THE DEVELOPMENT OF DIGITAL SLOPE-ASPECT DISPLAYS

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ABSTRACT

Slope-aspect information is widely used by earth scientists, environmental planners, and other analysts dealing with this facet of the physical landscape. Digital elevation model data in raster form are commonly employed to compute for each pixel the aspect azimuth and aspect class within which the azimuth falls. Various coloring schemes for displaying slope-aspect classes have been tried in the past. While most schemes employ hue differences to create visually distinguishable map classes, little attention has been given to visually relating aspect to the underlying landform. In this paper coloring schemes that simulate relief shading while maximizing visual discrimination of individual classes are presented for four and eight class slope-aspect maps, and the theoretical basis for color selection is reviewed.

INTRODUCTION

Slope-aspect, the compass direction of the maximum slope at a particular location on a surface, is a landscape characteristic fundamental to building site analysis, solar access planning, watershed management, and a host of other scientific and management activities. Although determining the aspect at a single location may be sufficient for some problems, most require an understanding of the pattern of slope-aspect variation across the landscape. Slope-aspect maps provide this regional view and are a required product in many instances. Computer produced slope-aspect maps are created most frequently, since aspect computation based upon grid cells in a digital elevation model (DEM) is a straightforward and efficient procedure as long as the elevations of adjacent cells can be retrieved quickly. Creating a visually effective display of the computed aspect azimuths on color CRT's or hardcopy devices is still a cartographic challenge, even when precisely calculated azimuths are generalized into a limited number of classes such as the four or eight cardinal compass directions. The foremost map design problem is to develop a cell coloring scheme that will maximize color contrast among classes while allowing the user to visualize the underlying landscape. In this paper past efforts are reviewed and new solutions to this long-standing map design problem are offered.

PAST ATTEMPTS

Numerous coloring schemes have been used on published slope-aspect maps. Although sequences of gray tones and sets of areal patterns have been used occasionally, coloring by hue differences predominates. The spectral hues of red, orange, yellow, green, blue and violet, and mixtures thereof, produce on some maps easily distinguishable classes in the map legend and within the map. These hues at varying levels of value and chroma have been either randomly assigned to classes or organized into full or partial spectral progressions. Yellow and neighboring lighter hues have been used to represent virtually all aspect directions, with an apparent association between "solar" yellow and south facing slopes found on many maps. Attempts to combine aspect and landform information have been restricted to overprinting aspect colors on a relief shaded base map, with generally disappointing results since shading inherently decreases our ability to distinguish among classes. Past attempts clearly indicate that slope-aspect display on maps needs a firmer theoretical footing.

SLOPE-ASPECT DISPLAY THEORY

Slope-aspect is a nominal level phenomenon since a particular aspect angle (azimuth or compass point) cannot be thought of as lesser or greater in physical magnitude or rank than any other. Hue and pattern differences are the correct visual variables to use when graphically portraying nominal level area phenomena, with hue differences used more often in computer mapping and geographic information systems. The set of hues selected for slope-aspect must allow the map reader to easily distinguish among classes, and yet see that aspect classes form a circular progression where adjacency implies greater inherent similarity. This rules out the use of randomly selected hues and points to the use of opponent-process colors.

Opponent process color theory "is a model of human color perception that predicts that there are four unique hues, with all others appearing as mixtures" (Eastman 1986). The opponent process model of human vision is based on the idea that although the cone cells in our eyes are sensitive to blue, green or red light, the ganglion cells linking the cones to the optic nerve interact to produce four perceptually unique colors -- red, blue, green and yellow. All other hues will be seen as mixtures of these "pole" colors, except that yellowish blues and reddish greens are not possible. These "pole" colors form the set of maximally different hues and hence are the easiest hues to distinguish. The implication for slope-aspect mapping is that a four class map should be symbolized with these "pole" hues if class discrimination is of paramount concern, whereas an eight class map should employ a progression of these hues alternating with the "mixture" colors of purple, blue-green, yellow-green and orange. These eight hues will be seen as a circular progression of related colors with mixture hues inherently similar to their two "poles".

Opponent process theory guides the selection of hues that are maximally discriminable yet seen as forming a circular progression of related colors, but the problem of hue assignment to particular slope-aspect classes remains. Assignment of "pole" hues to the cardinal aspect directions has been tried, but the resulting four class maps display the underlying land surface poorly. In some cases landforms are inverted and ridges appear to be valleys, and vice versa. Communication of slope-aspect information is enhanced when aspect class colors depict landforms correctly in a manner similar to relief shading where on north oriented maps northwest facing slopes are lightened and southwest slopes are darkened. The most fundamental form of analytical relief shading assumes an ideal diffusing surface with an apparent brightness that is proportional to the cosine of the angle formed between vectors representing incident rays coming from the northwest (315 degrees) and the surface normal (Horn 1982). Since slope-aspect alone is being mapped, the slope angle at each location is immaterial and can be assumed to be constant throughout. In this case the surface normal varies only with changes in aspect, and the cosine function describes the theoretical reduction in surface brightness that occurs as the aspect angle deviates progressively from the northwest incident illumination. Surface brightness can be thought of as proportional to light emitted from phosphors on CRT screens, meaning that the cosine law can be extended to electronic map displays.

Opponent process theory and the cosine shading law must be used in unison to create optimal slope-aspect coloring schemes for CRT displays. This translates to using yellow, the "pole" hue of highest inherent brightness and lightness, to display the aspect class centered on 315 degrees. Similarly, blue, the opposite "pole" hue of lowest lightness, is best applied to the class centered on 135 degrees. Red and green can be used interchangeably for the aspect classes centered on 45 and 225 degrees. An eight category map with red used for the 45 degree class would use these four hues plus orange, purple, blue-green, and yellow-green for the 0,90,180, and 270 degree classes, respectively.

Precise selection of the above "pole" and midpoint "mixture" hues, all with brightnesses close to falling on a cosine curve centered on yellow and scaled so that yellow equals one and blue zero, is somewhat subjective. However, the authors have discovered that, for the HLS color specification system used with Tektronix 4120 series terminals, holding all hues at maximum saturation (100) and progressively decreasing lightness from 50 for yellow to 40 for blue produces a visually effective hue progression that roughly follows the cosine lightness curve. Magenta and cyan, the true midpoint hues between the blue-red and blue-green "poles", were not found to work well regardless of lightness, since both are inherently much brighter than their "pole" hues and cannot be darkened so as to fall on the cosine curve without being "muddied" unacceptably.

CONCLUSION

Slope-aspect maps colored according to the above guidelines appear to be relief shaded as well, with landforms portrayed correctly and standing out clearly. The correct perception of landforms appears to enhance aspect recognition, since, for example, northwest aspects are seen as falling on northwest trending hillsides. This synergistic effect is seen on standard planimetric as well as on 3D-perspective slope-aspect maps displayed in either single image or stereoscopic image mode on recently introduced terminals such as the Tektronix 4126. Such judicious application of color theory should greatly improve the appearance and readability of future slope aspect maps.

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