The Production of Smooth Scale Changes in an Animated Map Project

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The proliferation of home and business computers has resulted in a dramatic increase in the number of animated maps in private, institutional, commercial, and academic settings. As authoring software that allows the production of such maps becomes cheaper and easier to use, animated maps will continue to become more numerous and sophisticated. This increase in the number and complexity of animated maps and the resultant need to automate their design and production calls for novel cartographic approaches. This paper stems from a project involving the design of animated maps for a typical multimedia product. An important element of the animations were the transitions between maps of different scales. An explanation of an algorithm to choose map scales suggests how aesthetic judgments can be incorporated into the automated production flow for the finished product.

ANIMATED MAPS, INTERACTIVE MAPS, AND HYBRID MAPS

Dynamic maps can take the form of animated maps, interactive maps, and combinations of the two. I will use the term *dynamic* to refer to the broad category of maps that can change during viewing. *Animated* maps offer little user control and present changes of map attributes in a manner that is either logically or chronologically linear. *Interactive* maps allow the user to adapt or control the map display.

Map design strategies for dynamic maps have categorized the maps according to the primary characteristic exploited by the temporal dimension: sonification, animation, and interaction (DiBiase et al. 1992). Sonification involves the use of sound to represent data (Krygier 1994), but since there is no fundamental role played by map scales in this type of map sonic maps will not be addressed in this paper. Scale changes are, however, useful and well-suited to animated and interactive maps. The animation in which there is "the illusion of motion created from a sequence of still images" (DiBiase et al. 1992) is perhaps the most common form of map animation. These maps, commonly found on television newscasts and educational computer software, are linear presentations of a series of frames or static map images. Scale changes are particularly useful for illustrative purposes in this sort of animated narrative (Dorling 1992b, 633). The animated maps discussed in detail later in this article are of this type.

Much of the literature on animation has emphasized its use for representing time series data. Some attention, however, has also been given to the role of animation and interaction for exploring non-temporal data (e.g. DiBiase et al. 1992, Dorling 1992a and 1992b). In the context of what he calls *animating space*, Dorling argues that changing the scale of the map is the only way to properly examine large and complex data sets (Dorling 1992a, 1992b). When the change over time of the mapped data is too complex for the observer to notice both spatial and temporal patterns, Dorling argues for temporally static maps, or maps that show a time slice from a particular moment. Zooming and panning across these maps allows the examination of details in cases where aggregation of data is unacceptable. This strategy of animating space instead of animating time is particularly useful in the social sciences where extreme variations in data values are found over small areas.

Unlike animated maps, interactive maps have no fixed structure; the user interacts with the display to view different scenarios or representations. The interaction allows the user to question data to gain a better understanding, or to tailor the display to match the knowledge the user brings to the map. Monmonier (1991, 4) points out the need for an "antidote" to the "dangerous abuse" that his Atlas Touring and other "carefully orchestrated sequence(s) of persuasive graphics" invite. He mentions the need for "experiential maps" that allow users to explore data interactively, thereby forming their own opinions.

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Interaction is essential in the analysis of three-dimensional digital data models (Moellering 1980). Kraak mentions the importance of geometric transformations in the visualization of three-dimensional maps, citing their complexity and the difficulty of the human mind to process depth clues. "Manipulation of the maps is not restricted to their content, but also includes their position in three-dimensional space" (Kraak 1993, 13–14). Geometric transformations like zooming, scaling (both involve scale changes) and rotating are necessary in order to take advantage of the added information in the terrain model. Since the display method—the monitor—is two-dimensional, interaction is necessary to "see" the information added by the three-dimensional model.

The importance of smooth scale changes in dynamic interaction and animated maps is underscored by a report (Harwood 1989) on dynamic map displays for helicopter flight. Pilots used on-board map displays for a variety of tasks, and their success was shown to improve when the map displays were smooth and unobtrusive. Similarly, researchers have found "greater user preference for and confidence in representations which provide smooth change between images" displayed on computer monitors (Rheingans 1992).

DESIGN FOR A MULTIMEDIA ENCYCLOPEDIA

Scale changes proved to be invaluable in keeping map viewers oriented and the narration coherent in thirty animated maps commissioned by Grolier for its *New Grolier Multimedia Encyclopedia* on CD-ROM (Grolier 1994). This encyclopedia is aimed at adult and high school-aged home users, and the animated maps were a major selling point for the 1994 version. The maps portray major world events such as the Gulf War, the Korean War, Magellan's circumnavigation of the world, and the spread of overland routes across the colonial United States. The animations include audio narration and also text narration for micro-computers that have no sound capability. Flashing symbols and areas are used to highlight important static map information while movement is represented with flow arrows and sprites.[1] The publisher's priorities were in creating a product of high aesthetic quality and visual excitement. David DiBiase has written in detail about the project (DiBiase 1994).

The design of the maps was intriguing because guidelines and conventions for the medium have not yet been established. Another challenge was the fact that the publisher failed to determine how well the animations, delivered in the form of Macromedia Director movies, would survive the final transition to QuickTime movies.[2] Finally, Grolier 's assumptions about the typical user's computer configuration limited, for example, the number of frames that could be used and the size of the maps on screen.

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[1] Gersmehl (1990) provides a glossary of this and other terms frequently used in animations.

[2] See Cartwright (1994) for an explanation of QuickTime and other technical terms.

MAP DESIGN

The pressure of designing fifteen animations in only twelve weeks forced us to confront many issues in a hurry. What elements that are common to static maps should be included? Which elements are redundant and should be abandoned? While these and similar issues regarding the transition from static to animated mapping have been noted (Cartwright 1994), few guidelines or design principles exist. Gooding and Forrest are clearly correct when they state that ". . . if video maps are to be used effectively, they should be developed specifically for that medium" (1990).

Similarly, our animated maps had to be designed for the desktop personal computer medium using CD-ROM. Resolution was limited to the 72 pixel–per–inch monitor standard to contain file size and the amount of required storage space on the CD-ROM. The map area was limited to a field four hundred pixels wide and two hundred eighty pixels high (roughly 5.5 by 4 inches) to ensure that the animations fit on the smallest Macintosh screens. This made the choices of map elements critical. Too many elements on the map display seemed to clutter the geographical information. A legend was one of the elements we found to be superfluous for our animated maps. It was more effective to explain an event and its players with spoken and written narration than by filling the map with placename lettering.

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The most significant and fundamentally unique design concern for the maps was the possibility of using time as a variable to express information (DiBiase et al. 1992, Kousoulakou and Kraak 1992, Kraak and MacEachren 1994). The use of animation time to correspond with historical time was fundamental to the animations produced; the stories were usually told in a chronologically linear fashion. Flashing symbols to symbolize events such as battles drew the viewer's attention to small places on small–scale maps. Repetition of animation sequences represented repeated attacks on cities. The timing of the story (through the manipulation of how long an animation frame was displayed) was important for making the stories comprehensible. Timing was also used for dramatic effect to underscore the numbers of people killed in wars.

The display of different maps at different scales over the course of the animation was essential to keeping the narratives coherent, and appropriate scale changes were the crucial link between these maps. Changing scale meant that the story could be played out on a map that was always at the appropriate scale for the subject matter. Making the scale change smooth provided a link between the maps and kept the viewer spatially oriented, providing a coherent narrative while keeping the viewer's attention focused on the story subject and not on the scale change.

THE ROLE OF SCALE CHANGES

The nature of the events to be animated demanded that we use maps at different scales. The animation of the Korean War, for example, opens with a map of southeast Asia to acquaint the viewer with the location of Korea. Narration then switches to a map of Korea on which troop movements can be shown. The animation of the United States Revolutionary War repeatedly changes scale. A small-scale map shows the shape and size of the original colonies to set the scene, then large-scale maps of troop movements in, for example, the New York–New Jersey region express the local and regional events.

Traditional static maps use insets to show where in the world the featured place is, or to show an area of detail. The nature of animations, however, makes these inset maps extraneous and pointless (and a cause of eye strain in a window less than six inches wide). Instead, maps can be presented as *dynamic insets* at the scale that is appropriate to the thematic information. Over time, the display can shift from one map to another at a different scale, thereby overcoming the spatial constraints that apply to the printed page. This is an example of the effective exploitation of the temporal dimension of animations.

An abrupt switch in an animation from one map scale to the next without a transition would be disruptive to the animation and to the flow of information, obscuring the spatial relationship between the maps, thereby disorienting the viewer. Therefore, there is a need for transition techniques such as *zoom-ins, zoom-outs,* and *exploding insets* (terms to be defined below) to provide the link between different maps. As is the case with many map design choices (like those concerning typeface, layout, and color palette), the effectiveness of these transitions lies in their ability to allow the map reader to remain focused on the theme of the map. Good map design avoids attracting the viewer's attention to individual elements by ensuring that the map elements remain transparent. Map animations, therefore, need to shift between different maps without losing the map user's attention to the transition.

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One way to accomplish this is by using a high number of frames in order to give the impression of continuous change. This ideal situation would be possible with unlimited memory space, but limits on the number of frames allowed are imposed at every link in the chain from the cartographer's computer to the display on the consumer's monitor. Animation files, especially when they include audio tracks as Grolier's did, require substantial amounts of storage space, a function of the length of the animation, the size of the animation window on the screen, audio bit depth (a function of the variation allowed in pitch, timbre, etc.), and the color bit depth (a function of the number of colors used in the palette).[3] Even when storage space isn't the issue, only the fastest microcomputers can move from one frame to the next at a rate faster than the eye can perceive a change on the screen. Finally, the monitors on which these animations are viewed can only refresh (or paint the next image onto) their screens at a certain limited frequency determined by their scan rate. Inevitably, then, a sophisticated viewer is able to distinguish between individual frames. But if the transition is well designed, the viewer's attention will be kept on the map and not on the difference between individual frames. Since technologic constraints demand that the number of frames remain small, the care put into the selection of transition frames must be great if transitions are to play their role inconspicuously.[4]

AN EQUATION TO DESCRIBE THE SCALE CHANGE

The simplest example of a scale change that we will consider is a zoom-in from a small-scale map to one of larger scale. Each map in the zoom is at a larger scale than the previous one, and its land area is smaller than the previous map's area. There is always only one map visible, and that map takes up the entire animation window.

Thematic content determines the map scales at the beginning and end of the zoom. The number of desired steps, or frames (usually a compromise between memory limits and desired frame resolution), must also be known. Regular intervals from one scale to the next, as defined by

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[3] Typical size for an animation file made with Macromedia Director by the author was 1.2 megabytes. The files had eight-bit color, a dimension of 400 by 280 pixels, no sound, and were about three hundred frames in length.

[4] The need to keep transitions "transparent" precluded using scale change techniques like motion-blur exploding insets and other techniques as too distracting.

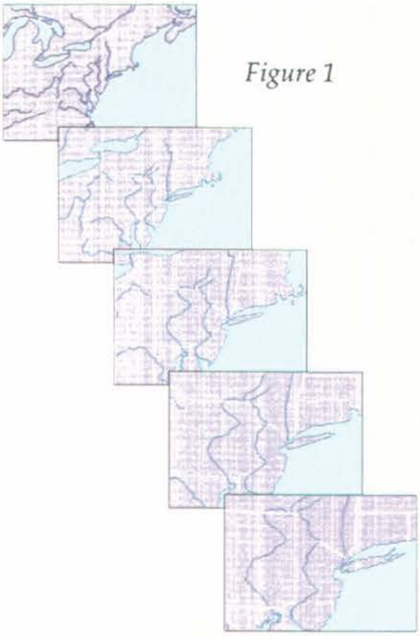

Figure 1

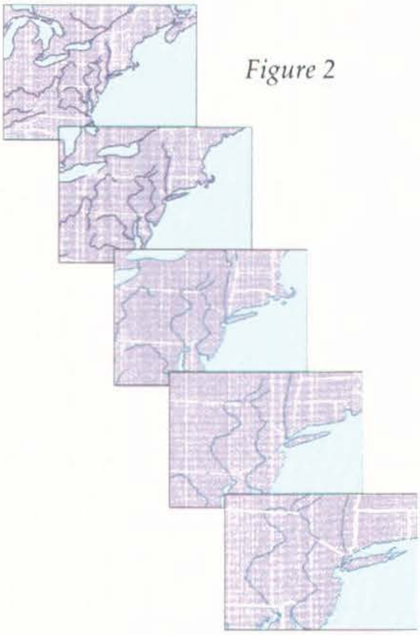

Figure 2

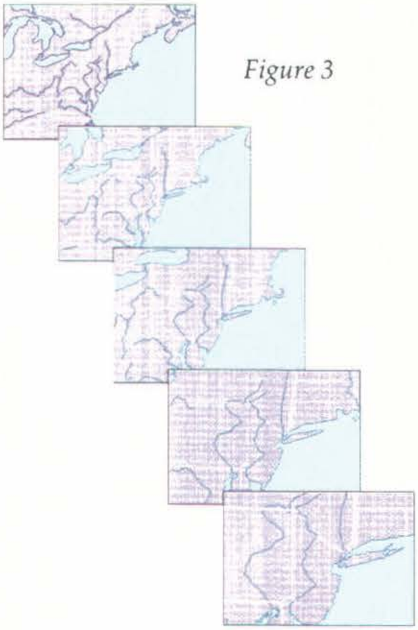

Figure 3

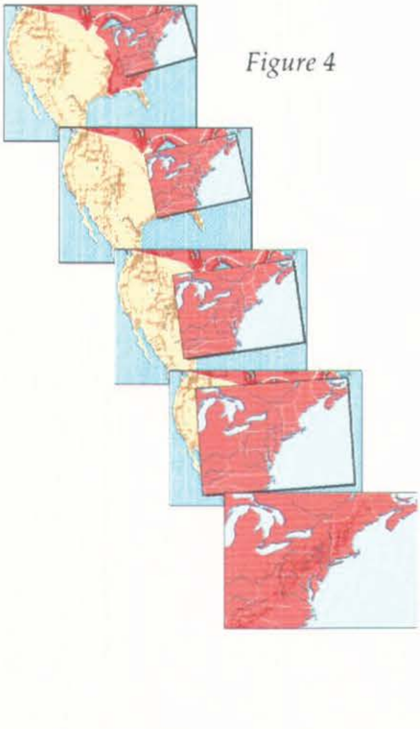

Figure 4

Equation 1 and exemplified with a hypothetical zoom in Table 1 (page 18), are easy to calculate but yield a scale change that is uneven.

When David DiBiase, project manager and director of Deasy GeoGraphics Cartographic Design Studio at Penn State University and I viewed this zoom on a monitor we judged that the zoom was inappropriate. The change in land area covered by the first frames was too great, and it was too little at the end of the zoom. Figure 1, for example, shows a significant leap in size of Long Island between the first two frames, while its size changes only slightly at the end of the zoom-in.

We then drew an exponential curve based on the equation $y=x^2$ on graph paper and read off the intermediary scales for the frames between our known starting and ending map scales (Equation 2). This seemed logical since the equation describes the relationship between the scale and the area covered by any map. But this equation we also deemed inappropriate. The size of New Jersey (see Figure 2) still changed too much at the start of the zoom-in and too little at the end.

Interpolating intermediate scales with logarithmic paper yielded zooms that we judged appropriate. Figure 3 shows how Long Island's size changes at a steady rate when the map scales are determined by Equation 3. All zooms and exploding insets made thereafter were made by drawing a straight line between the starting and ending points of the scale change on logarithmic paper. Zoom-outs were used frequently in the animations when the map scale decreased. They were constructed exactly like zoom-ins but with order of frames reversed.

The exploding inset (Figure 4) is another transition that allows the animation to move to a map of larger scale. Like a traditional inset on a static map, the exploding inset begins with a small-scale map with a box drawn around the area that is to be shown at a larger scale. The small-scale map remains in the background as the large-scale map section of interest increases in size until it is occupying the entire animation window, blocking out the small-scale map. The same logarithmic equation used for zooms describes exploding insets. Whereas map size remains constant while land area changes for zooms, the inverse is true for exploding insets: the land area covered by the map is fixed while the map itself grows (in the case of the exploding inset) or shrinks (imploding inset).

Tables 1–3 (page 18) track the scales of four intermediate iterations of a six-step exploding or imploding inset. The scale factor represents the relationships between each iteration and the starting map scale. The next column represents the portion of the original map's area taken up by each subsequent map of the same region at a smaller scale. The crucial column is the last one which shows how the size of each map varies from the previous map's size. For the logarithmic equation this number is constant, indicating that a transition that seems smooth is one in which the inset "blows up" or "collapses" at a steady rate.

Equation 1

$$\text{scale}_n = \text{scale}_{beg} + n\left(\frac{\text{scale}_{end} - \text{scale}_{beg}}{N}\right)$$

Equation 2

$$\text{scale}_n = \left(\text{scale}_{beg} + n\left(\frac{\text{scale}_{end} - \text{scale}_{beg}}{N}\right)\right)^2$$

Equation 3

$$\text{scale}_n = 10^{\log(\text{scale}_{beg}) + n\left(\frac{\log(\text{scale}_{end}) - \log(\text{scale}_{beg})}{N}\right)}$$

where:
n = the iteration in the scale change
N = total number of steps in scale change
scale_{beg} = map scale at beginning of scale change
scale_{end} = map scale at end of scale change

The production staff and the rest of the Deasy staff were responsible for deciding which zooms were appropriate. The project's commercial nature and short production time–frame meant there was no possibility of having outside reviewers or focus groups. The discovery of constant change of area for the logarithmic equation confirmed our subjective decision that this equation yielded the most appropriate scale change. Ours was an aesthetic judgment that, according to the tables, seemed to have an objective basis in the inherent relationships between map scale and map area.

GENERALIZATION AND PERCEIVED MAP SCALE

Generalization of features and linework as scales change is an important consideration. Some researchers argue that a feature like a city could be represented by three different symbols depending on the scale. "As you zoomed in on the city, its appearance would jump from one representation to the other" (Dorling 1992a, 218). This is acceptable, Dorling argues, because the change is not unexpected, and because it is a very efficient way to show scale changes without having to recalculate images on the fly. Although this strategy is acceptable for an interactive environment where the exact scale that the user chooses cannot be anticipated by the programmer, this solution is neither appealing nor necessary in non-

ARITHMETIC EQUATION

iteration	map scale	scale factor (scale$_1$ / scale$_n$)	map area relative to map$_1$ area (scale factor^{-2})	map area relative to area at previous iteration
1	1:500,000	1	1	
2	1:600,000	1.200	.694	69.44%
3	1:700,000	1.400	.510	73.47%
4	1:800,000	1.600	.391	76.56%
5	1:900,000	1.800	.309	79.01%
6	1:1,000,000	2.000	.250	81.00%

Table 1

PARABOLIC EQUATION

iteration	map scale	scale factor (scale$_1$ / scale$_n$)	map area relative to map$_1$ area (scale factor^{-2})	map area relative to area at previous iteration
1	1:500,000	1	1	
2	1:586,277	1.173	.727	72.73%
3	1:679,416	1.359	.542	74.46%
4	1:779,419	1.559	.412	75.99%
5	1:886,285	1.773	.318	77.34%
6	1:1,000,000	2.000	.250	78.55%

Table 2

LOGARITHMIC EQUATION

iteration	map scale	scale factor (scale$_1$ / scale$_n$)	map area relative to map$_1$ area (scale factor^{-2})	map area relative to area at previous iteration
1	1:500,000	1	1	
2	1:574,381	1.149	.758	75.78%
3	1:659,781	1.320	.574	75.79%
4	1:757,879	1.516	.435	75.79%
5	1:870,563	1.741	.330	75.79%
6	1:1,000,000	2.000	.250	75.79%

Table 3

interactive situations where the scales are predetermined. Increasing viewer sophistication demands that we strive for generalization strategies that are more subtle and draw less attention to scale changes. The time it would take to recalculate images on the fly on the computers that Grolier expects its multimedia encyclopedia to be viewed keep this from being a viable option.

One study (Eastman 1981) suggests that the alteration of the graphic elements on a map plays an important role in the viewer's perception of the map scale. Eastman studied the effects of varying line density, symbol size, and type size, and found that subjects could notice relative scale changes between static maps. Although changing the map elements did not always elicit the same changes in perceived scale, and judgments about how the scales of the sample maps compared were not consistent, generalization levels are nevertheless a factor in the perception of scale.

When maps of different scales appear in animated maps as dynamic insets, therefore, the level of generalization can act as an important second clue. An increase in the amount of detail following a zoom-in to a large-scale map would certainly be expected by the viewer, just as static, large-scale inset maps contain more detail. Our maps, however, were mainly backdrops for the story, a geographic reference locating the story. Zoom-ins were necessary not so that viewers could better see landscape features, but so that the subjects' movements (troops' or ships' routes, for example) could be displayed on a large-scale map. In accordance with Eastman's findings, we used slightly different colors in our insets to suggest a change of scene.

The small size of our animations meant that generalization was determined by the software, not the map scales. Final assembly was done in Director where all lines at all scales needed a width of at least one pixel in order to not become interrupted. Therefore after scaling the maps in Aldus Freehand according to the equation, line weights were made constant in all the maps of the zoom, regardless of their scale. The low resolution of 72 pixel–per–inch monitors limited the amount of detail permissible. As increased computer power and improved compression rates will allow higher resolution, animated map displays will, in turn, increase in size, increasing the need for appropriate generalization levels as scales change. Töpfer's *radical law* (Töpfer and Pilliwizer 1966) is a theoretical proposal that suggests the degree of generalization for different map scales. His equation could be incorporated into an algorithm producing scale changes for animations. Experience from this project, however, would indicate that a logarithmic equation might be more appropriate.

CONCLUSION

Adaptation of traditional cartographic techniques to mapmaking with animated media needs to be considered on a case–by–case basis. While many conventions need to be retained, other elements are redundant and can be eliminated from animated maps. The inset map is an example of a feature common to static maps that serves no useful role in animated maps. Its replacement, the dynamic inset map, appears to be useful and intuitive for the viewer when its transitions are designed well.

Animated maps and interactive dynamic maps can both be enhanced with appropriate scale changes, regardless of the application. Zooms between maps at different scales allow the user to investigate the mapped subject close up, or allow the animation to continue to the next section of the story while the user remains geographically oriented. The logarithmic equation offered in this paper is a useful step in the automation of the design of such scale changes so that these transitions can be the inconspicuous links that make possible a coherent, informative narrative.

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NOTE

An animation comparing zooms made with the three equations is available from the author. The file is in Macintosh format; no special software is required. ☐