

Animation-Based Map Design: The Visual Effects of Interpolation on the Appearance of Three-Dimensional Surfaces

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Computer animation is a potential aid in map design, because it provides a means for quickly reviewing many design alternatives. This research is a conceptual exploration of one aspect of animation-based design: The effect of inverse-distance weighting on the visualization of three-dimensional maps. The primary variable examined is the inversedistance weighting exponent. Changing the exponent in small intervals allows the creation of a series of three-dimensional maps that can be assembled, and played back as a frame animation. In this procedure, cartographers can view the visual effects of various exponents on the resulting surfaces. Design-based animations allow mapmakers to visualize effects of their decisions in advance of map production and to make more informed design decisions. It is suggested that this method can be expanded to examine map design for a great many forms of cartographic symbology. Ideally, automatic frame generation and a graphic user interface should become an integral part of the development of these visualizations.

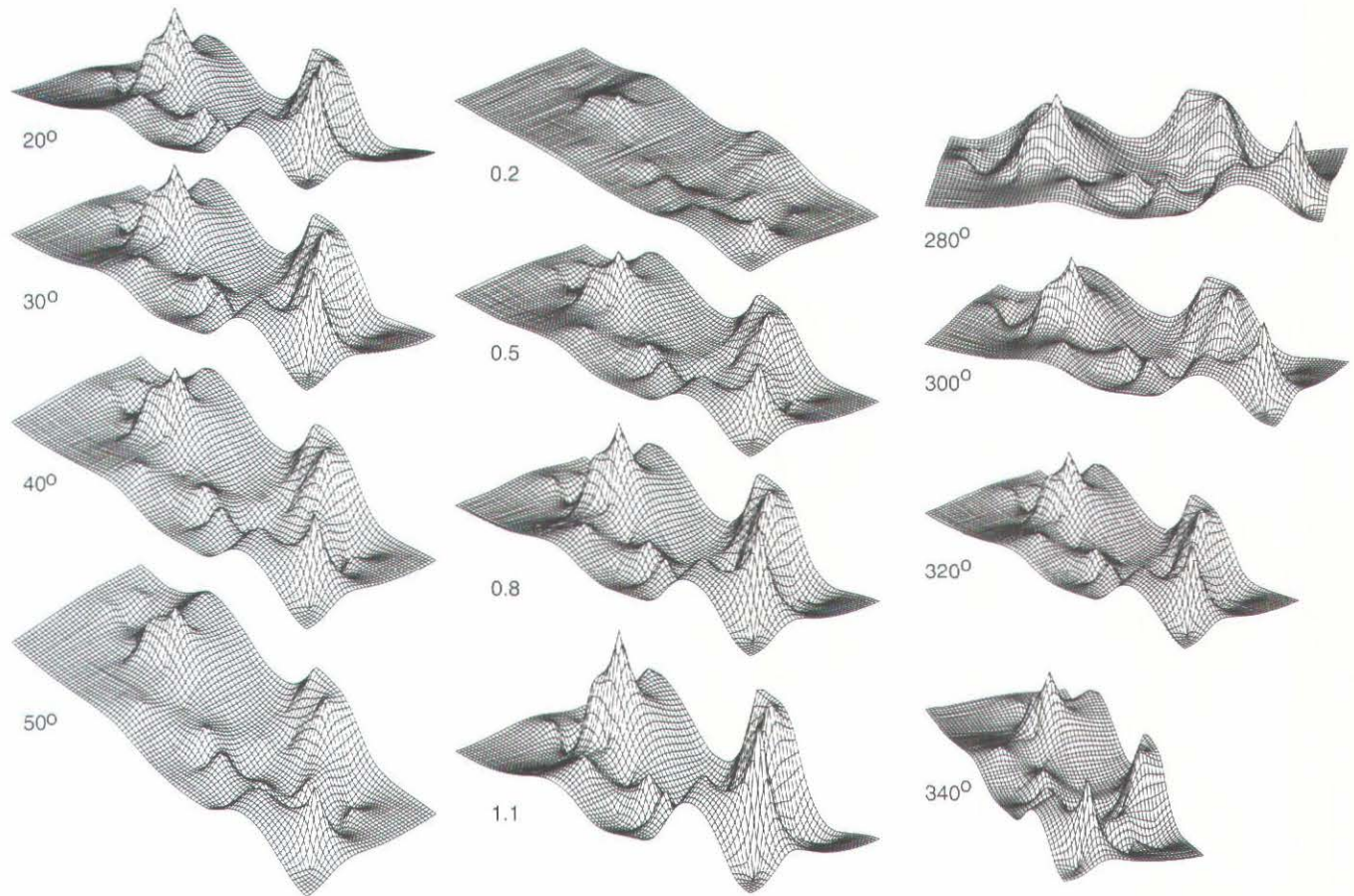
KEY WORDS

Animation, cartography, map, interpolation, inverse-distance weighting, map design, three-dimensional maps, visualization.

INTRODUCTION

The mapping of continuous geographic phenomena in three dimensions presents a significant challenge to the design-oriented cartographer. The challenge is a consequence of the variety and interplay of design decisions which, in various combinations, can radically alter the appearance of a map, and because of the greater than usual difficulty map-users have in interpreting three-dimensional maps (Rowles 1978, Jenks and Crawford 1971). Continuous spatial data is either measured or derived at control points, which, to a degree, are representative of the phenomena. In many cases, mathematical interpolation is then used to create a more extensive network of data values from which a visual depiction can be subsequently generated. The look of the surface is heavily dependent on choices made during interpolation, and these choices are numerous, including grid size and shape, search methods, and interpolation equations (Golden Software 1990). Depending on the interpolation methods selected and the parameters used in the interpolation algorithm, the resulting maps may give very different impressions of a single geographic data set.

Another set of design decisions are encountered following interpolation. These are decisions involving the visual orientation of the three-dimensional surface. These decisions deal more directly with visual map attributes, and for that reason, are more predictable in their visual manifestations than those involving interpolation. Figure 1 shows a variety of options including surface rotation, angle of view from the horizon, and vertical exaggeration, as well as a number of other controls that affect the eventual look of the surface. Although these choices can also profoundly influence map appearance, their effects are somewhat easier to anticipate than those involving the mathematical equations of interpolation. For



Vertical Angle. An angle of 90 degrees places the viewer directly above the surface

Vertical Exaggeration. A value of zero would show a totally flat surface.

Horizontal Rotation. A rotation angle of 360 degrees places the viewer due east of the surface.

Figure 1. Orientation variables in three-dimensional mapping

example, it is easier to envision what will happen to a surface if the angle of view above the horizon is changed from 30 to 50 degrees than it is to predict the visual effects of changing the inverse-distance weighting exponent from one to three. Consequently, this research is concerned with the more difficult case of visualizing the effects of interpolation decisions.

While it is true that contemporary three-dimensional surface-producing software allows experimentation with the effects of design choices on map appearance, this is usually accomplished one map at a time and normally requires many iterations before a satisfactory map is created. For example, SURFER (Golden Software 1990), a popular isoline and three-dimensional mapping program for Windows/DOS-based computers, permits the creation of one surface at a time, and does not give the user the capability to view a number of different surfaces in rapid succession. It is difficult and time consuming to compare the visual results of design alternatives, and this hampers the cartographer's ability to identify the most appropriate selections for representing data and communicating accurate and useful visualizations of geographic data.

Animations are potentially valuable aids in selecting optimum ways of designing three-dimensional maps, representing data, and gaining a more complete understanding of geographic data through exploration of varying interpolation options. Furthermore, many other types of cartographic symbols can be explored using similar methods. Although our

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focus is just one aspect of three-dimensional mapping, it is not unreasonable to assume that animation can be used to explore variations in unit-value in dot mapping, or the visual effect of varying isoline intervals, for example.

Visualization

Geographic visualization is an act of cognition through which mental images of geographic data which have no visual form are developed (Peterson 1995, MacEachren 1995). This notion of visualization can be extended to the realm of computer cartography in which data stored in computer memory can be displayed visually. Cartographic visualization of geographic data can facilitate examination and explanation of processes which evolve over time, over space, or a combination of both (Campbell and Egbert 1990). It is also a concept which focuses on the exploration of data rather than data presentation. As such, cartographic visualizations created with exploratory data analysis in mind are generated as animation sequences used to identify trends and relationships in the data. This identification which may or may not be observed in a non-visual setting, prompts new understanding of research problems or real world applications (MacEachren and Ganter 1990).

In our study map animation is used to construct a sequence of maps created by incrementing the weighting exponent in the inverse-distance equation. Visual differences between adjacent maps in the sequence may at first seem negligible, but examination of a lengthy animation sequence reveals pronounced variations as the weighting exponent increases. Clearly, animation enables mapmakers and map-users alike, to perceive differences which may otherwise go undetected when viewing a series of static maps, perhaps even the same maps that compose the animation. Animation adds a dimension to map interpretation and analysis that the viewing of individual static maps can not provide, just as the experience of viewing a motion pictures is quite different from looking at a sequence of individual stills from the same film.

This study is restricted to developing a case study whereby a sequence of three-dimensional surfaces is produced in which visual differences between surfaces are a result of small variations in the weighting value used in the inverse-distance weighting interpolation algorithm. Additionally, the method of control point search in interpolation was varied in one instance in order to provide a slightly different perspective to animation-based design in three-dimensional mapping. The sequence of changes in surface smoothness revealed by the animation allows map-designers to visualize and compare the effects of changing variables in the creation of three-dimensional surfaces.

Continuous Surface Interpolation

Interpolation of continuous geographic data for the purpose of three dimensional mapping provides estimates of data values for geographic attributes, such as precipitation and temperature, at unsampled grid points within the area of existing control points. The rationale behind all interpolation is that points close together in space are more likely to have similar values than points further apart (Monmonier 1982). Rather than drawing boundaries and generalizing the area around known control points as homogeneous, interpolation is used to model the expected variation of values within an area (Burrough 1986). Interpolated values are then used to generate a visual surface representative of the continuous nature of the phenomena being mapped.

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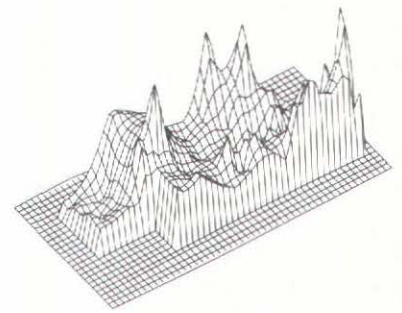
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The challenge of interpolation is to choose a technique which creates a plausible model of the variation between control points. Selection of the most appropriate method depends on the type of data used, the amount of computational time available, and the degree of accuracy required (Lam 1983), although this last factor is difficult to anticipate in advance. A wide variety of algorithms have been developed for point interpolation. For example, surfaces constructed by kriging, minimum curvature, and inverse-distance weighting interpolations are shown in Figure 2. As can be seen, variations in interpolation method can produce pronounced visual differences. Kriging is a regional variable theory technique that assumes an underlying linear variogram, and because of this it can produce an estimate of error associated with an interpolation (Burrough 1986, Sampson 1975). Minimum curvature keeps the grid surface fixed at known control points while iteratively applying an algorithm to smooth the gridded surface. Its primary benefit is that the resulting surface is constrained to pass through all control points (Golden Software 1990). Other interpolation methods include splines, polynomials, Fourier Series, Power Series Trend, and distance-weighted least-squares (Lam 1983). Each technique has a different way of modeling the variation between control points and produces a map surface with a distinctive appearance. Although it is beyond the scope of this paper to address benefits and liabilities of each interpolation method, consideration of these factors is an important cartographic endeavor, and the reader is referred to an excellent summary of interpolation methods written by Burroughs (1986, pp. 147-166).

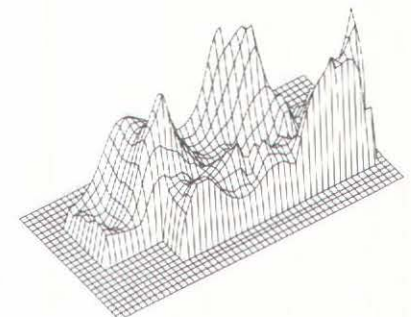
Inverse-distance weighting, the interpolation model used herein, was selected for several reasons. Inverse-distance weighting is a relatively simple technique, and due to its simplicity and availability in existing computer mapping software, is commonly used. Widespread application of this technique in cartography makes it a reasonable selection for demonstrating its visual manifestations. The general advantages of using inverse-distance weighting are that computation time is minimal, and the algorithm is relatively easy to understand (Burrough 1986). This last point will be discussed later in the section of this paper dealing with the detailed interpretation of changes seen in the maps due to variations in the interpolation weighting.

Most commonly, inverse-distance weighting is a type of moving average computation in which intermediate point values are calculated as an average value of a local neighborhood or 'window' (Burrough 1986). This aspect is also referred to as 'piecewise' because only a portion of the control points are used to calculate grid values, although all control points are sometimes used in interpolation (Lam 1983). By limiting the number of control points selected, local anomalies of the data can be represented without affecting the interpolation of other points on the surface (Burrough 1986). However, an inverse-distance weighting technique that encompasses all control points can be used to create a more generalized and smoother surface.

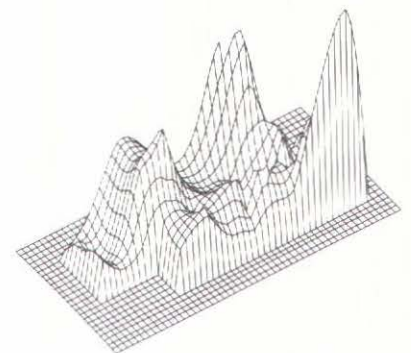
Because observations close together tend to be more alike than distant observations, distance between control points is a key element in the model. The contribution of each control point to the local average is based on its distance from the grid location. Distance is incorporated into the inverse-distance weighting equation as the quantity d , as shown in equation 1. The equation calculates a new data value (Z_{new}) for each grid intersection (I) on the interpolated surface. The last variable to be discussed, and the most important to this research because its visual effect can be observed in the animations produced, is the weighting exponent (w). As the weighting exponent increases, the influence of nearby points



Inverse Distance Weighting
(weighting = 2)



Kriging



Minimum Curvature

Figure 2. Examples of variations in three-dimensional surfaces resulting from three different interpolation methods. Data mapped are total July, 1995 precipitation for Nebraska.

$$Z_{new} = \frac{\sum (Z_i/d_i^{wt})}{\sum (1/d_i^{wt})}$$

where:
 Z = z value
 d = distance
 wt = weighting value

Equation 1. Inverse Distance Weighting Equation

on the local average also increases while the influence of more distant points decreases. Emphasizing nearby points creates more peaks and valleys in the surface in contrast to the smoother appearance resulting from the use of a low weighting exponent which gives distant points more numerical equity in the computation.

A single set of data values located at control points can be subjected to inverse-distance weighting interpolation and then, by incrementally increasing (or decreasing) the weighting exponent in small numerical steps, a sequence of maps showing weighting exponent effects on visual surfaces can be generated. Maps thus generated can be played back as a frame-by-frame animation, and the effects of differences in the weighting exponent can be observed. This can be done for either isoline or three-dimensional maps, but only three-dimensional maps are used in this research. The mapmaker, after a thorough examination of the animation, can then choose the map deemed most appropriate for the mapping purpose at hand, or the model or theory being examined. This type of visualization through animation can serve as a map-design tool whose utility extends well beyond visualization of weighting exponent effects and into numerous other arenas of map design, in ways that Peterson first explored in his sequencing experiments with choropleth maps (Peterson 1993).

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Constructing the Animations

Data for the animations was acquired from weather stations across the state of Nebraska. A total of seventy stations were used. At each of these control points (locations shown in Figure 3), precipitation for the month of July, 1995 was recorded. Animation frames were created in SURFER, v 4.5 (Golden Software 1990), and then imported into Animator Pro, v 1.2 (Autodesk, Inc. 1991) for playback. Figure 4 shows a selection of frames from two of the animations that were eventually constructed.

Control points used in the animation were selected because these climate stations have fairly uniform spacing throughout the mapped area. Inverse-distance weighting interpolation is easily affected by non-uniform

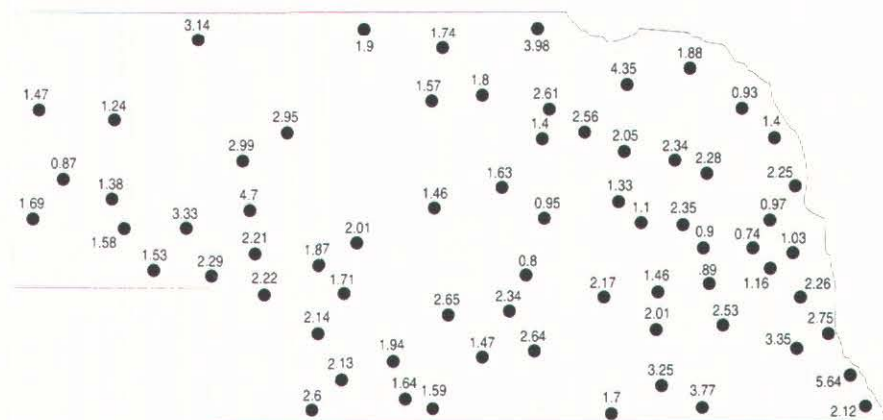


Figure 3. Location of control points and associated total July, 1995 precipitation values for the maps.

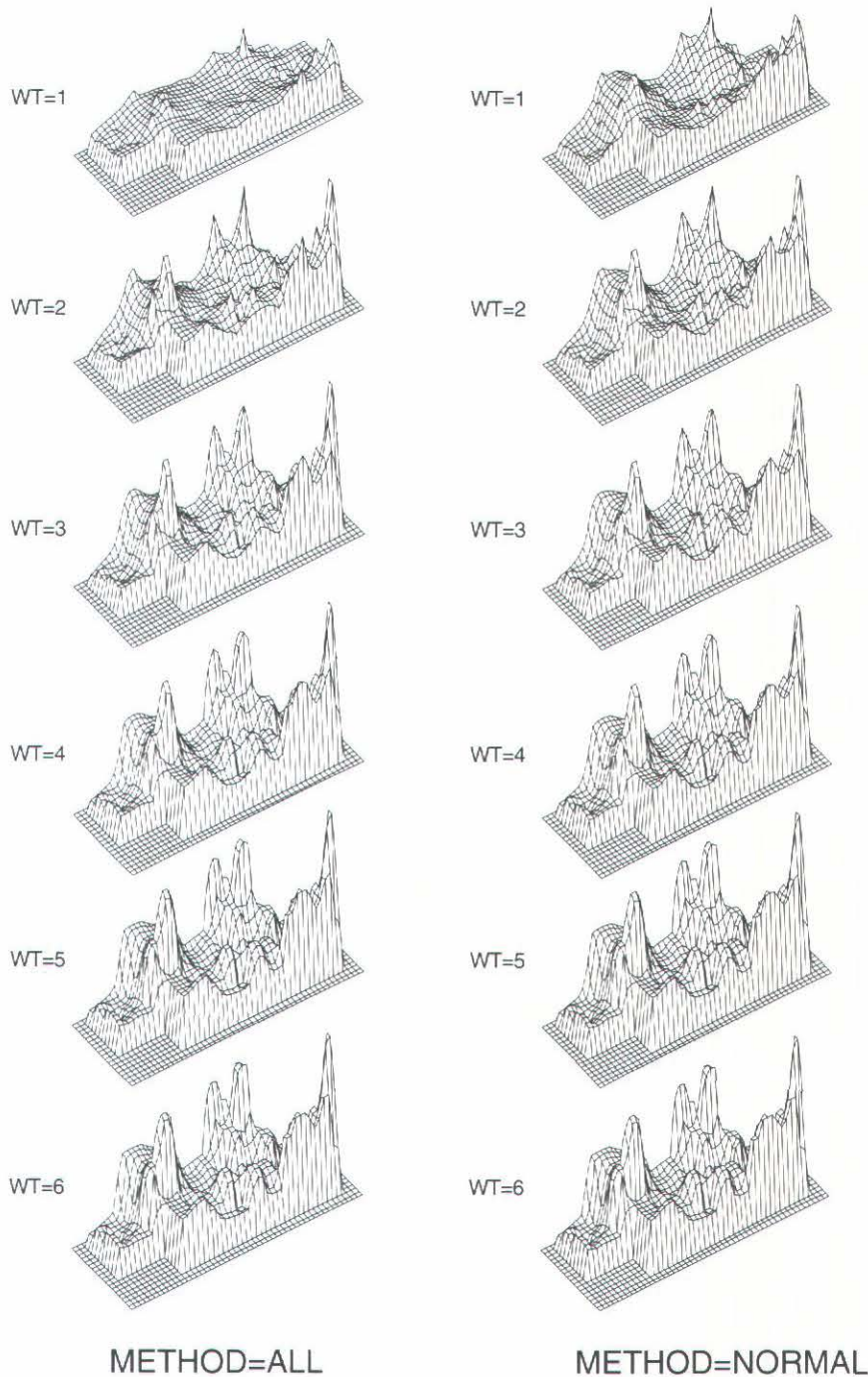


Figure 4. Frames selected from animations. Animations have a total of 120 frames. The method referred to as ALL uses all control point values in inverse distance weighting. The method referred to as NORMAL uses a regional selection of control points based on a selection of near-neighbors. WT is the weighting exponent.

distributions of control points because equal weights are assigned to each point even if it is in a cluster (Lam 1983). In reality, the mapmaker does not always have control over the locations of control points, but for the purposes of this study it was desirable to avoid the effects of uneven or clustered arrangements.

One long-standing, useful, and often violated convention in graphics and cartography maintains that the selection of symbols for maps and graphs should reflect the nature of data to be mapped (Tufte 1983,

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Robinson and Petchenik 1976, Dobson 1973). When studying the effects of inverse-distance weighting in three-dimensional animations, continuous data is most appropriate for visualization. Precipitation is a truly continuous geographic phenomena, and for that reason was chosen for animations in this study.

Individual animation frames (maps) were constructed in SURFER by entering control point x, y locations, and corresponding z-values (precipitation) for the seventy climate stations, and then computing the inverse-distance grid interpolation. For each successive frame, the weighting exponent was increased by a value of 0.05. This fairly small increment was chosen to produce a smoother animation, and one which lasted a sufficient length of time to allow examination of the visual effect of increasing weights. An attempt to utilize an increment of 0.1 was made but rejected because the animation appeared too discontinuous and jumpy between successive frames. Weighting exponents ranged from 0.05 to 6, stopping at 6 because higher weights produced little change in the three-dimensional surface. This exponent range and numerical increment yielded a total of 120 frames.

Most visual parameters were set and remained constant throughout production of individual frames for each animation. In order to examine the visual effect of other interpolation settings, some of these settings were varied between animations. Uniform vertical scaling was used in all animations, and was selected by first displaying the surface with the greatest vertical relief (wt=6), adjusting the vertical scalar until no clipping of the surface at the edge of the screen occurred, observing the numerical index of the vertical scalar (in this case, an index of 1.5), and then setting all subsequent frames to that index value. Angle of view from the horizon and horizontal rotation of the surfaces were set, and also remained constant throughout the animations. Angle of view was set at 45 degrees above the horizon, and horizontal rotation at 235 degrees (0 being a view due west). For the precipitation data used in this study, this orientation was chosen because it was the best for revealing the peaks, valleys, and spatial trends of this rather complex surface, while it also minimized hidden surfaces. Once initial settings were determined, individual frames were produced and screen-captured to GIF file format at 640 by 480 resolution. Frames were then imported into Animator Pro for playback.

Two variations of the animations are shown in Figure 4. Settings, as described above, are the same for each animation; the only variation is in the way control points were searched for and selected for interpolation. METHOD=ALL indicates that all control points were used to derive the interpolated surfaces, but they were still subjected to inverse-distance weighting. METHOD=NORMAL indicates that the number of control points was restricted to a set number of neighboring control points within a specified radius. One can observe that the animation produced as ALL has slightly smoother surfaces when lower weighting exponents are used. However, the surfaces rapidly become similar as weighting exponents increase. Further experiments with other search settings revealed the same trend. Weighting exponents greater than four produced surfaces that appear to be identical. It was also observed that vertical relief increases as weighting exponents increase because increasingly greater weights are applied to fewer control points. This occurs regardless of control point search and selection methods.

These observations are indicative, but not exhaustive of the utility of this sort of visualization, and the conclusions derived from our observations would have been difficult to arrive at by any other means. Selection of individual maps to be representative of an animation series will ulti-

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mately be determined by the author's purpose and goal, statistical considerations, the intended audience, and the author's knowledge of the geographic phenomena being mapped. In this regard, design-oriented animations can assist authors in making more informed map selections.

Animation-assisted map design is a promising tool for cartography, and can be extended well beyond animation of the visual effect of inverse-distance weighting on three-dimensional mapping. Virtually all variables encountered in designing and constructing three-dimensional surfaces can be animated, including data search procedures used in gridding, surface rotation, vertical scaling, and horizontal angle of view. The greatest potential for this method lies in examining design decisions whose consequences are difficult to visualize mentally, such as those dealing with the mathematics of grid interpolation. In a further example of related uses of animation, Figure 5 shows frames from an animation in which only the density of the interpolated grid is varied. Mapmakers can examine this animation to determine an appropriate level of grid-based generalization for the final product. The first frame (top) shows a surface that is made from a grid that is too coarse to give an adequate impression of a continuous surface, while the last frame's surface is made from a grid so fine that line symbols coalesce and obliterate portions of the surface. The animation shows that neither of these two choices, nor some of the other frames, would be appropriate. However, the actual selection of a surface must be made in consort with the purpose of the map, the mapmaker's intentions, and statistical guidelines, such as the error generated by interpolation. Animation-based design is not limited to examination of three-dimensional surfaces, and could just as easily be employed in examining design variables in isoline, choropleth, dot, and graduated symbol mapping, as well as other forms of symbolization, (DiBiase et al.1992). In order to become a truly useful design tool, creation of frames for animations should be automated, and the means for selecting variables for animations should be interactive and employ a graphic user interface (GUI).

Automated map generation is desirable because the construction of animations manually, one frame at a time, is a costly and time-consuming process. Unless animations can be produced automatically by interfacing a geographic data base with map construction software, animation-based design is not likely to be widely employed by cartographers. Availability of automated animation would provide a means to quickly construct and playback animations, make design decisions, and if a single map is desired, to produce the most appropriate map for display or publication.

The addition of interactivity and graphic user interfaces to auto-animation software gives even greater utility to animation-based design and exploratory data analysis as well (Peterson 1995, Lodding 1983). The interface should permit users to make design decisions by selecting data; interpolation method; design elements, either singly or in combination, to be varied through animation; legend structure and other ancillary map elements; and the number of frames. It should then render the animation and permit playback. The interface should allow the user to change animation speed, reverse the animation, pause and resume, and possibly to query the numerical geographic data base. Finally, the interface should permit the user to record their selections and produce a final map. In order for animation to become a robust means for design-based visualization, it is essential that these capabilities be repeatable. When this occurs, cartography will be closer to utility in the use of animation in map design and data exploration.

CONCLUSION

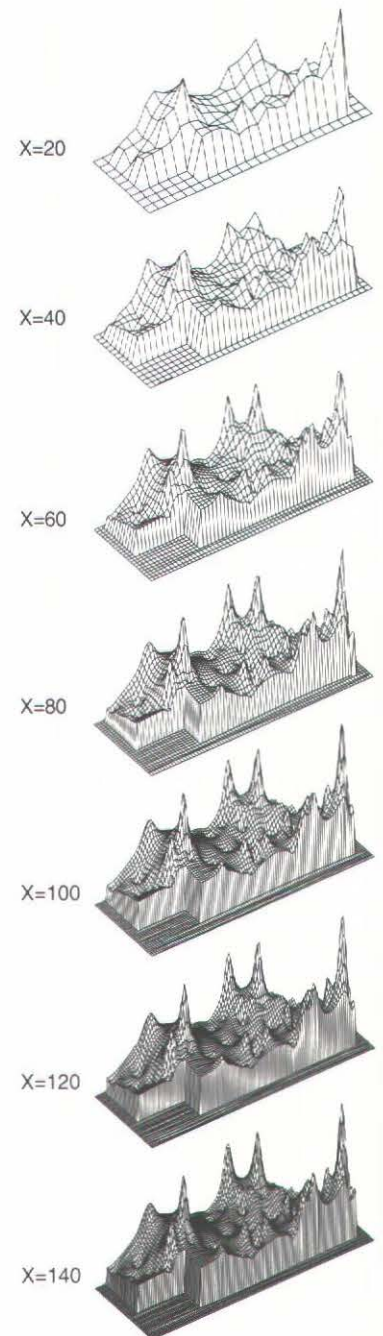


Figure 5. Frames selected from an animation which varies density of the interpolated grid using inverse-distance weighting. The weighting exponent is 2. X refers to the number of grid intersections on the horizontal axis.

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