

## Considerations in Design of Transition Behaviors for Dynamic Thematic Maps

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Maps provide a means for visual communication of spatial information. The success of this communication process largely rests on the design and symbolization choices made by the cartographer. For static mapmaking we have seen substantial research in how our design decisions can influence the legibility of the map's message, however, we have limited knowledge about how dynamic maps communicate most effectively. Commonly, dynamic maps communicate spatiotemporal information by 1) displaying known data at discrete points in time and 2) employing cartographic transitions that depict changes that occur between these points. Since these transitions are a part of the communication process, we investigate how three common principles of static map design (visual variables, level of measurement, and classed vs. unclassed data representations) relate to cartographic transitions and their abilities to congruently and coherently represent temporal change in dynamic phenomena. In this review we find that many principles for static map design are less than reliable in a dynamic environment; the principles of static map symbolization and design do not always appear to be effective or congruent graphical representations of change. Through the review it becomes apparent that we are in need of additional research in the communication effectiveness of dynamic thematic maps. We conclude by identifying several research areas that we believe are key to developing research-based best practices for communicating about dynamic geographic processes.

**Key words:** dynamic maps, animated maps, map design principles, tweening, temporal smoothing, cartographic transitions

### INTRODUCTION

Several models describing the process of cartographic communication have been suggested in the last fifty years (for reviews of these models see MacEachren 1995; Montello 2002). While each of the various models may differ in their level of complexity, they all seem to rely on the same basic parts: 1) the real world phenomenon, 2) the cartographer's conception of the phenomenon, 3) the design and symbolization of a map based on the cartographer's conception, and 4) the reader's perception and interpretation of the resulting map. For static map design, we have seen substantial research in many aspects of these four steps – and through this work many, but by no means all, basic principles of mapmaking have been refined into sets of guidelines and suggestions to simplify the process of creating simple yet appropriate static maps. For instance, cartographers identify an acceptable thematic map type by considering how the mapped

phenomenon occurs and changes in space (MacEachren 1992), or select a visual variable using charts that detail which one is most effective for our level of measurement (MacEachren 1994). These helpful guidelines and suggestions for symbolization in static maps have been detailed extensively in introductory cartography texts (e.g., Dent, Torgusen, and Hodler 2009; Slocum et al. 2008). However, they are not always sufficient for guiding successful design of dynamic thematic maps; the addition of a dynamic temporal dimension adds additional complexity to the entire mapping process, specifically with respect to how we conceptualize and communicate change in real world phenomena.

Dynamic thematic maps confront readers with the equivalent of multiple static maps shown in sequence with transitions between each set of maps. These transitions emphasize change in the state / existence, location, shape / size / extent, or attribute of the phenomenon being mapped (Harrower 2002). In order to depict these changes, a dynamic map must employ a transition effect such as a tween, morph, fade, wipe, or abrupt change. We believe that the appearance of the transition used to indicate change in or between attributes graphically implies information to the reader that depicts the nature of the change in time and mapped attribute. The nature of how we design these transitions is an interesting factor that needs special consideration with respect to the cartographer's conceptualization of the map and in how the reader is able to perceive and interpret the resulting map. Existing discussions of the cartographic communication model do not address issues of dynamic symbolization of change, or what we might simply call "change behaviors." Since the transition's appearance is symbolic and meaningful, and since there has been an increase in interest in using dynamic mapping methods, we feel that it is important to examine how static map design principles behave in a dynamic map environment and what they may imply to the map-reader about the change process.

In the recent ICA research agenda on cartography and GIScience (Virrantaus, Fairbairn, and Kraak 2009), the challenges of depicting the temporal nature of geospatial processes was a recurring theme in need of focused research. It has also been suggested that dynamic maps are challenging to read and that there is a general need improve our understanding of cognitive aspects of dynamic maps, and to assess whether dynamic displays actually enhance our ability to communicate dynamic processes (Slocum et al. 2008; Goldsberry and Battersby 2009). Inspired by these challenges, our aim is to evaluate behaviors of static map principles as they occur in a dynamic map environment, and to assess the conceptual applicability of specific static map design principles as they may be used in a dynamic environment depicting temporal change. As a guide for our assessment we use Tversky et al.'s (2002) Congruence Principle for effective dynamic graphics as we evaluate how transitions (with specific emphasis on smooth transitions) may influence our communication of change in an effective and cartographically appropriate manner.

## Background

To start, it seems appropriate to define what we mean by "dynamic thematic map." In the discussion of non-static cartographic products that show change many different terms have been used, for instance: animated-, dynamic-, or spatio-temporal thematic maps. We feel that this can be confusing, as the terms are often used somewhat interchangeably, and the maps to which they refer can differ substantially. To maintain clarity here we will use what we feel is the most inclusive term – dynamic thematic

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maps. Dynamic thematic maps include any thematic map that shows the process of change, regardless of the type of change or number of maps between which change is visible (e.g., to show dynamic change processes between two distinct maps or a one-hundred map series). The depiction of the process of change requires that the readers must personally identify and extract the implicit changes between two or more maps in map reading, the change depicted is not displayed in a single map (e.g., a single map showing the percent change in population between 1900 and 1910). Animated thematic maps are often defined as being a subset of dynamic thematic maps, with multiple snapshots of the same mapped extent shown in succession over time. Some definitions suggest that the series of maps in an animation is necessarily temporal (e.g., Weber and Buttenfield 1993), and some imply that any series showing change in time, space, or attribute is included (e.g., DiBiase et al. 1992; Lobben 2003; Peterson 1993). Regardless of which definition is used, both fall under the broader definition of dynamic thematic map.

Since dynamic maps are more complex than their static counterparts, we will also review a few fundamental terms that can be used to define their components. Dynamic thematic maps operate using a timeline that describes the sequence in which mapped data will be displayed and the duration that each individual map in the sequence will be visible. Note that the use of a timeline does not mean that the change reflected in the dynamic map is required to be temporal, only that the transition occurs over time. In these temporal sequences, the primary display element is typically a single static map (or “frame”). Given that most contemporary computer animations run at a display rate of 12 to 24 frames per second, duplicate frames (or maps) are commonly inserted into the sequence to ensure that readers have sufficient time to perceive individual snapshots. These sets of duplicate frames combine to form a scene, which, in animation terms, is defined as the representation of static situation (DiBiase et al. 1992). The duration of individual scenes depends on the number of duplicate frames inserted by the designer. Between scenes, other types of additional frames may be added to help generate a specific kind of transition.

### Transitions

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Transitions within a dynamic thematic map are commonly modifications to a visual variable that occur over time in a dynamic display. These transitions can show either temporal change, such as in a time series animation, or non-temporal change, such as a transition between different classification methods or attributes. Transition methods include all techniques for graphical representation of change, whether it is a graphical interpolation or “tween,” morph, fade, wipe, instantaneous change between scenes, or any other method for changing representation. In dynamic maps produced in recent years, we often see tweens (i.e. temporal smoothing), fades, and/or abrupt transitions, likely this is because these types of transition are default options in software commonly used for dynamic map design (e.g., Adobe Flash), and can be relatively easy to implement when working with vector data.

Changes to geographic phenomenon can be broadly grouped into two categories, smooth and abrupt (Graf and Gober 1992); different transition methods are useful for showing smoothly and abruptly changing phenomenon. Smooth transitions describe the process of gradual and continuous change to the visual properties of a graphical entity or the process of shifting one graphical entity into another entity (e.g., morphing shapes or

tweening the tint of a map feature). This type of transition can involve attribute change, or change to the existence of a single object resulting in the appearance or disappearance of the object. Conversely, abrupt transitions (or non-tweened changes) describe the process of immediate change to visual properties or existence of an object. While it is possible to incorporate smooth transitions in any dynamic map, the overall appearance and implications of how a transition may be interpreted by a reader depend on the behavior of the visual variables in the static map key frames that bookend the transition.

### Congruence and transitions

For representing dynamic processes, dynamic maps are believed to be superior to static maps since they permit the representation of change processes in a way that is more consistent with the temporal nature of real-world change (e.g., Thrower 1959; Moellering 1973). This alignment of the format of the map with the nature of the change adheres to the Congruence Principle of graphics proposed by Tversky et al. (Tversky, Morrison, and Betrancourt 2002). The congruence principle of graphics states that the content and format of a graphic should correspond to the content and format of the concepts to be conveyed. Cartographic transitions facilitate the congruent representation of many geographic change concepts. However, this facilitation depends on a crucial correspondence linking the content and the format of phenomenon – in this case geographic change, to the content and format of the change's graphic appearance – the transitional behavior of the map symbology. In other words, animations should be more congruent representations if the graphical depictions of change correspond to the nature and tendencies of mapped phenomenon's real-world change behavior. We operate on the assumption that congruence is beneficial to aid readers' interpretation of the graphic, however, we also recognize that congruence may not equal effectiveness in all cases.

There are many challenges to obtaining true congruence between geographic phenomenon and the resulting mapped data (Blok 2000). Of specific concern to dynamic mapping is the fact that although many geographic phenomena are continuous in nature, they are only measured at specific instances in time. These sampling instances are usually, but not always, distributed at regular temporal intervals even though geographic phenomena seldom change at regular intervals. This means that the discrete temporal snapshots that are the basis for many time-series animations are limited in their ability to accurately convey change processes on their own; transitions are required to create the impression of continuously occurring and gradually changing phenomena. Furthermore, loyal depictions of data sets – especially snapshot-based time-series GIS data sets – are often incongruent representations of the underlying geographic phenomena the data are intended to capture; the general process of translating from phenomena to data necessarily requires simplification, generalization, and reduction of dimensionality which will always place limits on our ability to maintain congruence.

Congruent depictions of temporally continuous processes should mimic the nature of the change exhibited by the mapped phenomenon. By inserting transitions in-between scenes of dynamic maps cartographers can provide visual smoothing that offers a more congruent representation of the changes that take place in temporally continuous geographic phenomena – even though they happen to be sampled at snapshots. The result includes a smoother, more fluid depiction of change. While these depictions may still not be sufficient to show the true variability of temporal change

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*“There are many challenges to obtaining true congruence between geographic phenomenon and the resulting mapped data.”*

(especially in instances with particularly lengthy sampling intervals), in many cases they are more representative of the nature of the change than are abruptly changing dynamic maps. They may also, however, be made ineffective (or inappropriate) based on other cartographic design decisions made for the static maps that act as key frames in the animation.

### Principles for dynamic map symbolization

While we have many accepted cartographic guidelines for symbolization of the static map key frames, for dynamic maps we have fewer guidelines, such as DiBiase et al.'s (1992) dynamic visual variables (extended by MacEachren (1995)) and Harrower's (2003) animated map guidelines. Dynamic visual variables describe the process of change in dynamic maps based on duration, rate of change, and order of frames in the map. In the context of examining transition properties, duration and rate of change are the most critical; duration describes the length of time that a static scene is displayed before a transition, and rate of change describes the ratio of magnitude of change and duration. Though DiBiase discusses the concept of magnitude of change with respect to duration of frames or scenes, it can also be examined in terms of transition duration. An abrupt transition would have duration of 0 (or in few enough milliseconds to be considered 0), while a smooth transition would require a lengthier duration to be noticeable. Harrower (2003) provided more concrete design principles to address the four challenges to watching and learning from dynamic graphics: disappearance, attention, confidence, and complexity. His suggestions largely focus on static map symbolization and map elements, such as inclusion of tools to control the map playback, and generalizing, filtering, or smoothing data so that only necessary information is included. For the most part, these dynamic map symbolization principles do not provide guidance in evaluating how static map symbolization behaves during the transitions that communicate change or how these transitions may influence the congruence of the map.

*“... while we have many accepted cartographic guidelines for symbolization of the static map key frames, for dynamic maps we have fewer guidelines.”*

### Transition behaviors for map symbolization

For discussion of transition behaviors, we start with general design issues of level of measurement and classification method – two important decisions that underlie the structure of thematic maps. Following this, we move to discussion of the behaviors of the visual variables that specifically define the attributes undergoing transition. Through this discussion we aim to highlight problems that may arise in representation of change in dynamic maps.

#### Level of measurement

According to the Congruence Principle an effective graphic will conform to the content and format of the concept to be conveyed. From a dynamic map standpoint, we must ask whether the concept being conveyed is the change to the geographic phenomenon being mapped, or the concept of change as represented by our sampled data – with concern for somewhat realistic estimation of what happened between sampled points. These two concepts are different in that a focus on change in the data depends largely on how we have sampled and classified or categorized the data – and thus more on the level of measurement for the data that we have chosen to represent the geographic phenomenon; the focus on change to the geographic phenomenon artificially removes concern with the level of measurement

of the representation. Because of this, we feel that we cannot disconnect the issue of congruence and the nature of the data representation. In mapping as we are always forced to simplify and use data representative of snapshots of our phenomena of interest, however, in dynamic situations we strive for data representation that is congruent with how we believe the phenomena changes.

Since geographic phenomena can exhibit temporally abrupt or smooth change patterns, and the level of measurement is dependent on the data collected for the phenomenon, it is logical that we may encounter all of the combinations of level of measurement and type of change at some point. The question is whether the behavior of data represented at each of these levels of measurement is equally congruent (or effective) at representing the change. Essentially, we need to ask what exactly does the state between two distinct classes of values mean for each level of measurement? In this section we examine the four commonly recognized levels of measurement – nominal, ordinal, interval, and ratio and how data at these levels of measurement may behave when used to represent change in a dynamic environment.

#### *Nominal*

Nominal data is categorical – depending on the nature of the categories and the drivers of the change the transition state between categories could properly imply a fuzzy categorization (or “graded membership”) of transitional areas (e.g., as discussed by Chrisman 1998). Of course, simply showing change between the beginning and end categories seems to imply that the change is entirely dependent on these two categories and that there was no possible interplay of other nominal categories. With influence from more than two categories, a transition only reflecting the influence of the origin and destination categories is not congruent with the drivers of the change. For example, consider a map showing categories of largest church membership for each county. Over time, we may see switches to the category representing the religious congregation with the largest membership. With this type of change, it is likely that the ratio of all religious groups identified in the area is going to change; it isn’t simply a change in the relationship between two categories with one becoming more populous than the other. In that case, the change isn’t really just between two categories, so while the transition between categories has still been a smooth progression, the fact that it involves more than the origin and destination state makes the transition itself less of a clear, smooth change.

Nominal transitions are particularly tricky when we consider the process of change between classes. It is of particular importance that we understand (to the best of our ability) the drivers of the change if we are going to attempt a transition that is congruent with the temporal and categorical nature of the change. We feel that good nominal transitions will largely be driven by selection of appropriate visual variables and through exploration of a variety of different methods for visualizing the change (more than the smooth tween that we have often seen applied in dynamic maps).

#### *Ordinal*

Ordinal data implies a structured relationship between categories, but it does not imply any specific numeric difference between the categories. A smooth transition to show sufficient increase or decrease in an attribute to

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cause a change in ordinal category may imply that there is a continuous, numeric relationship between the categories as represented. While the data represented in the dynamic map may have been collected at a numeric level, its classification at an ordinal level requires that the transitions conform to the rules of ordinal categorization – that there is no explicit indication (or implication) of numerical spaces in between the categories. While the congruence principle suggests that we should maintain a relationship with the change as it occurs in the geographic phenomenon represented, this is in conflict with the ordered, categorical relationships of the level of measurement.

#### *Numeric*

Numeric data (interval and ratio level) involve ordering of data with clear numeric difference between the categories (with or without an arbitrary zero point). At this level of measurement, the congruence of smooth transitions to show change in attributes seems most reasonable. Since a smooth transition would be showing a smooth increase or decrease in numeric value, the transition would be most congruently indicating the general pattern of change to the collected data (though it may not be reflective of the finer temporal-scale fluctuations that may occur in the phenomenon itself). There are issues with classification and the how transitions between, and the invisible transitions within categories, are represented. As a whole, however, amongst the standard levels of measurement the transitions for numeric data make the most sense from a congruence standpoint.

For each of the levels of measurement there are instances where the change can be displayed in a more congruent fashion and instances where it may be less congruent. Recognizing that this is only a general overview of the possible problems with congruence at each of the levels of measurement, we must also consider the impact of the transitions on the visual variables that represent attributes on our maps. While we may have data that is appropriate to represent with a smooth transition, the visual variable(s) that we select and our choices with respect to data classification may negate the effectiveness of the transition.

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#### **Classed vs. unclassed maps**

It can be argued unclassed maps are a more congruent representation of geographic phenomena as they do not artificially group or classify values. However, classed maps are much more popular than unclassed maps, at least for static maps (Robinson and Morrison 1995); with respect to dynamic maps, only recently have we begun to see discussion of the possible benefits of unclassed dynamic maps (Harrower 2007). One of the benefits of classed mapping is that the classes limit the number of unique symbol-types that appear on the legend. While this technique is less congruent than unclassed methods, it is also more familiar to readers – however, it is not necessarily easier to interpret. Perceptual testing has shown that in the static domain unclassed maps can be interpreted at least as well as classed maps (Muller 1979); Harrower (2007) has found similar results for maps in the dynamic domain. To evaluate these two techniques for organizing and representing data from a congruence standpoint, in this section we examine how classed and unclassed maps behave in transition situations. Both techniques have potential for congruent representations with the nature of the geographic phenomenon they represent, however the principle of unclassed maps to show transition may be more appropriate for showing continuous numeric change, while classed maps can only really

show change between levels of class membership and may falsely imply a strictly numeric relationship.

Since most classed maps contain between four and seven classes, map-readers only have to discern between a small number of symbols. Dynamic thematic maps depict differences in attributes over both space and time. As an individual geographic entity such as a single enumeration unit in a choropleth map changes over time its representation on the map shifts as well. To show continuous change to the geographic phenomenon in a classed map, our symbols must smoothly change between classes. Software packages that enable gradual transitions commonly interpolate or blend to generate intermediate frames that – in sequence – combine to create a smoothing effect in which the symbol gradually transitions between an origin state and a destination state. However, this often leaves us with a contradiction between map symbolization and the legend defining our values (Figure 1). For example, in Figure 1 as the enumeration units gradually fade between the discrete hues on the legend the intermediate fills are undefined according to the legend. While the transition may be “congruent” by definition, it is cartographically questionable as it provides un-defined information to the reader. Abrupt changes in classed maps do not exhibit this same problem; all values on the map throughout the transition are defined in the legend.

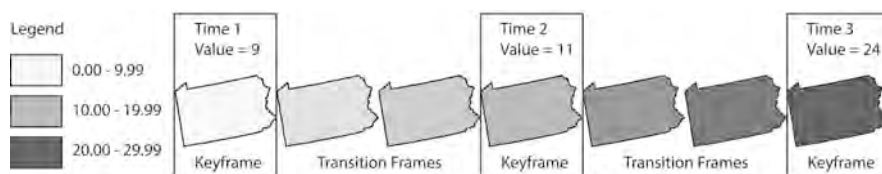


Figure 1. Transitions between key frames may lead to undefined symbology. (see page 67 for color version)

*“Although the data classification process can be helpful in static map-making, it might be harder to justify in dynamic maps that rely on smooth transitions . . .”*

Although the data classification process can be helpful in static map-making, it might be harder to justify in dynamic maps that rely on smooth transitions to achieve congruence with temporally continuous geographic phenomena. Unclassed maps, by virtue of the steadfast links connecting attribute values to precisely proportional symbology, may perform more consistently during smooth cartographic transitions. In an unclassified approach, the frames in smooth transitions remain loyal to the continuous legend since all values are defined individually (Figure 2). With respect to representation of abrupt changes to geographic phenomena, unclassified choropleth maps provide an interesting problem for congruent representation – abrupt changes in unclassified choropleth maps may be viewed as being “smooth” due to relatively subtle shifts of color between individual time steps (Harrower 2007). In other words, regardless of the cartographers attempt to maintain congruence with the phenomenon being represented, the transition may be misinterpreted as a smooth change – even if the phenomenon changes abruptly.

### Visual variables

In this section we review the possible implications of transitions between the different static visual variables, and what they may mean when used in a dynamic map. According to the Congruence Principle, the representation of change in the dynamic map should correspond with the nature of change to the geographic phenomenon, however for the map to be effec-

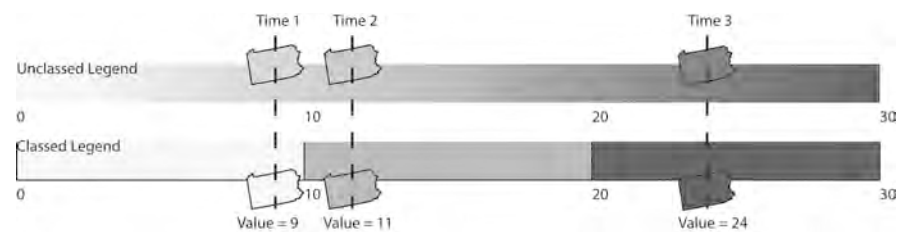


Figure 2. Differences between transitions in classed and unclassed maps. (see page 67 for color version)

*“... however, for the map to be effective, the represented change must also be intuitive for the reader.”*

tive the represented change must also be intuitive for the reader. While in some cases a cartographer can congruently depict the nature of temporal changes with a smooth transition, the visual implications of these transitions still derive from the static visual variables (Bertin 1983), which means that the dynamical representation of change may still be inappropriate due to lack of meaning in the visual variable's transition states. We feel that some visual variables transition in more intuitive ways than others. In other words, the intuitiveness of the symbols within transitional frames is directly dependent upon the selected visual variables.

#### *Quantitative visual variables*

For quantitative data that changes smoothly over time we can consider six of the visual variables that would commonly be used in static maps: spacing, size, perspective height, hue, lightness, and saturation (Slocum et al. 2008). Transition of these visual variables would be intended to show continuous progression of values in their transition states. For instance, with perspective height, the intermediate frames between a “short” symbol and a “tall” symbol will be medium height symbols that grow over time in sequence. Similarly, during a transition involving size (e.g., on a dynamic proportional symbol map), the intermediary symbols will gradually shrink or grow over time. However, not all of these quantitative visual variables will be equally as effective at clearly representing the intermediate values. Figure 3 demonstrates how these six variables behave during smooth transitions and demonstrate that not all of the quantitative visual variables have intuitive transitional states. Of these visual variables, the ones appearing to have the most intuitive transitions imply sequential change of an ordinal or quantitative nature. Of course, the visual variable transition cannot be considered in isolation – as we discussed earlier, it is important to also consider the level of measurement for the attribute change – for instance, is the smooth transition of size incorrectly implying numeric change for ordinal data?

#### *Qualitative visual variables*

The sequential nature of the transitions of the visual variables recommended for qualitative data, orientation, shape, arrangement, and hue are less clear than those commonly used for quantitative data. During smooth transitions the qualitative visual variables are less capable of signifying many, but not all, sequential transformations (e.g., cyclical changes between categories such as indicating transition of leaf color through green, yellow, and brown). Transitional symbols between known states are less predictable for qualitative maps; for instance, when transitioning between orange and blue what will the intermediate symbols look like and what do they mean? Similarly, what symbols occur to show the transition between

*“Transitional symbols between known states are less predictable for qualitative maps . . .”*

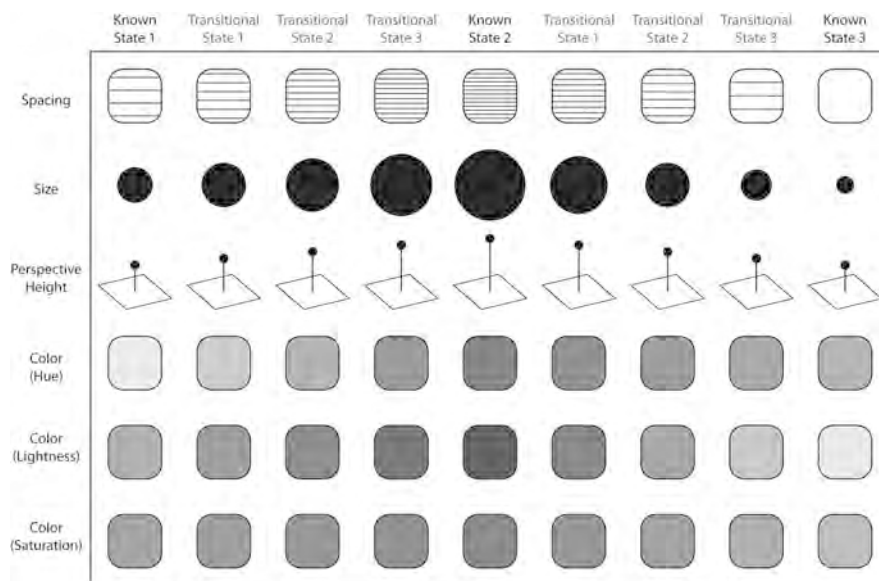


Figure 3. Transition behaviors of six quantitative visual variables. (see page 68 for color version)

a cross and a circle? The so-called “qualitative” visual variables clearly transition very differently than the “quantitative” ones. Figure 4 demonstrates how the qualitative visual variables may behave during smooth transitions.

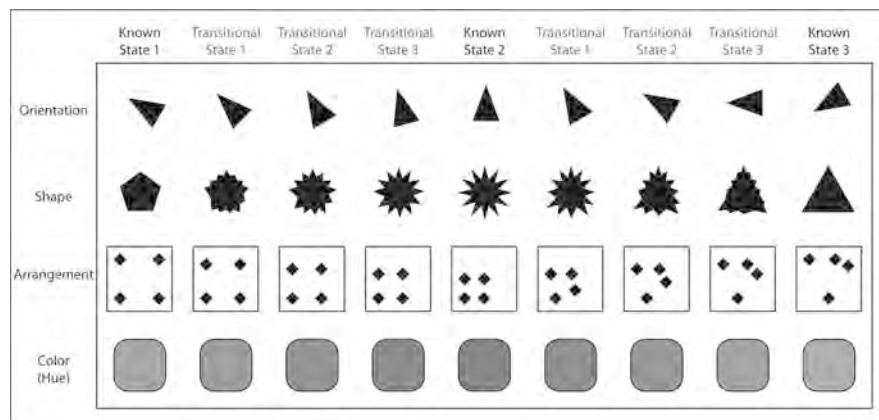


Figure 4. Transition behaviors of four qualitative visual variables. (see page 68 for color version)

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In terms of the congruence principle, the visual variables’ differences in transitional behavior are critical. If a dynamic thematic map intends to imply a gradual or smooth change in quantity between key frames then the cartographer needs to craft a transition that depicts this gradation accordingly. Such a transition needs to be designed in accordance with both the behavior of visual variables during transitions as well as the overall symbolization scheme of the map – which means that there may be some visual variables that are inappropriate for some types of dynamic mapping. Transitional sequences have the potential to represent the temporal structure of an attribute over time; however this potential can only be met if the transitions are intuitive to the map-reader. The transitional sequence is the key to depicting how an attribute behaves in time, yet more research is needed to determine how effective different visual variables are at representing this behavior.

### Discussion

*“... we are at a point where it is important to direct research towards understanding the effectiveness of our designs.”*

From a design standpoint the dynamic cartography literature has often encouraged the use of smooth transitions in animated or dynamic map designs (Lobben 2003; MacEachren and DiBiase 1991; Moellering 1980) rather than relying on apparent motion, or “the illusion of motion created from a sequence of still images” (DiBiase et al. 1992). While this was previously a challenging task, we now have technological capability that makes it easy to artificially create the in-between images that provide a smooth transition between the still images. This means that we are at a point where it is important to direct research towards understanding the effectiveness of our designs. From a cognitive standpoint, it has been suggested that dynamic maps are more effective communication devices when they maintain congruence with the worldly phenomenon that they represent (Tversky, Morrison, and Betrancourt 2002). However, smooth transitions are not always a means to achieve congruence; depending on a phenomenon’s natural change behavior, smooth transitions may mislead readers into believing an abruptly changing phenomenon changes gradually or continuously. This is analogous to portraying a discretely occurring and abruptly changing spatial phenomenon (e.g. number of employees at county courthouses (MacEachren and DiBiase 1991)) with an interpolated surface and isolines. Similar to spatial interpolation, the process of temporal interpolation is only appropriate in certain instances.

The interest in considering smooth transitions in dynamic maps for design and/or cognition purposes leads us to a need to understand how the symbology of dynamic maps behave in transitions and whether or not the symbology is appropriate for dynamic mapping. In this paper we have reviewed three common choices that cartographers must make in designing the static maps that act as key frames in our dynamic maps, level of measurement for data representation, classed vs. unclassed schemes, and the visual variables that we use to represent our attributes. For each of these we have discussed how our decisions in these three areas influence the appearance of map symbology in transition states.

*“The behavior of the symbol can be designed to align with the behavior of the attribute describing the phenomenon.”*

In designing any thematic map we often start by making a decision about the level of measurement at which data will be represented. This decision has substantial implication for creation of dynamic maps; the level of measurement directly influences our ability to both maintain congruence with the geographic phenomenon and to select symbology that is appropriate. At nominal and ordinal levels (and possibly with classed numeric data) it is more complex to develop representations are congruent and graphically appropriate; tweened or morphed in-between stages of cartographic transitions may have little relationship to the symbols that have defined values on the map. It is also questionable whether nominal or ordinal classifications should have any in-between values at all since by nature of the categories, there is often no definition for the in-between classes. For instance, if we mapped the most common major for students in each residence hall on a campus and showed the change over time, what category would be halfway between Geography and Math major? At the numeric level it is easier to attach meaningful values to symbols in the transition, as the attribute’s transition up or down in value can scale the represented value (size, saturation, lightness, etc.) in direct proportion to the data. The behavior of the symbol can be designed to align with the behavior of the attribute describing the phenomenon.

When we look more closely at challenges of using numeric data in dynamic maps we must also evaluate the behavior of our maps when using classed and unclassed data. Similar to nominal and ordinal classifications,

it can be difficult to interpret a smooth transition between classed numerical ranges of quantitative data, which, by definition, have no numerically defined space between ranges – yet smooth transitions can mislead readers by graphically implying that such a space does exist. Smooth transitions are likely more compatible with unclassed maps (e.g. proportional symbol maps or unclassed choropleth maps) since designers can ensure that transitional symbols between key frames correspond with a numerical definition within the symbology scheme. However, smooth transitions on unclassed maps may reduce the perceptual salience of changes and make the map harder to interpret (Fabrikant and Goldsberry 2005).

In considering the behavior of individual visual variables used in transitions we find that there are some that lend themselves to smooth transitions more than others. Many of the so-called quantitative visual variables – size, perspective height, lightness, and saturation perform well in showing in-between stages; these variables each produce intuitive progressions between discrete states. For example, as a symbol smoothly changes in size it will appear to gradually grow or shrink. The qualitative visual variables, orientation, shape, arrangement, and hue are much more challenging to work with to show clear patterns of change.

### Conclusions

With respect to following the Congruence Principle for effective dynamic graphics, we find that smooth transitions are questionable in many situations; the principles of static map symbolization are not always amenable to congruent graphical representation in a dynamic domain, nor do some common design decisions appear appropriate for clearly depicting change. This is not entirely unexpected, however, as it seems unwise to expect map design principles that perform well in the static domain to serve equally well in the dynamic domain (Bertin 1983).

In the recent ICA research agenda on cartography and GIScience (Virrantaus, Fairbairn, and Kraak 2009), the challenges of depicting the temporal nature of geospatial processes was a recurring theme in need of focused research. In light of this, and considering the need to improve our understanding of cognitive aspects of dynamic maps and how the maps can enhance our ability to communicate dynamic processes, we feel that there are still a number of important issues to tackle. Awareness of transition behaviors in our maps is one thing, but it does not guarantee that the message being communicated will be clear to the reader (or will be more effective than using symbology that seem incongruent or inappropriate). It was beyond the scope of this work to evaluate these issues of visual perception; however, this perception issue is critical in the quest to design dynamic maps that are more effective as communication devices. To that end, some of the important unanswered questions that we have identified are:

- Does achieving congruence between cartographic transitions and the natural change behavior for a mapped phenomenon influence the way readers interpret the nature of the change(s)? Map-readers infer ideas about geographic phenomena based upon their graphical structure within an external representation; cartographers need to understand how the appearance of the graphical model influences map-readers' perception of the mapped phenomenon. For instance, Harrower (2007) has found that abrupt transitions in unclassed dynamic choropleth maps were incorrectly seen as being "smooth," falsely implying to the reader that the change occurs continuously.

*"Awareness of transition behaviors in our maps is one thing, but it does not guarantee that the message being communicated will be clear to the reader."*

It has also been suggested that, regardless of congruence, smooth transitions may be more effective at cueing readers to notice change (Fabrikant et al. 2008), which is key to successful communication of dynamic processes. If empirical research indicates that this is the case, it raises the question of whether or not smooth transitions should only be used as a mechanism to achieve congruence with continuous change processes, or if they can also be used as a means to increase the perceptual salience of transitions in dynamic maps.

*“How do dynamic maps work effectively with respect to readers’ internal representations of change?”*

- How do dynamic maps work effectively with respect to readers’ internal representations of change? This paper examined analogies between the form and/or appearance of a real-world phenomenon and external (graphical) representations designed to mimic the phenomenon’s space-time behavior. The correspondence linking the natural structure of a geographic phenomenon and its graphical representation is a central component of the principles of cartographic symbolization (Slocum et al. 2008); cartographers typically employ certain mapping techniques depending on the spatial arrangement and attribute characteristics of the mapped phenomenon. However, even if an external representation achieves statistical correspondence with the mapped phenomenon it does not guarantee intuitiveness. Previous research has demonstrated that observers fail to apprehend information encoded in some complex displays even though they realistically mimic a complex natural phenomenon’s space-time behavior apprehension and there is evidence that merely viewing a congruent animation does not necessarily lead to an accurate internal representation of mapped phenomenon (Hegarty, Kriz, and Cate 2003). This evidence suggests that more cartographic research is needed to help us understand how observers internalize space-time events. If the goal of a map animation is to foster strong understanding of spatiotemporal geographic phenomena, than it is imperative that future investigations measure the effectiveness of animations based upon their ability to facilitate intuitive internal representations.
- How can the uncertainty associated with transitional values be evaluated and (if necessary) communicated to readers? In our attempts to achieve congruence we create new interpolated values to transition between the known values at discrete time steps. It is yet unclear how a reader interprets these transitional values and whether or not they are assumed to be “real” data values, or are simply recognized as a graphical transition. If the assumption is that they are accurate data values then it is imperative that we investigate techniques that provide congruent representations of change while communicating the uncertainty of the transitional data to the reader. The issue of uncertainty in the transition also raises the question of how readers of dynamic maps utilize the legend in their interpretation of displayed data. For instance, does the inclusion of transition states on the legend encourage the reader to identify the transition as a real data value and/or does the lack of a corresponding legend value imply more accurately that a transition is simply a transition, not an accurate representation of value?
- How do we design smooth transitions for qualitative data that make sense? With most quantitative data we can design our maps so that the change to the map symbols scales in proportion to the quantity of change to the phenomenon. However, as we have demonstrated in

this article, the so-called “qualitative visual variables” transition in a less intuitive fashion. As a consequence, gradual changes in qualitative attributes present a difficult challenge to cartographers. More research is needed to help cartographers create intuitive transitions between key states of qualitative attributes.

- What is the just noticeable difference (JND) between symbols in a dynamic map? We have seen research in this area for static map symbology (e.g., examining differences in proportional symbol size (Flannery 1956, 1971), hue, or lightness (Brewer et al. 1997)) but these differences have not been tested in a dynamic environment – what may be sufficient difference for a static map may be insufficient in a dynamic environment. Of particular interest to the authors are the JND issues with proportional symbols and color (hue, lightness, and saturation). Since these are some of the most common visual variables that we rely on in our static maps it is critical to understand more about how they change, how the changes are interpreted (or not), and how we can make them more effective for communicating dynamic processes. Change signals within dynamic thematic maps depend upon, or are derivatives of the graphical structure of the static key frames. The functionality of dynamic thematic maps depends upon the legibility and intuitiveness of change signals, which in turn are dependent on the graphical structure of static key frames. We also feel that it is important to ask if there such a thing is a “just noticeable transition,” or a minimum requirement for producing a perceptually salient change, and can this help mitigate problems of change blindness in dynamic thematic maps?
- How should magnitude of change between scenes influence the design of transitions? Can certain transitional designs enable readers to notice, perceive, and understand more changes than others? For instance, with a classed choropleth map (which may or may not be a good choice to begin with), it seems like we should be particularly cautious with smooth transitions for changes that are greater than one class. In any scheme that involves variation in both hue and lightness or saturation the in-between states are less clear when the magnitude of class change is large. Unless we artificially force our transition to go through intermediate classes the symbol representation in the transition is challenging to interpret due to the creation of an unlimited number of new “transition” classes that have no corresponding symbol in the legend except for at the key frames bookending the transition (Figure 5).

The figure shows the original Color Brewer colors assigned to classes (top), potential transition states for an enumeration unit changing from Class 1 to Class 5 (middle), and a proposed scheme that requires the enumeration unit to pass through the color assigned to each intermediate class during the transition (bottom).

Perception and interpretation are fundamental issues in evaluating the quality of a map – if the map does not communicate clearly enough that the reader can understand the message it is not a successful design. As Tufte has written, “graphical excellence begins with telling the truth about the data” (Tufte 2001, 53), however, as MacEachren and DiBiase (1991, 224) have pointed out, this “inhibits creativity by denying the role of rhetoric.” In a dynamic environment we will always struggle with the spatial and temporal limitations of our data and it is necessary to find creative ways

*“In a dynamic environment we will always struggle with the spatial and temporal limitations of our data . . .”*

*“... there is no reason to show continuously changing phenomena in an abruptly changing slideshow format ...”*

*“... there are substantial challenges in how we best represent the dynamic nature of these phenomena.”*

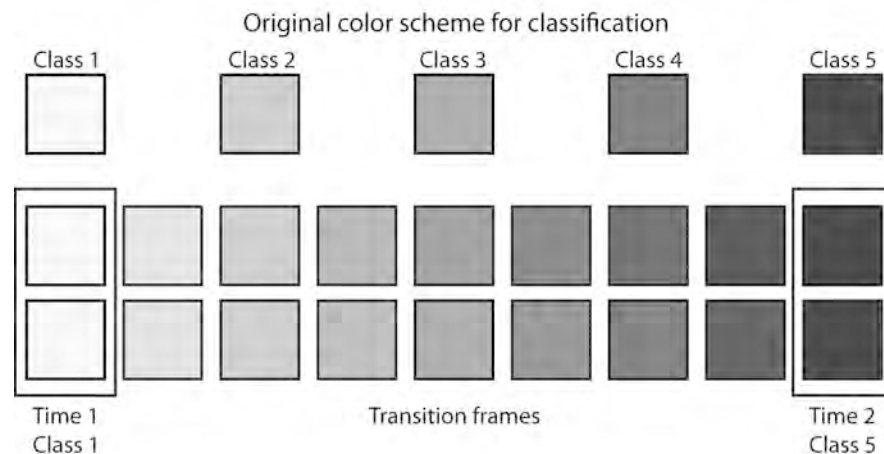


Figure 5. Possible transition states for a classed dynamic choropleth map. The figure shows the original Color Brewer colors assigned to classes (top), potential transition states for an enumeration unit changing from Class 1 to Class 5 (middle), and a proposed scheme that requires the enumeration unit to pass through the color assigned to each intermediate class during the transition (bottom). (see page 69 for color version)

to fill in the gaps between collected data points in order to clearly communicate dynamic processes as accurately as possible. With our current technological capabilities there is no reason to show continuously changing phenomena in an abruptly changing slideshow format, however, there are substantial challenges in how we best represent the dynamic nature of these phenomena. When considering the problems that may arise with common choices for static maps, it becomes clear that we need critical evaluation of the cartographic communication process in dynamic mapping – specifically on how we conceptualize the change process and how these design / symbolization choices impact the reader’s perception and interpretation of our dynamic maps.

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