INTERACTIVE COLOR MAPPING

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Introduction

The information theory model of cartographic communication depicts the map maker as sender of information, the map reader as receiver and the map as the communication medium. The model helps to clarify the two different communication processes of encoding (preparing) the map and decoding (interpreting) the map, and distinguishes between the mental maps of the sender and receiver and the material map of the medium.

Interactive color mapping involves these various components of the communication process. In preparing the map, the nature of the geographical data induces a range of choices for color symbolism. Secondly, the capabilities of the map display equipment provide a set of available colors. And thirdly, the interpretation of the map by readers or viewers is affected by the physiological and perceptual characteristics of color.

The Nature of Color

Different systems have evolved for describing color in the areas of physical, physiological, and perceptual studies. Each system has a different set of parameters for defining the attributes of a color.

Physics

The physics of color begin with the visible portion of the electromagnetic spectrum. The colors of the spectrum range from about 400 nanometer (nm) wavelength violet light to about 700 nm wavelength red light. Color resolution, the just noticeable difference in wavelength, varies from 4 or more nm at the ends of the spectrum to two separate minima of about 1 nm: one at 500 nm in the blue-green region and one at 580 nm in the yellow region. Due to this visual resolution, there at least several hundred distinguishable "monochromatic" colors in the spectrum.

Spectrally pure colors are only a small fraction of those which may be perceived. The "achromatic" colors have a flat spectral distribution, i.e., equal amounts of all colors, and are black, gray, or white to the eyes. All other colors are "polychromatic", having one or more peaks in their spectral distribution with lower amounts of energy in adjacent bands. The amount of energy present in a color (whether transmitted by a self-luminous object or reflected by a non self-luminous object) is perceived as the lightness of the color.

Black is the color of zero energy at all wavelengths. The physical description of a color may be represented graphically by a two dimensional graph of energy versus wavelength showing the spectral distribution.

Physiology

It was postulated in the nineteenth century, and has been experimentally verified since, that human color vision operates with three kinds of receptors, each most sensitive to a separate part of the spectrum. The peak responses of these receptors are in the blue, green, and red regions, respectively. During this century it has been proposed, alternatively, that the vision system employs opposite colors, blue-yellow and red-green, in transmitting color information. If the neural processing can be represented by three opponent pairs, blue-yellow, red-green, and black-white, then a three variable system is again appropriate. Since three variables, either as component colors or as opponent pairs, seem to be both necessary and sufficient, color vision is a problem with three variables.

The applied physiology of color measurement represents the mixtures of red, green, and blue colors in a chromaticity diagram. By effectively placing the violet part of the spectrum at the origin, a two dimensional graph shows the possible mixtures of the three primary colors. Spectrally pure colors occur on a curve in this graph called the spectrum locus. All other colors are inside the locus.

The chromatic specification of a color can be made in two ways. First as an (x, y) pair of values defining a position in the chromaticity chart, or second as a dominant wavelength defining a position on the spectrum locus and a purity defining a position along the line from the equal energy mixture of colors (or white spot) to the dominant wavelength. The third physiological variable relates to the physical variable of quantity of energy, and is called luminance. It is defined as the amount of radiant energy per unit area in a single direction and can be thought of as giving a set of z values defining a solid on top of the chromaticity chart.

Perceptual Psychology

The concepts of spectral composition, radiant energy, dominant wavelength, purity, and luminance are related to the perceptual systems of color description developed for practical applications. Perceptual color description uses parameters which seem to be easy for people to use when selecting colors in given situations, smoothing out some of the nonlinearities in the way the eye responds to physical stimuli.

The hue of a color corresponds to the maxima in the spectral distribution and to the dominant wavelength in the chromaticity chart. It is the "colorful" aspect of color. Saturation (or chroma) corresponds to purity and describes the amount of grayness in a color. And lightness (or brightness for self-luminous objects) is the subjective counterpart of luminance, placing a color in the range between darkness and lightness, or between black and white.

The scales for assigning hues to colors take into account the integrative nature of physiological color processing by giving similar weight to hue differences around the spectrum. Hue scales include the non spectral integrated colors in the purple range between violet and red. In a like manner, saturation and lightness scales attempt to measure similar differences in the perception of these variables.

The perceptual description of color is represented by a color solid.

The parameters of a color solid are hue, lightness, and saturation, where the shape of the solid depends on the specific system. Typically, hue is defined circularly; saturation radially within the hue circle; and lightness axially through hue circle centers. Cylinders, double-ended cones, or other rotating axis solids are the resulting geometric figures. The color solid may be defined to provide nearly equal perceptual steps in any one of the three parameters or to represent hue mixtures linearly. The complex nature of color vision does not allow, however, all desirable characteristics to be represented with one kind of color solid.

How the Nature of Data Affects Color Mapping

The form of the data to be mapped has significant impact on color selection. There are five characteristics of data which affect the use of color: the number of variables, the spatial dimension of the variables, their measurement scaling, the data collection units, and color connotations of the data.

When more than one variable is represented the association of hue with variable can be important. If one variable is assigned a gradation of colors between several distinct hues, while other variables use single hues, then the multicolored variable will likely have greater visual impact.

Secondly, the geometric dimension of the mapping units affects the choice of colors. Points and lines subtend smaller visual angles and must generally be portrayed with more saturated colors than areas. The shape and size of areal data collection units also has a bearing. When mapping imagery, or other information collected by regular grid samples, it is possible to produce the effect known as mosaic fusion. This occurs when small adjacent areas of color are merged by the eye into an additive mixture, and is the basis for color printing processes. The fusion effect may significantly alter the perception of data variation.

On the other hand, when displaying relatively large, arbitrarily shaped areas, color contrasts between neighboring polygons can change color perceptions. Because of opponent pair processing, achromatic colors such as grays can be perceived as one member of an opponent pair.

Measurement scaling refers to the different kinds of data. These are conventionally divided into nominal (or categorized) data, ordinal (or ranked) data, and interval and ratio data (both also called metric). The more highly metric, i.e., less nominal, the data, the more useful a color assignment varying saturation and lightness within a small range of hues will be. Categorized data, on the other hand, can benefit from the color connotations and distinctiveness of separate hues.

Emotional responses to color can also play an important role in determining color choice. Not only are there the common associations with warm reds and cool blues, but more subtle effects which artists often employ, such as perspective modeling with color. When mapping any kind of information which has inherent color associations, such as vegetation, choosing colors is complicated. Even statistics about health or crime problems, with strong emotional messages for many people, need to have colors chosen carefully.

Computer Equipment for Interactive Color Mapping

Interactive CRT terminals for color mapping have been introduced in the past several years with considerable variety in capabilities and features. The important parameters describing these terminals are resolution, color control, hard copy output, internal memory structure, and price. Resolution affects the complexity of display and varies from high values approaching human visual resolution to quite low values where one picture element (or pixel) may be a large fraction of an inch. Resolution on CRT's is conventionally expressed as number of horizontal elements times number of vertical elements and ranges from (1280 X 1024) to as low as (64 X 48). Resolution expressed in this way, however, does not take into account screen size. Furthermore some terminals are configured with non-square, that is, rectangular, pixels.

Color Control

Color control on interactive terminals varies considerably. The colors which can be used at one time are called the displayable colors. There may be as few as four or as many as 4000 or more of these. The displayable colors may be fixed or variable. That is, there can be a set of selectable colors from which the displayable colors are chosen. Thus, perhaps 8 colors from a palette of 64 can be displayed.

When the number of displayable colors is less than the number of selectable colors, a structure is built into the terminal called a color table or color map. This table specifies which selectable colors are to be used for the current display and is usually changed with terminal commands. By changing the color table in rapid sequence a pseudo animation effect can be achieved.

The table which maps displayable colors to selectable colors is to be distinguished from another kind of table called a compensation table. Compensation tables are generally implemented in hardware to allow for a relatively straightforward, i.e., linear, specification of lightness. This is necessary because the perceived lightness (or brightness) on the screen is not a linear function of the driving amplitudes of the cathode ray guns.

Color Space

Another parameter of color control on interactive terminals is the color space in which colors are chosen (when there is a choice). The simplest form of color selection is by name or number such as light blue or R103 or a similar convention. When generality of color specification is provided, usually the red-green-blue color cube space or the hue-lightness-saturation space is used. RGB specifications generally work on 0 to 1 or 0 to 100 scaling for each component. Some experimentation is then necessary to produce desired colors. HLS systems have a more direct relationship to the perceptual parameters of color.

Additional color control is available on some terminals through the use of patterning. By this technique a certain amount of color mixing is possible by alternating pixels of different colors. Whether the alternating pattern of color is perceived as a checkerboard effect or is fused into an (additively) mixed color depends on the resolution of the image as viewed. From sufficient distance the eye will always perform mosaic fusion.

The possibilities for permanent copies of maps made on interactive screens is currently provided by xerographic, photographic, and microfilm technology. Some terminals have video output which allows the copying equipment, whether xerox or film, to be driven directly. Alternatively, photographs may be made of the screen itself, of course.

Memory Structure

The most important distinction in the memory structures of interactive color terminals is between frame buffer memories and coded picture definition memories. Frame buffers are so named because they provide buffer or storage space for an entire frame, or screen filling. Most often there is one cell, or word, in a frame buffer for each pixel on the screen. Supporting software is then needed to position map objects such as points, lines, or areas into the appropriate locations in the buffer. In a coded picture definition system, map objects are presented to the system by their coordinate description and are stored in the memory in a similar way.

Coded picture definition memories allow color changes by class of object much more directly than frame buffers, which would normally require the objects to be recreated in the frame buffer. Data such as radar or satellite imagery, however, is more directly represented and manipulated by frame buffer systems.

Price

The costs of interactive color mapping equipment have been continuing to decrease and there are now at least three low cost (ca. $1000) personal computers on which low resolution mapping can be done (Apple, Ohio Scientific, Texas Instruments). Medium resolution terminals (to 512 X 512) are in the $8000 to $20,000 range and high resolution (more than 1000 lines) starts about $30,000.

Software costs, on the other hand, are increasing as sophistication in dealing with color increases. Most currently available mapping software has something like a color or pen command which selects the color (pen) to be used for drawing following objects. This model of color control is based on color plotters. More advanced specification of color, currently being developed, will link map objects with a color defined in terms of a standard color space such as HLS.

Conclusion

With the appearance of relatively inexpensive computer equipment for making color maps; with the better understanding of how different kinds of data can be represented with color; and with more knowledge of how color is perceived, interactive color mapping is a practical way to portray geographical information.

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