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The Development of Process-Printed Munsell Charts for Selecting Map Colors

Cynthia A. Brewer

ABSTRACT. Color charts aid cartographers in the difficult task of choosing color schemes for maps. The perceptual organization of Munsell charts presents many potential color schemes. The colors on Munsell charts, however, are painted and many maps are printed with process-color inks. Combinations of process inks (percentages of yellow, magenta, cyan, and black) that approximate the Munsell organization are developed using color measurement followed by systematization of percentage progressions and visual adjustment. Diagonal arrangements of progressions of ink percentages approximate the perceptual organization of the painted Munsell charts. Value and chroma progressions and constancy of hue on ten printed Munsell charts are shown to be acceptable by measuring and mapping discrepancies between the original and printed colors.

KEYWORDS: map colors, color charts, Munsell system, process printing.

Well-chosen colors increase both the attractiveness of a map and the effectiveness with which it communicates spatial information. Color selection is, however, a difficult problem in map design. I have become dissatisfied with conventional color charts as aids for color selection through my experience in designing color schemes for printed maps and assisting students with color selection. Likewise, Brown (1982) and Castner (1980) discuss the difficulties of using conventional lithographers’ charts, which show colors resulting from combinations of screened printing inks. The disadvantages of such charts are that systematically chosen sequences do not possess equal visual differences between colors and the colors of logical schemes are often located pages apart, which makes the colors difficult to find and compare. Recommendations for map color selection are often made using phrases such as “values of one hue,” “spectral progression,” “distinctive hue,” “differences in value and intensity,” and “more intense colors” (Robinson et al. 1984, 186). Charts with colors arranged according to perceptual attributes (such as hue, value, and intensity or chroma) should therefore be helpful to cartographers because these attributes are used in map-color selection.

The objective of this study is to produce process-printed approximations of Munsell charts to aid cartographers in the selection of colors for printed maps. Castner (1980) warns that “[b]ecause of the large number of variables in the photographic, plate making and printing processes, it will be impossible to furnish a precise translation system for any color notation system” (p. 377). Similarly, Brown (1982) states that the precise conversion to Munsell would require a prohibitively large number of screen percentages. Approximating the Munsell charts is a worthwhile task, however, because the useful perceptual organization of the charts is unavailable with conventional printed charts. The use of standard screen percentages, which are commercially available, makes the charts of practical use to cartographers.

Background and Literature Review

Color systems are divided into the categories of appearance and mixture systems (Judd and Wyszecki 1975). Color-appearance systems are systematic collections of color examples that provide a uniform sampling of psychological color space and show by example the attributes of color perception. Mixture systems are constructed by mixing colors in systematically varied proportions to provide examples of the range of colors (color gamut) possible with specific colorants or lights. Munsell and lithographers’ charts are examples of appearance and mixture systems, respectively.

Judd and Wyszecki (1975) describe the Munsell Book of Color (1976) as the most prominent example of a color-appearance system. The Munsell system is used to establish color standards and acceptable ranges of color deviation for commercial products and to classify colors, as with the Munsell Soil Color Charts (1975). The attributes of color used in the Munsell system are hue, value, and chroma. Under ordinary viewing conditions, Munsell Hue and Munsell Value correspond to hue and lightness. Munsell Chroma speci-

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fies the difference between a color and gray of the same value. The organization of these three dimensions in the Munsell system provides a cylindrical coordinate system for the description of perceived color (Figure 1a). Within this cylindrical coordinate system, the volume occupied by existing Munsell chips forms the color solid shown in Figure 1b. Steps between colors along each color dimension are intended to be perceptually uniform, but the steps of one Munsell attribute are not equal to the steps of another.

An example color-mixture system is constructed using systematic variations of the four process-color printing inks: screenings of yellow (Y), magenta (M), cyan (C), and black (K). A full gamut of hues is produced by overprinting screened percentages of these four inks. The Kueppers Color Atlas (1982) provides a sampling of process-color combinations and is described in Figure 2 (similar charts are also produced by numerous printers and firms such as Pantone). All adjacent colors on the atlas charts differ by 10 percent of an ink, but this regular variation does not produce perceptually uniform differences. Some neighboring colors look similar. For example, differences between 80, 90, and 100 percent of an ink cause little change in perceived color. Conversely, there is a perceptually large change in color with a change from 0- to 10-percent ink. Thus, fewer colors from perceptual color space are represented in these areas of the printed charts.

In the cartographic literature, the most thorough reviews of color systems and color designation are found in the texts by Dent (1985) and Robinson et al. (1984). The CIE coordinate system, Munsell system, and printed-color system are described in both texts. In addition, Dent describes the Ostwald system and ISCC-NBS color designations and Robinson et al. describe the red-green-blue color cube.

Brown (1982), Castner (1980), and Kimerling (1980, 1981) relate printed color to alternative color systems for cartographic applications. Kimerling presents color-theory research relevant to map printing, and he describes the positions of process-color screen combinations in the CIE-xyY coordinate system with two- and three-dimensional diagrams. Both Brown and Castner discuss the importance of ordering color by perceptual attributes on printed color charts for cartographers. Castner also recommends use of substantial differences between adjacent chart colors to encourage cartographers to select colors that will remain distinct with color variation in map printing and with induced changes in color appearance by surrounding map colors. Castner suggests a format for color charts (Figure 3) that he feels is more appropriate than the organization of conventional printed charts for selecting map colors. Castner’s chart form is based on the Ostwald color system, and Brown also

Figure 1. The Munsell color system. Diagram 1a illustrates the cylindrical relationships among Munsell hue, value, and chroma. The isometric drawing of the three-dimensional color solid (1b) was constructed using the maximum chroma at each value level on the 40 hue charts in the Munsell Book of Color (1976). Student Set color charts represent slices into the color solid along the spokes in diagram 1c. The abbreviations for chart hues are R for red, Y for yellow, G for green, B for blue, and P for purple. The standard form for the Munsell notation of a color is Hue Value/Chroma (for example, 5 R 6/12 is a medium-value high-chroma red).
Ostwald solid. The regular format of the Ostwald system is readily adopted for process-printed charts, but the three perceptual attributes of color are not as rigidly ordered in the Ostwald system as they are in the Munsell system. The Ostwald system also does not maintain perceptually equal spacing between colors, which is a useful quality of the Munsell system.

Cartographers' interest in uniform perceptual steps in a color system is shown by the extensive research on equal-value gray scales, which is summarized by Kimerling (1985); extension of this idea to full color using CIELUV notation (Robertson and O'Callaghan 1986; Shellswell 1976); and the use of perceptually equal screen increments by the DMA (Stoessel 1980). Color research has produced numerous perceptual color systems, such as Munsell, CIELUV, and the OSA Uniform Color Scales (Agoston 1979), but none are accessible to cartographers as process-printed color chips with percentage-ink specifications.

**Methods**

Munsell notations were produced for printed colors in a multiple-stage procedure. Spectrophotometric measurements were made for a regular sample of colors from printed charts, and software (Davidson Colleagues 1985) converted the measurements to Munsell notations. Linear interpolation was then used to calculate Munsell notations for the remaining printed colors (Table 1). A Kueppers *Color Atlas* (1982) was used as a physical example of printed color for the measurements because it was commercially available and relatively inexpensive. The list of Munsell notations for each of the 5,324 printed colors in the atlas was searched for the printed colors perceptually closest to each of the 238 chips on the charts in a Munsell *Student Set* (1984). Perceptual distances between Munsell notations were calculated using the modified Godlove equation (Judd and Wyszecki 1975). The *Student Set* was used because it provided a sample of ten hue charts representative of the Munsell system, and the set was inexpensive. A detailed description of the above procedure is provided in Brewer (1986).

Although the selected printed colors were the best mathematical matches with individual Munsell chips, the collections of colors for each chart were only rough representations of the systematic perceptual organization of a Munsell chart as a whole. The match between the process and printed Munsell charts was improved by first making irregular progressions in the ink percentages systematic in all directions on the charts (Table 2). The color matches were refined using colors only from the sets of color charts (cubes) that include black (YMK, YCK, MCK), because it is easier to maintain hue when colors are desaturated with black rather than with the third primary (Bruno 1985).
Table 1. Example interpolation results for part of a Kueppers Color Atlas chart. The underlined colors are measured colors from which remaining notations were interpolated.

<table>
<thead>
<tr>
<th>Process Color Specifications for the Color Atlas colors</th>
<th>%Y %M %C</th>
<th>%Y %M %C</th>
<th>%Y %M %C</th>
<th>%Y %M %C</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 0 30</td>
<td>30 10 30</td>
<td>30 20 30</td>
<td>30 30 30</td>
<td></td>
</tr>
<tr>
<td>30 0 40</td>
<td>30 10 40</td>
<td>30 20 40</td>
<td>30 30 40</td>
<td></td>
</tr>
<tr>
<td>30 0 50</td>
<td>30 10 50</td>
<td>30 20 50</td>
<td>30 30 50</td>
<td></td>
</tr>
<tr>
<td>30 0 60</td>
<td>30 10 60</td>
<td>30 20 60</td>
<td>30 30 60</td>
<td></td>
</tr>
</tbody>
</table>

Munsell Notations for the above Color Atlas colors

<table>
<thead>
<tr>
<th>Hue</th>
<th>Value/Chroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.05 GY 7.68 / 4.46</td>
<td>6.19 GY 7.25 / 3.30</td>
</tr>
<tr>
<td>4.79 G 7.20 / 4.76</td>
<td>3.85 G 6.80 / 3.43</td>
</tr>
<tr>
<td>9.34 G 6.72 / 5.58</td>
<td>9.73 G 6.36 / 4.22</td>
</tr>
<tr>
<td>2.54 BG 6.24 / 6.73</td>
<td>3.43 BG 5.92 / 5.39</td>
</tr>
</tbody>
</table>

Table 2. Comparison of results from the computerized and final matching. These examples for magenta and black inks are from the 5 R hue chart. Yellow percentages are also part of the complete specifications for this chart.

<table>
<thead>
<tr>
<th>Computer Matches</th>
<th>Chroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>/2 /4 /6 /8 /10 /12 /14</td>
</tr>
</tbody>
</table>

Final Matches: Systematized and Visually Adjusted

<table>
<thead>
<tr>
<th>Value</th>
<th>Chroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 10</td>
<td>20 10</td>
</tr>
<tr>
<td>10 20 30 40 50</td>
<td>30 20 10 5 0</td>
</tr>
<tr>
<td>20 30 40 50 60 70</td>
<td>40 30 20 10 5 0</td>
</tr>
<tr>
<td>30 40 50 60 70 80 90</td>
<td>50 40 30 20 10 5 0</td>
</tr>
<tr>
<td>40 50 60 70 80 90 100</td>
<td>60 50 40 30 20 10 5</td>
</tr>
<tr>
<td>50 60</td>
<td>70 60</td>
</tr>
<tr>
<td>60 Magenta Ink</td>
<td>80 Black Ink</td>
</tr>
</tbody>
</table>

0 = no ink, 10 = 10%, ..., 90 = 90%, 100 = solid ink, − = no match
A distance-threshold matching criterion caused unmatched colors.

This restriction is important because the Munsell charts include many desaturated colors that are particularly vulnerable to hue distortions with changes in color balance during printing.

The initial systematicatization of the matches produced a generally diagonal organization of the ink percentages (Table 2). The primaries (yellow, magenta, and cyan) usually increased in percentage downward, causing decreasing value, and to the right, causing increasing chroma. A common left-diagonal increase in black caused decreasing chroma to the left and decreasing value downward. To arrive at the final specifications, percentage trends were restricted to systematic diagonals and percentage combinations were repeatedly adjusted and visually compared (using daylight) until the best systematic visual matches were obtained between 3M Color Key proofs and the Munsell charts.

To evaluate the accuracy of the printed Munsell approximations, spectrophotometric measurements were made for each color from five sets of visually-acceptable printed charts. The measurements from
the five samples of an ink combination were averaged and converted to a Munsell notation with the Davidson Colleagues software (1985). The average notations of the printed-chart colors were then graphically compared with the target Munsell notations.

Discussion of Results

The results of the chart development are displayed in Figures 4 and 5. Figure 4 presents the final printed charts and corresponding process-color specifications that approximate the Munsell Student Set charts. Figure 5 shows the measured Munsell notations from the printed charts plotted in Munsell space.

Distorted grids in Figure 5 connect the measured value and chroma coordinates of the printed chart colors. Displacements of grid intersections show that, generally, values are within one value step of desired notations and chromas are within two chroma steps. Rotation and stretching of the grids reveal variation in value across rows and variation in chroma down columns of the printed charts (value is constant along rows and chroma is constant down columns of the painted charts). Grid relations break down most frequently at maximum chroma and low value. The crushed maximum-chroma edge of the 5 B chart is an example of failure to maintain chroma steps. The skewed grid cells at the bottom of the 5 PB and 5 P charts show loss of value differences at low value. The measured grids are shifted and twisted, but overall grid topology is well maintained and systematic changes in value and chroma are approximated on the charts.

Deviations in hue are shown by circle sizes and the presence or absence of circle tints in Figure 5. The printed 5 RP chart is the most accurate in approximating the 5 RP hue. The hue of the 5 R chart is shifted toward RP by a relatively constant amount. On other charts, hue changes are orderly and deviation usually increases as chroma increases. The 5 BG and 5 P charts show the greatest distortions of hue. Hue shifts rarely push colors into a neighboring hue (compare circle sizes with the last row of the legend in Figure 5) and, therefore, hue categories are maintained on the charts.

The edges of the charts show the greatest distortions of hue, value, and chroma. Weakness in these areas occurs because the proportions of inks that provide acceptable matches and perceptual ordering for the majority of a chart fail toward the edges of the chart. These compromises at the chart edges result from the decisions to maintain diagonal organizations of percentages and use 5- and 10-percent screen increments. A set of screens that offers a greater range of low percentages and perceptually equal differences between screens should allow a diagonal organization of percentages to produce perceptually ordered color charts of greater accuracy than those developed.

Concluding Comments

The objective of this research was to print an approximation of Munsell color charts with process inks. The exact hue, value, and chroma of corresponding Munsell colors and the constancy of visual steps between adjacent colors in the Munsell system were not maintained on the printed charts. Given the variability of process proofing and printing and the precision of specification in the Munsell system, producing an exact replica was neither realistic nor anticipated. The organization of the perceptual dimensions of the Munsell system, however, was approximated and this quality makes the printed charts potentially useful to cartographers.

The study produced interesting and useful information about the relationship between the Munsell system and process ink combinations. When colors were organized by the perceptual dimensions of value and chroma, the general trends in ink percentages were consistent from hue to hue; constant percentages were arranged on diagonals with black and the primary colors increasing in opposite directions (Table 2, Figure 4). Intersecting these two trends caused the desired decrease in value downward, with approximately constant chroma in each column, and increase in chroma to the right, with approximately constant value along each row.

The selection of thematic map schemes is assisted by the perceptual organization of the Munsell-based charts. Quantitative relationships between map categories are commonly represented by a progressive change in value accompanied by a systematic treatment of chroma. Figure 6 demonstrates path orientations useful for the selection of quantitative schemes from Munsell charts. The charts are also useful in the design of qualitative schemes, for which hue is the primary attribute used to distinguish nominal classes. For example, a cartographer may be searching for high chroma colors to represent land uses of small areal extent and near-neutral colors for categories that cover the majority of the mapped region. Each Munsell chart presents a single hue with low chroma colors on the left and high chroma colors on the right, and this ordering simplifies the cartographer's color search.

The form of the printed charts is restricted because they are designed to simulate existing Munsell charts. The shape of each commercial Munsell chart is partly limited by the maximum chroma attainable with permanent paints. This restriction is irrelevant to printing with process inks because permanency is not considered in percentage selection. A potential extension of this study is to examine more complete understanding of the relationship between process inks and the Munsell system.
The triangular charts on which percentage trends are extended until one of the inks reaches either zero or 100 percent. However, difficulty maintaining value steps, chroma steps, and correct hue at the edges of the Munsell-based charts suggests that perceptual order would be compromised on extended charts.

A color chart cannot replace experience during the complex process of color selection, but perhaps the
Figure 5. Measured Munsell notations of the final printed charts. The value and chroma notations of the colors on the Student Set charts are represented by the regular white grids. Color chips are located at grid intersections and are attached to measured notations of corresponding printed colors with thin black lines. The black grids connect these measured notations. Circle sizes are proportional to euclidean distances between target and measured hues and are thus proportional to perceived differences because Munsell is a perceptual color order system. The legend at the top-left of the figure allows comparison of perceived differences at each chroma level for sample hue differences. The second row of the legend, for example, shows that deviation of 5 hue steps at chroma /14 is perceived as a greater difference than 5 hue steps at chroma /2. Clockwise directions of hue difference are shown by open circles and counterclockwise directions by tinted circles.
difficulty of using conventional charts is one reason why so much experience is needed to select map colors effectively. An excellent understanding of color is required to select perceptually logical schemes from perceptually illogical charts. The problem of designing color maps should, therefore, be simplified by the addition of perceptually organized Munsell-based color schemes to cartographers' repertoire of color-selection tools.

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REFERENCES


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