to be noticed, how does the display size of an animated map affect viewers' ability to perceive change? Do we need different design guidelines for different potential media and screen sizes?
3. **Temporal length of change and magnitude of change.** One technique suggested in the cartographic literature to avoid change blindness is to use tweens to smooth the transition between time steps in an animation (Fabrikant and others 2008). Studies of visual perception suggest that smooth transitions may be just as likely to induce change blindness, however – though these studies have used transitions that are longer (at 12 seconds) than the typical transition in an animation. Is there a maximum threshold for transition length to minimize change blindness? How does this relate to the magnitude of change in individual enumeration units or regions and to the change for the entire map? Should transition time be varied depending on the quantity of change?
4. **Design to meet the needs of different types of reading tasks.** In the previous section we identified several different types of map-reading tasks relevant to animated choropleth maps. Each of these tasks – survey, locally focused, and globally focused tasks – requires a reader to attend to changes in different ways. In some instances the reader simply needs to identify that change has taken place; in others, the reader is interested in assessing quantitative change. We should investigate how design variables, including classification and tweening, may influence the level of difficulty associated with different map-readings tasks.

We believe that by addressing these issues, we can enhance our understanding of animated choropleth maps. Animation can be a potent mechanism for representing time-series geographic data. But just as academic research of previous mapping techniques helped to advance static cartographic design practices, we remain in need of more investigations into dynamic maps, their design, their strengths, and their weaknesses. This line of research should address design criteria that take into account visual perception and task-specific needs for effective animated choropleth maps.

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References

Bertin, J. 1983. *Semiology of Graphics: Diagrams, Networks, Maps*, trans. W.J. Berg. Madison: University of Wisconsin Press.

Brewer, C.A. 1992. "Review of Colour Terms and Simultaneous Contrast Research for Cartography." *Cartographica* 29/3&4: 20–30.

———. 1996. "Guidelines for Selecting Colors for Diverging Schemes on Maps." *Cartographic Journal* 33: 79–86.

———. 1997. "Evaluation of a Model for Predicting Simultaneous Contrast on Color Maps." *Professional Geographer* 49: 280–94.

Brewer, C.A., and L. Pickle. 2002. "Evaluation of Methods for Classifying Epidemiological Data on Choropleth Maps in Series." *Annals of the Association of American Geographers* 92: 662–81.

DiBiase, D., A.M. MacEachren, J.B. Krygier, and C. Reeves. 1992. ''Animation and the Role of Map Design in Scientific Visualization.'' *Cartography and Geographic Information Systems* 19: 201–14.

Fabrikant, S.I., and K. Goldsberry. 2005. ''Thematic Relevance and Perceptual Salience of Dynamic Geovisualization Displays.'' Paper read at the 22nd ICA/ACI International Cartographic Conference, 9–16 July, A Coruña, Spain.

Fabrikant, S.I., S. Rebich-Hispanha, N. Andrienko, G. Andrienko, and D.R. Montello. 2008. ''Novel Method to Measure Inference Affordance in Static Small-Multiple Map Displays Representing Dynamic Processes.'' *Cartographic Journal* 45: 201–15.

Goldsberry, K. 2004. ''Stabilizing the Rate of Change in Thematic Map Animations''. *Master's thesis.* University of California at Santa Barbara.

Grimes, J. 1996. ''On the Failure to Detect Changes in Scenes across Saccades''. In *Perception (Vancouver Studies in Cognitive Science)*, vol. 2, ed. K. Atkins. New York: Oxford University Press. 89–110.

Harrower, M. 2003. ''Tips for Designing Effective Animated Maps.'' *Cartographic Perspectives* 44: 63–66.

———. 2007. ''The Cognitive Limits of Animated Maps.'' *Cartographica* 42: 349–57.

Klein, R., A. Kingstone, and A. Pontefract. 1992. ''Orienting of Visual Attention''. In *Eye Movements and Visual Cognition: Scene Perception and Reading*, ed. K. Rayner. New York: Springer.

Lambert, A., I. Wells, and M. Kean. 2003. ''Do Isoluminant Color Changes Capture Attention?'' *Perception and Psychophysics* 65: 495–507.

Levin, D.T., N. Momen, D. , S.B. Simons, and D.J. Simons. 2000. ''Change Blindness: The Metacognitive Error of Overestimating Change-Detection Ability.'' *Visual Cognition* 7: 397–412.

Lu, S., and K. Zhou. 2005. ''Stimulus-Driven Attentional Capture by Equiluminant Color Change.'' *Psychonomic Bulletin and Review* 12: 567–72.

MacEachren, A.M. 1995. *How Maps Work.* New York: Guilford.

Miller, G.A. 1956. ''The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information.'' *Psychological Review* 63: 81–97.

Monmonier, M. 1994. ''Minimum-Change Categories for Dynamic Temporal Choropleth Maps.'' *Journal of Pennsylvania Academy of Science* 68/1: 42–47.

Morrison, J.B., M. Betrancourt, and B. Tversky. 2000. ''Animation: Does It Facilitate Learning?'' Paper read at the 2000 AAAI Spring Symposium: Smart Graphics, 20–22 March, Stanford, CA.

Nagy, A.L., R.R. Sanchez, and T.C. Hughes. 1990. ''Visual Search for Color Differences with Foveal and Peripheral Vision.'' *Journal of the Optical Society of America* A7: 1995–2001.

Nothdurft, H.-C. 2006. ''Salience-Controlled Visual Search: Are the Brightest and the Least Bright Targets Found by Different Processes?'' *Visual Cognition* 13: 700–32.

Pashler, H.E. 1988. ''Familiarity and Visual Change Detection.'' *Perception and Psychophysics* 44: 369–78.

Pylyshyn, Z.W., and R.W. Storm. 1988. ''Tracking Multiple Independent Targets: Evidence for a Parallel Tracking Mechanism.'' *Spatial Vision* 3: 179–97.

Rensink, R.A., J.K. O'Regan, and J.J. Clark. 1997. ''To See or Not to See: The Need for Attention to Perceive Changes in Scenes.'' *Psychological Science* 8: 368–73.

Robinson, A., R.D. Sale, and J. Morrison. 1978. *Elements of Cartography.* New York: Wiley.

Simons, D.J., and C.F. Chabris. 1999. ''Gorillas in Our Midst: Sustained Inattentional Blindness for Dynamic Events.'' *Perception* 28: 1059–074.

Simons, D.J., S.L. Franconeri, and R.L. Reimer. 2000. ''Change Blindness in the Absence of a Visual Disruption.'' *Perception* 29: 1143–54.

Simons, D.J., and R.A. Rensink. 2005. ''Change Blindness: Past, Present, and Future.'' *Trends in Cognitive Sciences* 9/1: 16–20.

Slocum, T.A., R.B. McMaster, F.C. Kessler, and H.H. Howard. 2008. *Thematic Cartography and Geovisualization.* Upper Saddle River, NJ: Pearson.

Swienty, O., T. Reichenbacher, S. Reppermund, and J. Zihl. 2008. ''The Role of Relevance and Cognition in Attention-Guiding Geovisualization.'' *Cartographic Journal* 45: 227–38.

Theeuwes, J. 1995. ''Abrupt Luminance Change Pops Out; Abrupt Color Change Does Not.'' *Perception and Psychophysics* 57: 637–44.

Tobler, W.R. 1970. ''Computer Movie Simulating Urban Growth in the Detroit Region.'' *Economic Geography* 46: 234–40.

Tversky, B., J. Bauer Morrison, and M. Betrancourt. 2002. ''Animation: Can It Facilitate?.'' *International Journal of Human–Computer Studies* 57: 247–62.

Williams, P., and D.J. Simons. 2000. ''Detecting Changes in Novel, Complex Three-Dimensional Objects.'' *Visual Cognition* 7: 297–322.

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