CO-144

ILLUMINATED CHOROPLETH MAPS

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ABSTRACT

Choropleth maps are commonly used to show statistical variation among map enumerations such as countries or other administrative units. Mapmakers take into account numerous considerations and make many decisions to produce a product that will effectively communicate spatially complex information to the map user. One design consideration is the choice between classed or unclassed choropleth maps, which has been a topic of much discussion in the cartographic community during the last forty years.

Unclassed maps assign a unique color, shade, or pattern based on each unit's value. These maps are rich in information but might not be optimal for visual discrimination of regions or identifying values from a legend. Classed maps classify enumeration units based on unit values and in some cases consider geographic area per class or contiguity. These classed maps better delineate regions and interclass variation but are designed to eliminate visibility of intraclass variations.

We present a method designed to use colors for choropleth classes and soft shadows to show intraclass variations associated with adjacent or nearby polygons. We conceptualize the choropleth data as a three-dimensional prism model under simulated illumination, with the height of each enumeration unit a function of its mapped value. Our user studies have demonstrated that participants were able to use soft shadows to better identify which of two adjacent units was of greater population density, regardless of whether units were in the same or different classes. Additionally, the resulting soft shadows rarely interfere with the map reader's ability to match color classes to a legend or to compare estimated differences in mean and variance of population density between two regions. Such visual discriminations are not useful for widely spaced units, but are useful for those adjacent to or within the shadow of nearby units.

BACKGROUND AND OBJECTIVES

The objective of this study is to add information to classed choropleth maps to show subtle variations between adjacent polygons that may or may not be identified by changes in class color. Choropleth maps show the variation in quantitative data among enumeration units (Robinson et al. 1995; Slocum et al. 2008). The variation throughout the mapped area is displayed using such visual variables as hue, spacing, or lightness (Slocum et al. 2008). Although statistical data were classified for map display since shortly after the first unclassed choropleth map appeared in 1826 (Robinson 1982), they only became a focus of study when Jenks and Caspall (1971) introduced methods to optimize the values of class breaks. Shortly thereafter, Tobler (1973) suggested assigning unique symbols to each enumeration unit to create unclassed choropleth maps.

Our research focuses on adding more detailed information to classed choropleth maps using soft shadows from unclassed values. In these illuminated choropleth maps, the hue–saturation components of color of the units are based on the class. The shadows are based on an illumination model applied to a volumetric model of the enumeration units. In the volumetric model, each unit is extruded to a height based on the attribute being mapped. For a given illumination direction defined for the former model, the length of the shadows will be a function of the difference in values between adjacent units. These shadows act as a second unclassed visual variable, used with the intent of adding detail to classed choropleth maps in a manner that is perceptually intuitive.

Our illuminated choropleth maps are planimetrically correct. Because hard shadows would obscure some units, we focus on creating soft shadows that vary the tone of class colors in a subtle manner. We use a clear day illumination model so that maps match theoretical shading based on the distribution of light in the sky. In doing this, we are attempting to create a map display that is easily and intuitively visually interpreted. Our testing (Stewart and Kennelly, 2010) indicates that users can correctly interpret shadows with respect to local variations, and that shadowing does not interfere with users' abilities to match unit colors to a legend or to make regional comparisons of mean and variance among large areas.

Our illuminated choropleth map, in its use of an attribute being displayed using multiple visual variables, shares similarities and has important differences when compared with traditional cartographic techniques. It is similar to maps of smoothly varying statistical surfaces such as topography that employ layer tinting with hill shading and shadowing.

Early researchers pointed out the similarity of choropleth and topographic maps. Jenks and Caspall (1971, 218) stressed the impression a choropleth map will have on the map reader: “First, he may seek an overview of the statistical distribution from the choropleth map, much as he obtains the ‘lay of the land’ from a topographic map.” Monmonier (1972) endorsed symbology that helps to display choropleth maps simply and clearly. He drew analogies to the varying contour intervals and classes of hypsometric tints used to create topographic maps that appear spatially organized. Tobler (1973) drew an analogy between selecting larger class intervals to generalizing a topographic surface by, for example, choosing a large contour interval.

Cartographic techniques include various methods for mapping terrain, such as hill shading and associated shadowing. Hill shading generally uses a simple directional illumination model to vary the shade of gray of individual map units (Horn 1982; Imhof 1982). The shade of gray is determined by the angular difference between the direction of illumination and the surface normal. Hill shading was first automated by calculating

shading values for a small grid (Yoeli 1965), relating these shades to the density of black dots on a white background (Yoeli 1966), and using a computer-controlled electronic typewriter to print and overprint characters to match desired hill shades (Yoeli 1967).

Subsequent efforts led to use of special characters on a line printer (Brassel, Little, and Peucker 1974) and finally continuous shades of gray on gray tone plotters (Peucker, Tichenor, and Rase 1974). This type of hill shading would be ineffectual for choropleth maps, as all enumeration units have the same (horizontal) orientation.

The same directional illumination model can also be used in terrain mapping to define areas in shadow. Although shadows provide important visual cues to local relief, they have a poor reputation in cartography because of their tendency to obscure local details

(Imhof 1982). Applying a simple directional illumination model to the data in this study, we get a map with dark, sharp, hard shadows obscuring more areas. More sophisticated clear-sky illumination models allow units beneath soft shadows to cast their own shadows, as diffuse illumination from other sectors of the sky is not obscured.

Additionally, the illumination model can serve to shade flat units. This shading results from diffuse light distributed throughout the sky being partially blocked at certain locales by high areas in the prism model that are not in the line of sun illumination. Examples of an urban elevation model with equal illumination from all directions can be found in Kennelly and Stewart (2006). Flat tops of buildings are rendered inmany shades of gray, depending on how much of the virtual sky is obscured by other buildings. The implication for illuminated choropleth maps is that units more obscured will be shaded slightly darker than surrounding units in the same class, even if they are not covered by an obvious shadow.

Illuminated choropleth maps and topographic maps with layer tinting and hill shading represent very different types of geographic phenomena, but similar shading methods can be used to represent them. In terrain maps, elevation layer tinting applies the same colors over continuous regions within specified ranges of values. These colors are modulated by a derivative map based on a directional illumination model that defines shading based on local relief. Our illuminated choropleth method applies the same colors over potentially less continuous, stepped surfaces within specified classes. These colors are modulated by a different derivative map based on a more sophisticated illumination model that defines soft shadowing based on attribute variations among adjacent or proximal polygons.

APPROACH AND METHODS

The most commonly cited aspect direction for illuminating is from the northwest (Robinson et al. 1995). Imhof (1982) theorizes that this is because maps are generally oriented with north to the top, and users are accustomed to lighting from above and left, a legacy of left-to-right writing in our predominantly right-handed western culture.

Imhof (1982) also notes that northwest illumination had been an issue, because this direction is not consistent with solar illumination in the northern hemisphere.

The vertical inclination angle from the horizontal of a point illuminator is also important. Imhof (1982) suggests angles of less than 20° for flat, undulating terrain and angles of 45° or more for steep slopes. A low angle of illumination in high relief terrain will result in large areas being shadowed. Imhof (1982) dislikes shadows, as they are cast from some distance and have no relationship to the local terrain. In essence, shadowing can mask detailed areas of hill shading.

For digital terrain, shadows can be avoided in two manners. First, the user can select an angle at a large enough inclination to cast no shadows. This angle can be determined by calculating slope and identifying its maximum value. Second, the user can shade without shadowing. The calculation is identical for hill shading, and shadows are simply not computed. Although this is geometrically impossible, it is a quite common practice in relief mapping. As the inclination angle approaches 90°, the appearance of the rendering changes significantly. Imhof (1982) calls this slope shading, because with vertical illumination, the brightness values are identical to the cosine of the slope at each surface element. Slope shading follows the principle of “the steeper the darker” (Imhof 1982, p. 162). For most users, the 3D effect is greatly diminished with vertical point source illumination.

Local variations in the direction of illumination were common before the advent of computer-based terrain rendering. Imhof (1982) describes the aesthetic basis for such variations and points out that they are especially effective at bringing out detail in ridges and valleys oriented parallel to the primary direction of illumination used for rendering. He suggests variations in the aspect and the inclination of the local illumination vector by angles of less than 30° from the regional illumination vector. The resulting Swiss-style shading is highly acclaimed for its detail and beauty. Brassel (1974) was the first to automate this technique, and Swiss cartographers continue to develop techniques in this fashion (Jenny and Raeber 2002). Researchers focusing on the surface to be illuminated and attempting to add more detail to specific locales than would be present in a rendering using one point source of illumination.

We approach the challenge of offering additional detail to rendered surfaces from a different perspective. We explicitly define a general illuminating sky model that inherently adds more detailed shades of gray to any surface. The choropleth renderings in this report are made using a clear day sky illumination model. A sky model is used to define shading and shadowing from multiple sectors of the sky (Stewart and Kennelly, 2010). The result is a discretized approximation of ideal clear day illumination.

RESULTS

Figure 1 shows a rendering of all 3,184 polygons representing 3,109 counties or county equivalents in the conterminous United States. The data mapped is the population density as of the year 2000. This choropleth map uses a sequential white-yellow-orange-red color scheme divided into five classes. Details are shown in the map legend, which is the same legend used for subsequent figures.

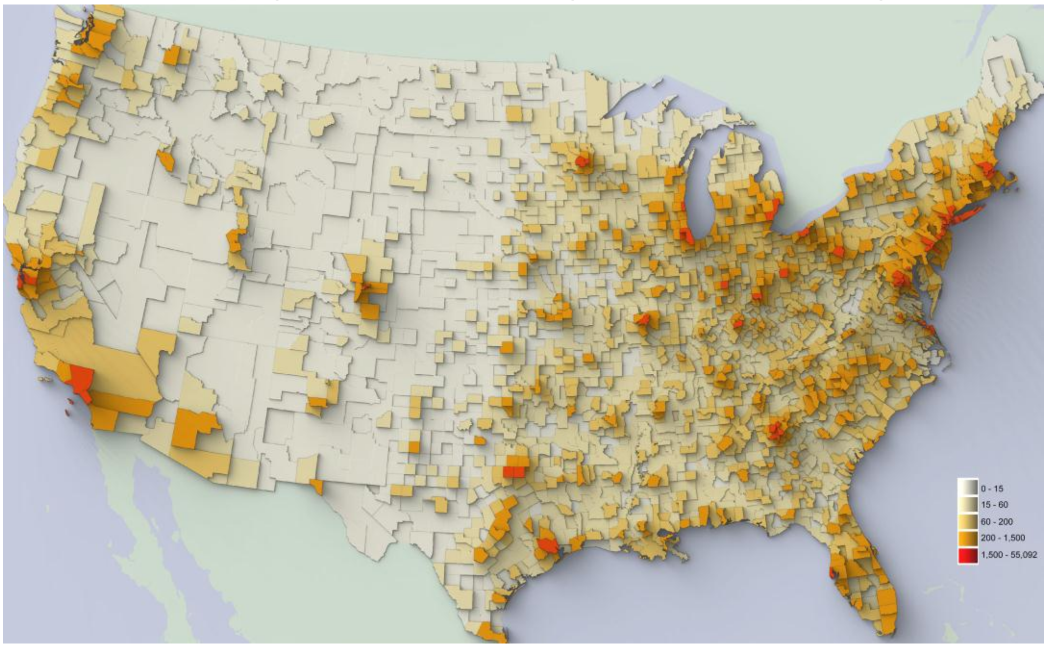

Figure 1: An illuminated choropleth map of the conterminous United States.

Although the counties of higher population density are casting shadows to the southeast, these shadows are diffuse and designed, and verified by user testing (Stewart and Kennelly, 2010) not to completely obscure other counties upon which they are cast. Large water bodies such as oceans are represented in blue. These areas also have diffuse shadows cast upon them when they occur to the south or east of populated counties. Other countries are shown in light green, and demonstrate similar shadowing.

Close-ups of this map illustrate some of the detail of the shading from clear-day illumination. Figure 2 shows the northeastern portion of the United States. The area of

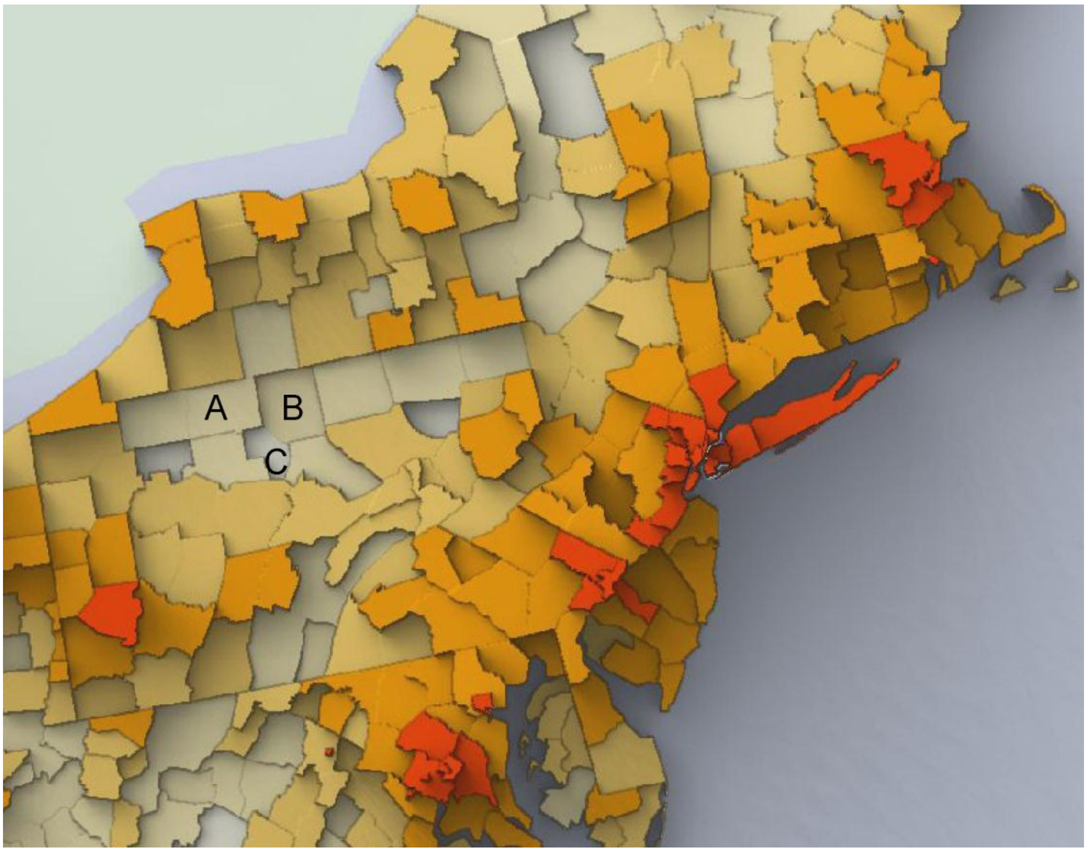

Figure 2: Close-up of illuminated choropleth map of the northeastern United States.

High population density near the coastline stretches from Washington, D.C. to the south to Boston, Massachusetts to the northeast. The labeled area of low population density in north-central Pennsylvania illustrates one utility of such illuminated choropleth maps. Although counties labeled A and B are in the same class, shadowing indicates that the prism height is much less between counties B and C than between counties A and B, even though C is in a different class.

Additional details of counties in the mid-northwestern United States are shown in Figure 3. This close-up shows the densely populated area of Minneapolis/St. Paul, Minnesota to the northwest. The densely populated area in and around Chicago on the western shore of

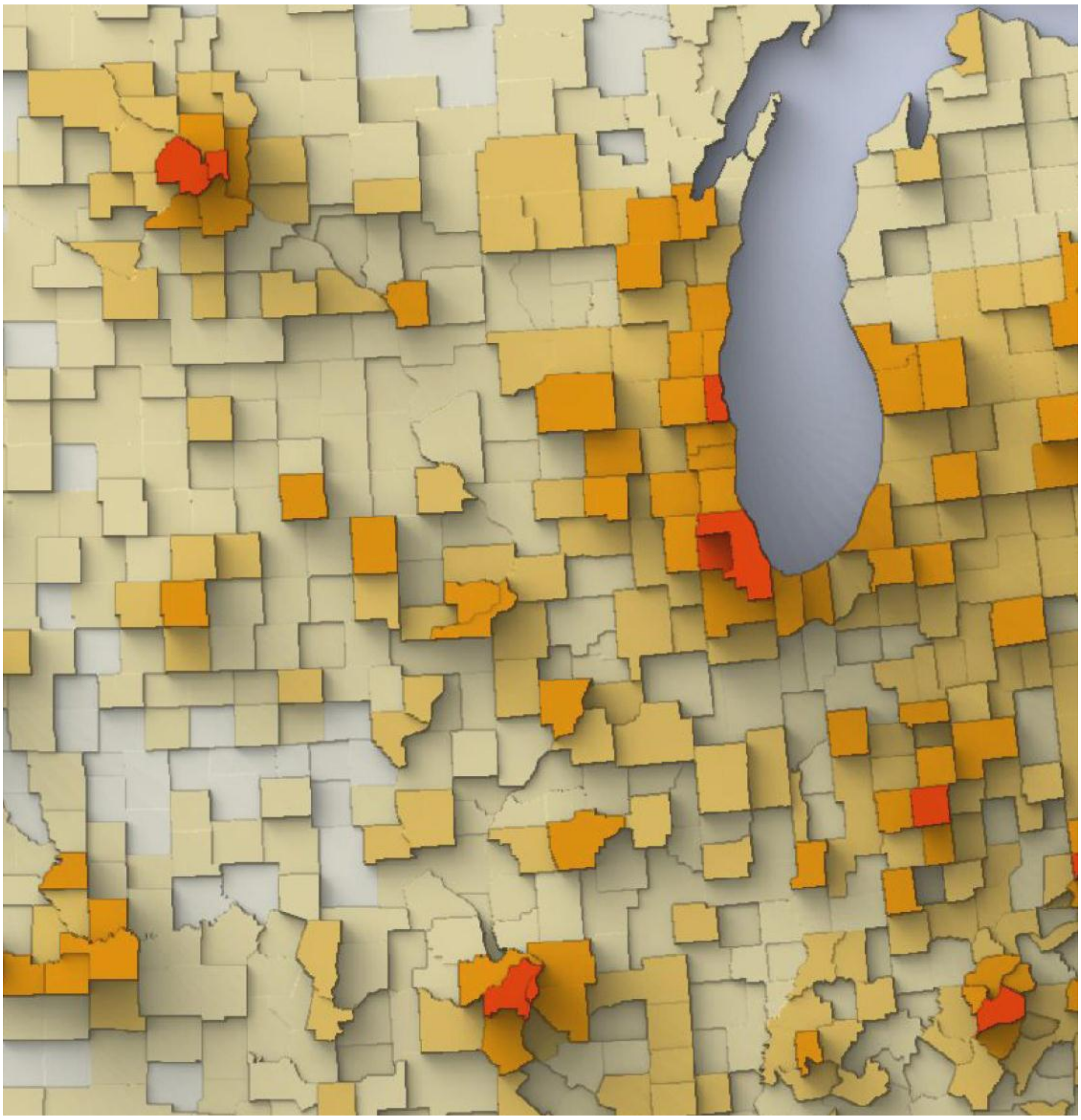

Figure 3: Close-up of illuminated choropleth map of the north-midwestern United States.

Lake Michigan is depicted in red, with the St Louis, Missouri area further to the southwest. Although the clear sky model is finely sampled to produce this shadowing effect, there are some remnants still visible. This is most apparent on Lake Michigan, modeled as a flat area with no population density. Careful inspection reveals subtle shadows from the edge of an isolated and densely populated county, with the shadows fanning out to the southeast. Although such effects become less apparent with more numerous sky samples, it is difficult to remove this artifact from sharp, isoloated edges.

CONCLUSION

Our illuminated choropleth map technique can add information of subtle differences in value between adjacent polygons in classed chloropleth maps. Clear day illumination simply sums shading and shadowing information from all portions of an illuminated sky to provide a rendering with additional detail when compared to a point source illumination. The brightness of a surface under clear day illumination is a function of the amount of the visible sky and the distribution of brightness in that sky.

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