Technical Note
Relief Modulated Thematic Mapping By Computer

Denis White

ABSTRACT. One way of mapping shaded relief with a computer works like a form of signal processing. The shaded relief 'signal' derived from a digital elevation model modulates a thematic 'signal' representing land uses or other thematic information. The composite signal is transmitted to a computer graphics terminal where the thematic signal determines the hue and saturation of the symbolic colors and the relief signal determines the lightness. The computer programs embodying this technique have been used to prepare maps for studies of several environmental planning and design problems.

KEY WORDS: shaded relief, computer mapping, signal processing

The portrayal of topographic relief on maps has occupied the attention of many cartographers. The importance of relief patterns in many kinds of mapping continues to encourage the development of methods to better or more economically display relief on maps. A number of cartographic studies have treated methods of portraying relief (Keates 1961; Yoeli 1964; Castner and Wheate 1979; Imhof 1982). In recent years of computer-assisted cartography, a number of techniques have been developed for automated relief depiction (Yoeli 1965; Brassel 1974; Peucker, Tichenor, and Rase 1975; Horn 1982). This article describes a method for making relief-shaded thematic maps with a computer. First, this cartographic method of relief shading is described as a type of signal processing programmable on a computer. Next, some applications of this method are discussed. Finally, the computer programs that produce the relief-shaded maps are explained.

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RELIEF SHADING AS A FORM OF SIGNAL PROCESSING

One way of thinking about topographic elevation on maps is as a quantity that modulates other map information. Thus, political zones or land cover types might form a set of map units upon which a form of topographic symbolization can be superimposed. Contours, hypsometric tints, or relief shading may all be used in this way. The notion of relief modulating the thematic landscape becomes more concrete if we consider a map composed of two images: a thematic image and a topographic relief image. Each image is thought of as an input 'signal.'

The signal processing model of relief mapping is especially suitable for implementation on a digital computer. Consider a thematic map whose classes may be represented as a dense set of integers (contiguous integers from 1 to the total number of classes). Each location on the map has an integer assigned to it, corresponding to the thematic class number at that location. Therefore, one of the input signals is the list of thematic codes for each map location.

A second input signal is a list of integers representing shaded relief by gray tone values from darkest to lightest

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(or vice versa). We assume here that the two signals have been spatially registered. The 'thematic' signal may now be modulated by the 'relief' signal to produce a combined map signal. This can be done by creating a new set of integer codes as a combination of the thematic codes and the relief codes. The new codes can be constructed by taking the relief codes as the base and adding to them the thematic codes multiplied by the cardinality of the relief codes. The expanded set of codes has a cardinality that is the product of that of the two input sets.

For example, a four-class thematic map combined with a five-class relief shading results in 20 codes. The formula giving the output code from the input thematic and relief codes is

$$\text{output code} = (\text{thematic code} * 5) + \text{relief code},$$

where the thematic codes range from 1 to 4, the relief codes range from 1 to 5, and the output map codes range from 6 to 25. So a map location having thematic class 3 and relief class 2 results in output map class 17. Figure 1 illustrates this technique of generating codes.

This method of combining thematic information with relief shading is well adapted to assigning colors to maps produced on color terminals. If each thematic class is represented (symbolized) by a different color defined by a triple of numbers indicating hue, saturation, and lightness, then the relief shading classes can modify the thematic colors by specifying lightness values while holding hue and saturation constant. The modulated output codes then can be used directly as indices into the color table of the terminal.

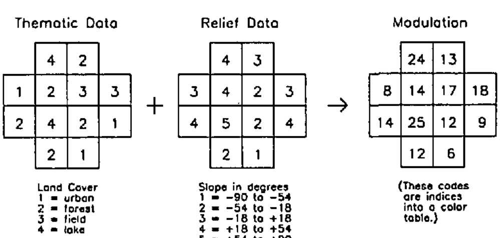

Figure 1. Generating modulated map codes.

APPLICATION EXAMPLES

This technique is illustrated with data created in a studio course in the Department of Landscape Architecture at Harvard University's Graduate School of Design (Steinitz 1982). The data base consists of two grids of values: one containing elevations and the other a set of land use or land cover codes. The grids cover an eight town region centered about Mount Monadnock, a dominant peak in southern New Hampshire. The resolution (cell size) of the grids is one hectare; thus, there are approximately 57,000 data cells in each grid.

The first three maps show three renditions of the Mount Monadnock elevation data. The first map (Figure 2) shows a hypsometric tint series with 16 classes. The tints are an approximation to Imhof's Type II as described on page 307 of Imhof (1982). This tint series is called an "Elevation Color Gradation for relief maps at large and medium scales with hill shading." It starts at the lowest elevations with a greenish blue-gray and ascends through desaturated greens and yellows to very light pink, orange, or brown colors at the mountain tops.

The second map (Figure 3) presents the same data in the form of a shaded relief map. The calculation of shades for this map is particularly simple. The algorithm computes slope in a northwest direction by comparing the elevation of each cell with that of its neighbor to the southeast (one row down, one column across) to obtain a signed elevation difference. This difference is then used to compute the slope via a tabled or computed arctangent transformation. Finally, the slope is linearly mapped to a gray tone after suitable scaling. Sixteen levels of shading were used in this map.

The relief modulation of hypsometric tints is shown in the third map (Figure 4). The elevation value of each cell (as classified) is modified by the slope toward the northwest at that cell to obtain the map color code. The number of hypsometric classes was again set to be 16, but the number of shading classes was reduced to 15. Since the display device has a total of 256 colors that may be displayed at one time, a 16 by 15 class map leaves 16 colors for background or lettering.

The key on the left shows the 16 by 15 = 240 colors that could potentially be used on the map. The hypsometric tints vary vertically and the slope shadings vary horizontally in the key. Since all possible combinations of elevation classes and slope classes might not occur in the data, all of the colors in the key might not appear on the map.

The last map shows the relief modulated mapping of thematic data not directly related to elevation. For this map (Figure 5), 23 land uses were identified by the studio for the Mount Monadnock area using Landsat imagery, existing maps, aerial photos, and ground surveys. The land use codes are then mapped as modulated by the relief at each location. Although 23 distinct thematic classes exist in the data, not all are visibly distinct on the map. Even though each class was assigned a technically separate set of color values, the perception of a number of the colors is similar or identical across classes. The only way to keep colors separate when creating a map of this type is to carefully select the colors. Other land cover maps made with this technique, but using fewer classes, have been more successful.

THE COMPUTER PROGRAMS

Three computer programs are used to construct maps of the type described in this paper. The first, Imago Mundi, prepares the cartographic image of the geographic data representing: a) relief and b) the particular theme to be combined with relief. The second, Imago Legenda, prepares: a) the color coding for the map and b) a legend showing the colors for each thematic class. The third, Picture, is a general graphic program used to prepare titles, scales, and north arrows.

Imago Mundi

The input to this program is a rectangular grid, or matrix, of values representing either elevations or thematic data. To create relief shading, the program uses the elevation grid to compute the slope in a northwest aspect. This simulates shading (but not shadows) produced by illumination at the horizon in the northwest. (For an extensive discussion of the history and an illustrated comparison of methods of relief shading, including the simple but effective technique used by this program, see Horn (1983)). The slope in this aspect is then scaled to fit in the range of the number of relief classes. Thematic data is assumed to be represented by a set of numbers indicating the classes of the data. These numbers are simply recoded by the program to fit in the range of the number of thematic classes (if they do not already).

The shading codes and the thematic codes for the eventual map are produced in separate executions of the program and are therefore contained in separate output files. Linking them together is the specification of which part of display memory each will occupy. The usual division of memory has been three or four memory planes for relief (allowing up to 2**3 = 8, or 2**4 = 16 relief classes), and, correspondingly, five or four memory planes (up to 32 or 16 classes), respectively, for the thematic data. Producing the two components separately (in separate files) allows more than one set of thematic data to be combined with the same relief shading, a feature used extensively in studio work.

Imago Legenda

This program prepares the color commands for the display terminal and produces a legend to accompany the body of the map. Input to the program are a number of parameters describing the coloring of the map, including a specification for each thematic class of its "base" color (i.e., the color used to symbolize the class were there no relief shades), and a descriptive title for the class. Base colors may be specified in either a modified Munsell system of hue, lightness, and saturation (HLS), or in

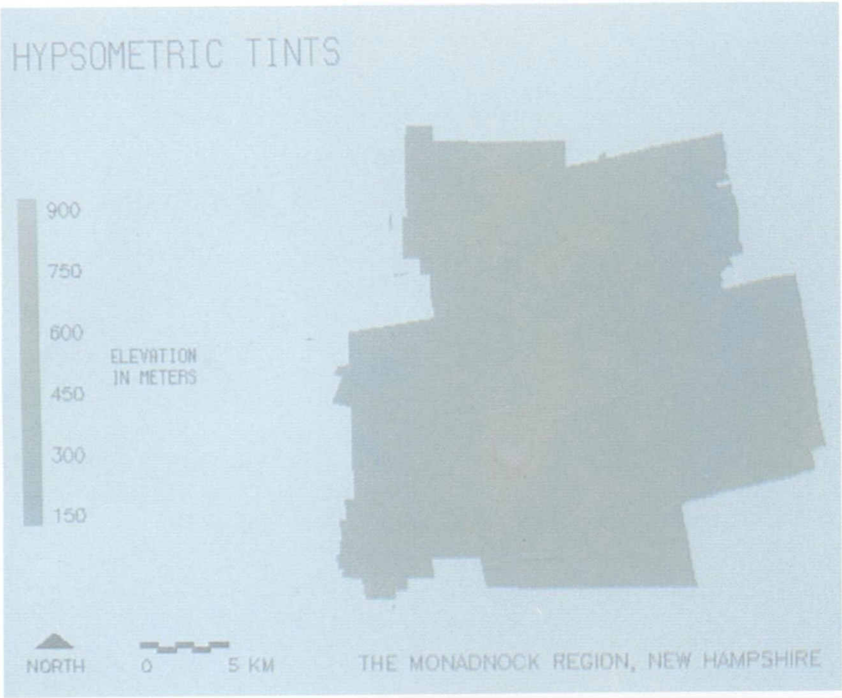

Figure 2. Hypsometric tints for the Mount Monadnock area.

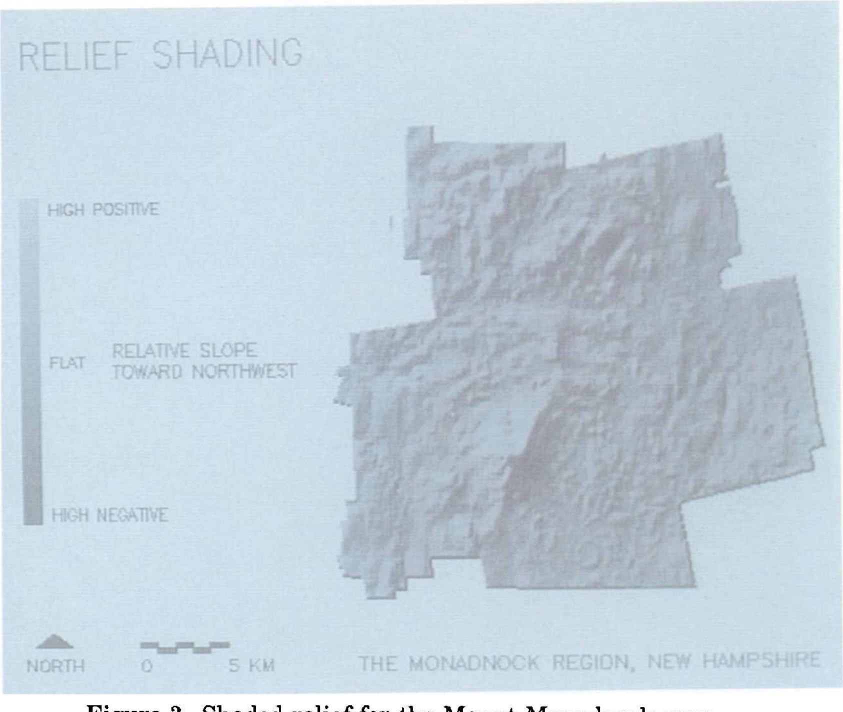

Figure 3. Shaded relief for the Mount Monadnock area.

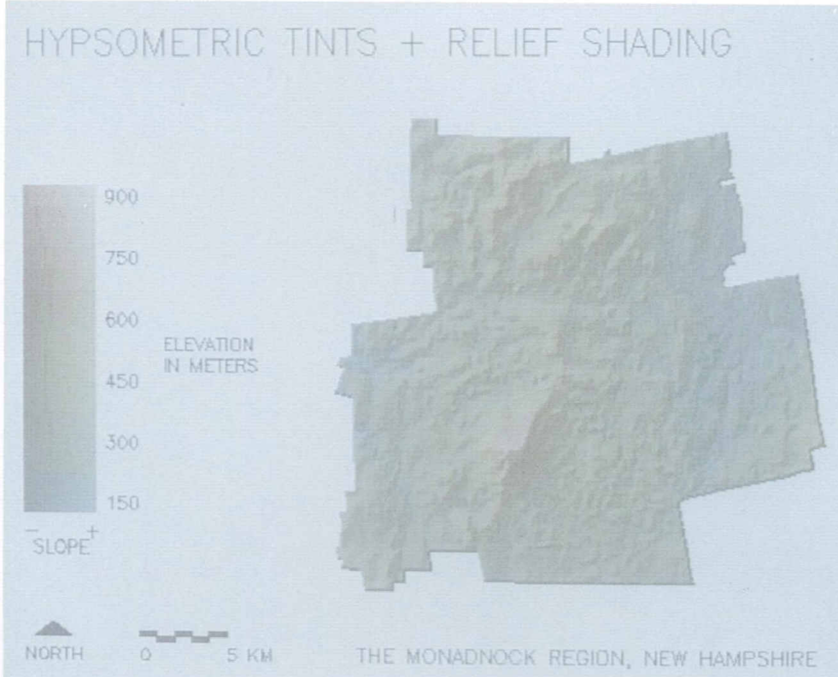

Figure 4. Shaded relief modulating hypsometric tints for the Mount Monadnock area.

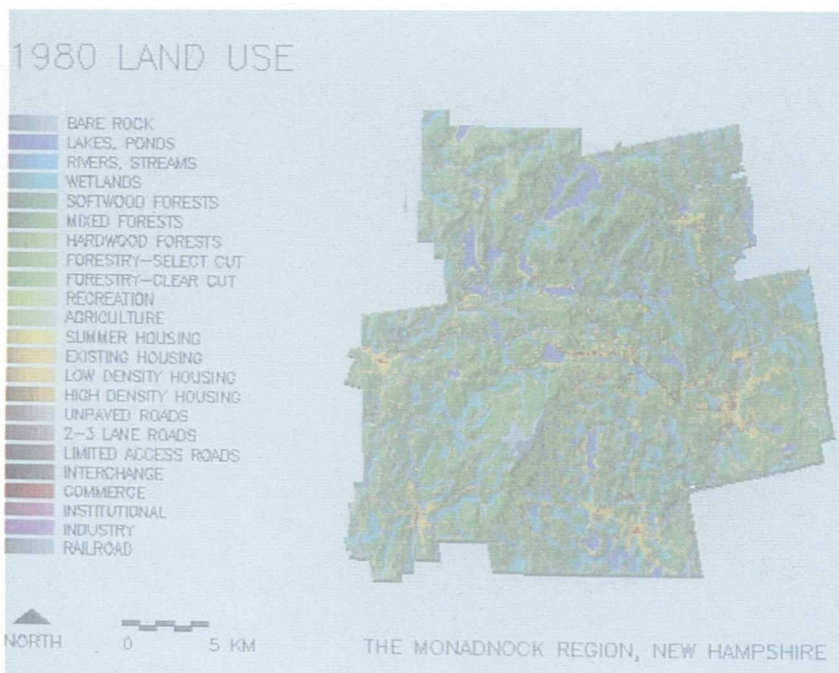

Figure 5. Relief modulated land use for the Mount Monadnock area.

percentages of red, green, and blue (RGB). Also input are various size and position characteristics of the legend. In creating the range of colors to be used for a given class, the program interpolates lightness values about the base lightness (after converting to HLS if necessary). The range of lightness values is given either as a percentage gray range centered on the base lightness, or as a set of equal intervals between a minimum and maximum percentage of white.

The legend is produced as a vertical column of horizontal color bars, each bar depicting the range of lightness values for the specified hue and saturation for one class. The class title may appear next to its bar. The output from this program is a file containing the instructions for setting the appropriate color values in the display terminal's color table, and also, if desired, the graphic commands that construct the legend. Since the color instructions may be produced separately by themselves without the legend, the map produced by Imago Mundi and the legend by Imago Legenda may be initially displayed, and then the colors finely tuned without regenerating all of the graphics.

Picture

This program provides a two-dimensional figure drawing capability using a standard command language interface (Dougenik 1978.) The Picture program allows points, lines, and areas to be drawn as symbols, in outline form, or to be filled with colors and patterns. A variety of character fonts provide for textual annotation. For the maps described in this article, this program was used to prepare titles, graphic scales, and north arrows. The output from the program may be graphics drawn directly on the display terminal, or a file containing the desired graphics.

Integration

Since the output from each of the three programs may be in the form of a file (on secondary storage), the composition of a complete map normally consists of copying the relevant files together (using the host computer's file management facilities). The final composite map file may then be copied to the display terminal whenever the map is to be displayed. Figure 6 depicts the connections between the programs and external files.

These programs are written in the Fortran language (using a preprocessor that supports structured control statements) and are targeted for output to a specific color graphics terminal, an Advanced Electronics Design model 512. Although adaptations could be made for other equipment, the programs currently are dependent on certain features of this terminal. These features are a display resolution of 512 by 512 pixels; a color depth of eight bits per pixel (256 active colors); a nominal color resolution of 256 levels of red by 256 levels of green by 256 levels of blue; an imaging capability allowing byte (pixel) streams to be sent to arbitrary rectangular windows of the screen; and a capability to send graphics to a subset of the eight memory planes.

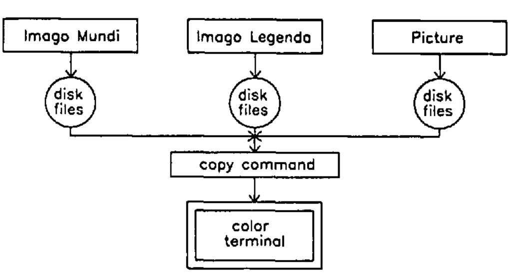

Figure 6. Program relationships.

CONCLUSION

The professional and public response to maps generated with the technique embodied in the Imago Mundi programs has been favorable. Maps produced as part of studio projects have been used for academic reviews of student work; in addition, they have been included in presentations of studio analyses of design and planning problems in the study areas given to public officials, federal agencies, and citizen audiences. These maps have been useful in presenting information about the environment in design and planning contexts.

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• **New Masters Program.** A new masters degree program in geography focusing on cartography, remote sensing, and geographic information systems has been initiated at Oregon State University starting in winter quarter, 1985. This program formalizes the strong interest in cartography long held by the Department of Geography and is supported by several faculty members including A. Jon Kimerling and Charles L. Rosenfeld. Financial assistance in the form of teaching and research assistantships is available on a competitive basis. Letters of inquiry should be sent to:

Chairman
Department of Geography
Oregon State University
Corvallis, Oregon 97331

[Source: Jon Kimerling]

• **Ferguson Map Company Expands.** Ferguson Map Company, Inc. of San Antonio, Texas has purchased the assets and business of Map Graphics, Inc. of Houston. Ferguson will take over publicating the *Blueline Mapbook* of Houston, a product used extensively by the local engineering and construction community. The company is now equipped to provide cartographic services for utility companies such as Houston Light and Power.

[Source: Ruby Daniels]

• **Mapping Sciences and Remote Sensing Journal.** A new cartography journal, *Mapping Sciences and Remote Sensing,* will provide translations of important articles selected from leading periodicals devoted to the mapping sciences and remote sensing as well as translations of original contributions from colleagues in the USSR and eastern Europe. This journal replaces *Geodesy, Mapping, and Photogrammetry,* but with a greater emphasis on cartography and remote sensing. For further information contact the publisher:

V. H. Winston
7961 Eastern Avenue
Silver Spring, MD 20910

[Source: Joel L. Morrison]

• ***Guide to U.S. Map Resources.*** The holdings of map libraries in the United States are summarized in a recent American Library Association publication: *Guide to U.S. Map Resources.* Over 900 collections are analyzed in this report compiled by the ALA Map and Geography Round Table (MAGERT). Additional information can be obtained from:

Jim Walsh
Coe Library
University of Wyoming
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[Source: Alberta A. Wood]