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Color Palette Considerations for Digital Map Displays

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The Map Data Formatting Facility is creating a library of Compressed Aeronautical Chart (CAC) data on a compact disk (CD) media in support of mission planning systems and airborne digital moving-map systems for military aircraft. The CAC library is generated by transforming the Defense Mapping Agency's Equal Arc-Second Raster Chart (ARC) Digitized Raster Graphics data from the ARC projection system into the Navy-specified tessellated spheroid projection system. The data are then color and spatially compressed using a technique known as vector quantization. This report discusses the method by which a standard set of thirty 8-bit color palettes, which are used for the color-compression portion of CAC generation, are built. Briefly, color compression is achieved by reducing the amount of color information from 24 bits per pixel to 8 bits per pixel via a color look-up table. A CAC color palette, which contains 256 entries (including 16 that are reserved for vector graphic overlays), is used to define the color look-up table. In addition, the color palette is written onto the final CAC CD-ROM for decompression operations. Since a single color palette will be used to color compress ARC digitized raster graphics data for one-fifth of the world at a given scale, prudent color selection is vital.

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COLOR PALETTE CONSIDERATIONS FOR DIGITAL MAP DISPLAYS

INTRODUCTION

The emergence of airborne digital moving-map systems in military aircraft (Fig. 1) has promoted the development of a global database of scanned aeronautical charts that are engineered specifically to support these systems. Graphically oriented, visual digital information, such as a scanned chart database, typically requires a tremendous amount of storage capacity for data, particularly when the information is in raster form and in 24-bit color. Many compression methods have been developed that significantly reduce the storage requirements of color, raster, data sets. The Naval Research Laboratory has designed and developed a VAX-based computer center, known as the Map Data Formatting Facility (MDFF). The primary objective of the MDFF is to create a library of compressed aeronautical chart (CAC) data on compact disk-read only memory (CD-ROM) in support of military aircraft mission planning systems, as well as airborne digital moving-map systems.

The CAC provides the Navy with a standard, world-wide, seamless database of raster—scanned aeronautical chart images at six different scales, specifically designed for use by mission planning systems and digital moving-map systems. The requirements of this database include that it use a minimum amount of storage space, that it be rapidly and easily displayed, and that it be of optimal resolution. The CAC library is produced at the MDFF in three steps:

Fig. 1 — Airborne digital moving-map display

- The transformation of source chart images, which consist of Defense Mapping Agency (DMA) ARC Digitized Raster Graphics (ADRG), from DMA's ARC projection system into the Navy-specified Tessellated Spheroid (TS) projection system.

- The color compression of the transformed TS data.

- The spatial compression of the reduced-color TS data.

The transformation from ARC to TS involves a neighborhood averaging method, which reduces the resolution of the image data by approximately one-half (Lohrenz et al. 1992). This reduction in resolution is required for compatibility with the resolution of the aircraft display systems (128 pixels per inch), and it reduces storage requirements of the image data by 4:1. Color compression is achieved by reducing the amount of color information from 24 bits per pixel (bpp)—8 bits each of red, green, and blue information—to 8 bpp via a color look-up table. A color vector quantization process (Gray 1984) selects the closest match of 240 8-bit entries in the look-up table to represent each 24-bit pixel. This reduces storage requirements by an additional 3:1. Finally, spatial compression is achieved by applying another vector quantization process that replaces 4-pixel blocks of data (32 bits) by a single 8-bit code word from a 256-entry codebook. This procedure further reduces the storage requirements of the data by 4:1. The total compression achieved is 48:1 (Lohrenz and Ryan 1990).

The completed CAC library will have a standard set of 30 color palettes, one palette for each TS zone and scale (Fig. 2), which will remain constant for the life of the library. A color palette file is depicted in Fig. 3. The color palette, which contains 256 entries (including 16 that are reserved for vector graphic overlays), is used to define the color look-up table for the color compression portion of CAC processing. The palette is also written onto the final CAC CD-ROM for decompression and display operations. Since only one color palette is used for each TS scale and zone, and since the standard set of 30 palettes will only be generated once for the entire CAC library, accurate color representation is vital.

This report focuses on the techniques for creating the 30 standard CAC color palettes and the impact of color selection on the color-compression portion of CAC processing. One fundamental goal of color compression is to make any apparent loss of color information seem to be a normalization of the scanned aeronautical charts' colors. In other words, reduce the number of colors

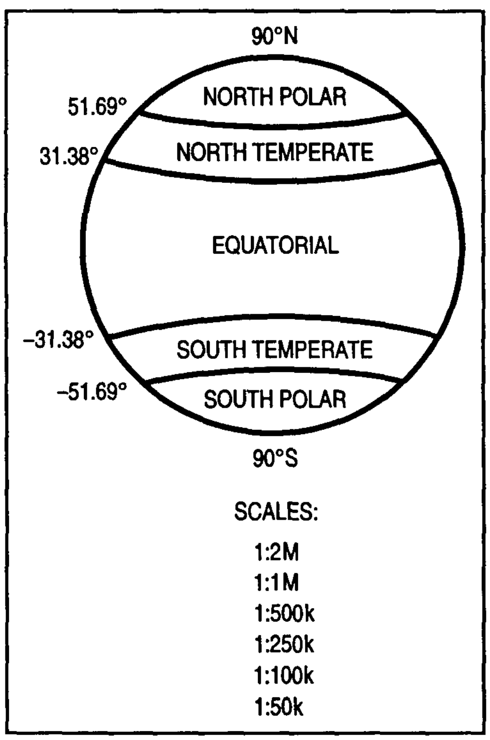

Fig. 2 — CAC color palette boundaries

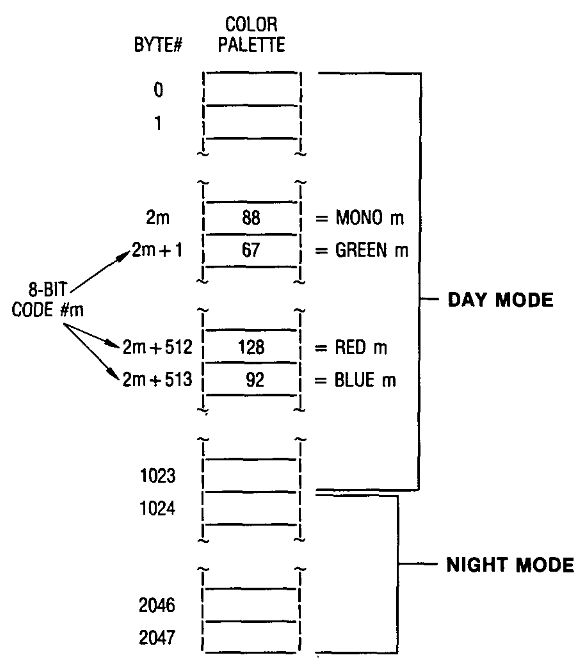

Fig. 3 — CAC color palette file layout

available by identifying and eliminating colors that represent scanner noise, chart fold lines, etc. Care must be taken, however, to ensure that those colors that represent, for example, scanner noise, do not also represent a true chart color. Several issues and tradeoffs must be considered when selecting colors for a particular color palette. Two methods of color selection are the median-cut algorithm and the use of "algebraic" palettes. The attributes and drawbacks of each method are mentioned, and a "hybrid" method that incorporates the characteristics of both techniques, is presented. Enhancement strategies are discussed with regard to the human visual system and quantitative analysis.

MEDIAN-CUT ALGORITHM

The median-cut algorithm bases its color selection upon a set of image data that is chosen by the user for its variety of colors (Foley and Van Dam 1990). The preparation for this algorithm, which is illustrated in Fig. 4, is highly user-intensive. First, a set of paper charts must be manually selected from the TS zone and scale (chart series) of interest. Taken collectively, the charts should represent as wide a variety of colors for that zone and scale as possible. Next, a sample of points must be collected from each selected chart, where each point is chosen for the number of different colors that are observed within a predetermined radius around the point. In any given chart, enough points should be chosen to represent most of the colors in that chart. Finally, all of the ADRG CD-ROMs that correspond to the selected charts must be loaded, and all of the points that were selected from each of the charts must be manually input to the program that builds the color palette. The program inputs all of the pixels that are within the predetermined radius of each user-selected point and then executes the median-cut algorithm (Heckbert 1982; Wan et al. 1988).

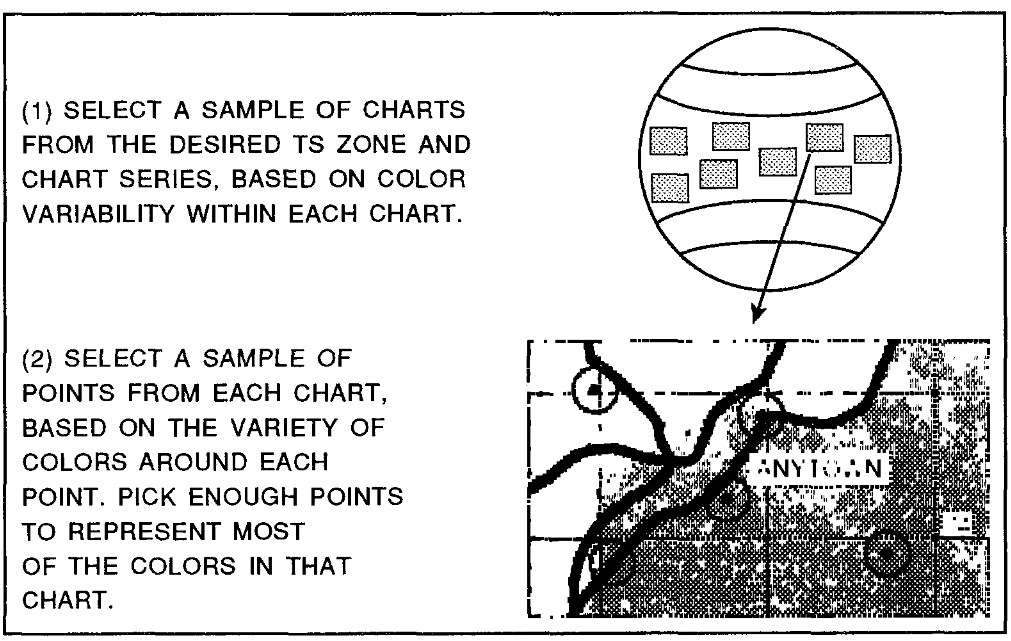

Fig. 4 — Sample chart and point selection for median-cut palette

Table 1 provides a sample set of 12 pixels to illustrate the basic principles of this method of color reduction. Briefly, the median-cut algorithm sorts the input set of 24-bit pixels with three different keys: the pixels' red values, the green values, and the blue values, in that order. As shown in Table 1, the euclidean differences between adjacent pixels (after each sort) are recorded; after all three sorts are completed, the algorithm splits the original set of pixels into two bins at the point of greatest euclidean divergence. For the example in Table 1, this split occurs between pixels B and D in the set that was sorted by green values; thus, pixels J, A, K, L, C, and B are in the first bin, and pixels D, F, E, G, I, and H are in the second bin. The process repeats itself for each of the new bins of pixels and continues to reiterate until the desired number of bins, or clusters, is reached. Figure 5 shows the location in red, green, and blue (RGB) space of the 12 pixels in this example

Table 1 — Example Sort Tables for Median-Cut Algorithm

Sorted by Red					Sorted by Green						Sorted by Blue				
Pixel	R	ΔR	G	B		Pixel	G	ΔG	R	B	Pixel	B	ΔB	R	G
L	20	0	55	134	BIN 1	J	20	0	40	147	C	43	0	145	60
K	35	15	50	112	BIN 1	A	50	30	110	60	A	60	17	110	50
J	40	5	20	147	BIN 1	K	50	0	35	112	B	60	0	125	75
A	110	70	50	60	BIN 1	L	55	5	20	134	K	112	52	35	50
B	125	15	75	60	BIN 1	C	60	5	145	43	L	134	22	20	55
C	145	20	60	43	BIN 1	B	75	15	125	60	J	147	13	40	20
F	185	40	170	190	BIN 2	D	155	80	200	180	D	180	33	200	155
I	185	0	225	245	BIN 2	F	170	15	185	190	F	190	10	185	170
D	200	15	155	180	BIN 2	E	170	0	220	200	E	200	10	220	170
H	200	0	235	240	BIN 2	G	180	10	205	210	G	210	10	205	180
G	205	5	180	210	BIN 2	I	225	45	185	245	H	240	30	200	235
E	220	15	170	200		H	235	10	200	240	I	245	5	185	225

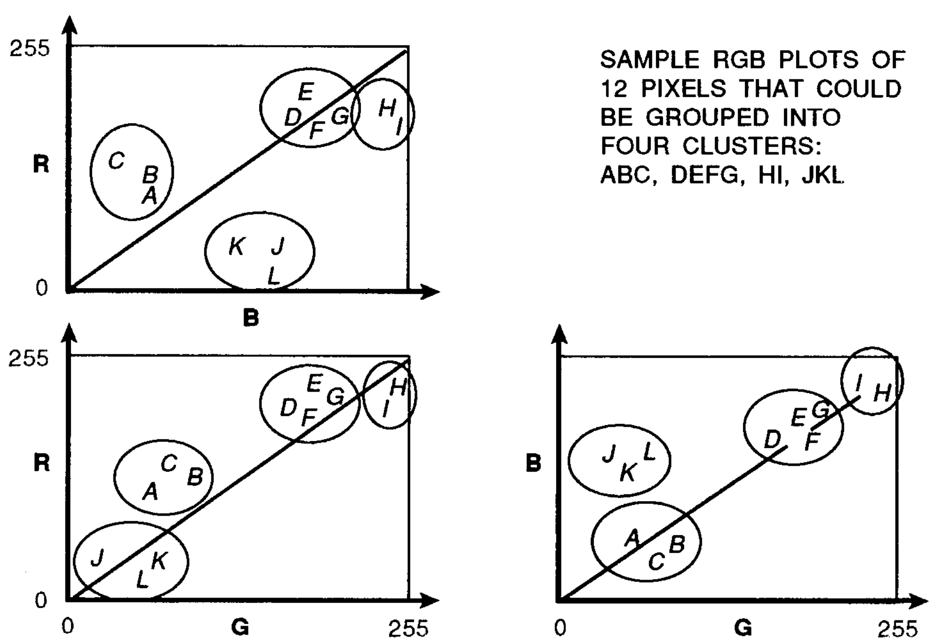

Fig. 5 — Sample pixel clustering for median-cut palette

and shows them grouped into four final clusters. The RGB value of the centroid of each final cluster is entered into a color table, and that value will replace the RGB value of each pixel assigned to that cluster during color compression. One cluster is required for each slot in the final color palette. In the case of CAC, each color palette has 240 entries. Therefore, the median-cut algorithm must continue until 240 clusters are generated, and the 240 centroids are entered into a CAC color palette. The final palette is sorted by increasing intensity, I, where $I = (\text{red})^2 + (\text{green})^2 + (\text{blue})^2$.

The median-cut algorithm tends to produce pastel colors, since the final clusters tend to lie close to the achromatic axis in RGB space (i.e., along the line of grays that runs from pure black (0,0,0) to pure white (255, 255, 255)). However, the colors produced by this algorithm generally retain a close resemblance to the original 24-bit input image data. The method is adequate as long as the initial user-selected set of charts and points provides a good representation of all of the data to be processed with that palette. Figure 6a illustrates a coastal area whose color palette did not provide a good representation of all of the required chart colors. Specifically, the color white is missing. Figure 6b illustrates a corrected version of the image in Fig. 6a. The method by which the corresponding color palette was corrected is described later.

ALGEBRAIC PALETTES

The goal of an algebraic method of palette generation is to generate an equalized palette with a selected number of reds, greens, and blues; e.g., 8 reds, 6 greens, and 5 blues would generate 240 ($8 \times 6 \times 5$) final chart colors in the palette (Foley and Van Dam 1990). Some advantages of using algebraic palettes are listed:

- Generating such a palette is much faster than generating a palette with the median-cut algorithm, since no labor-intensive preprocessing is required.

- Compressing chart images with an algebraic palette is also considerably faster. Since the palette colors are equally separated in RGB space, replacing an 8-bit palette color for a corresponding 24-bit chart color can be done with a simple algebraic operation, instead of the relatively computer-intensive color lookups and comparisons required to compress a chart with a palette that was not generated algebraically.

A disadvantage of using the algebraic method, however, is that it does not seek a close resemblance to the original 24-bit image data but, instead, attempts to separate the map colors into visually distinct hues. This method tends to enhance edges in the image data, but it also accentuates noise. This noise enhancement is a problem, since the source ADRG data are initially generated by a 24-bit scanner that introduces a significant amount of noise. In addition, compressing chart images with an algebraic palette causes the loss of some of the map hues that lie between palette entries. In turn, this "algebraic compression" often reduces the readability of the compressed image. Another undesirable effect of algebraic palettes, which is exacerbated by noise in the original 24-bit image data, is that a large, monocolor area is often mapped into two or more different palette entries. Figure 7 exemplifies such an effect with brownish noise mapped into blue water, which is caused by the high contrast between two palette colors.

HYBRID COLOR PALETTE METHOD—COLOR ELIMINATION

Both methods of color palette generation have limitations. The median-cut algorithm requires that the CAC color palettes be built from a limited user-selected data set. Until a substantial amount

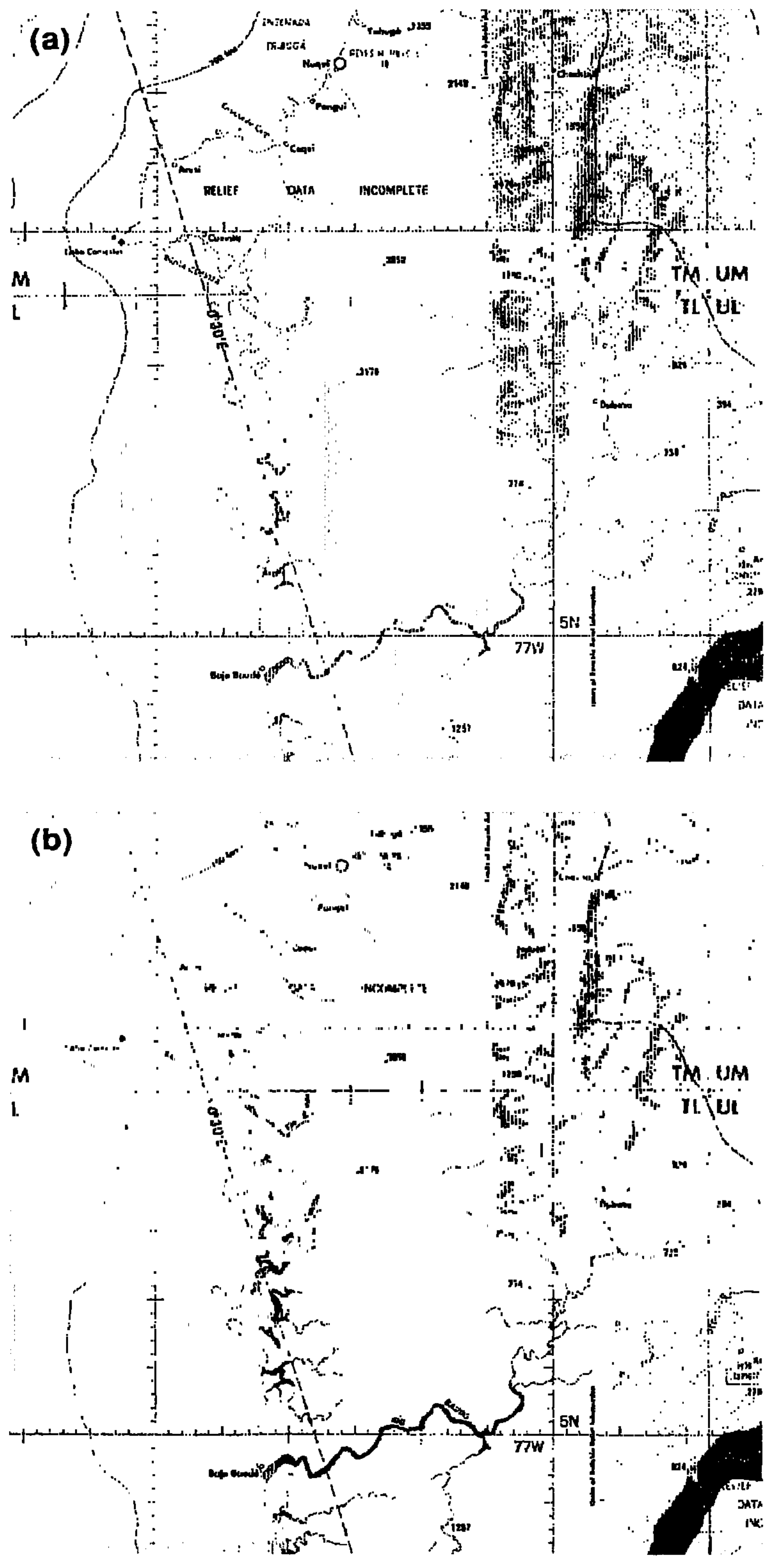

Fig. 6 — (a) Median-cut palette containing no white color and (b) Hybrid palette correcting median-cut palette

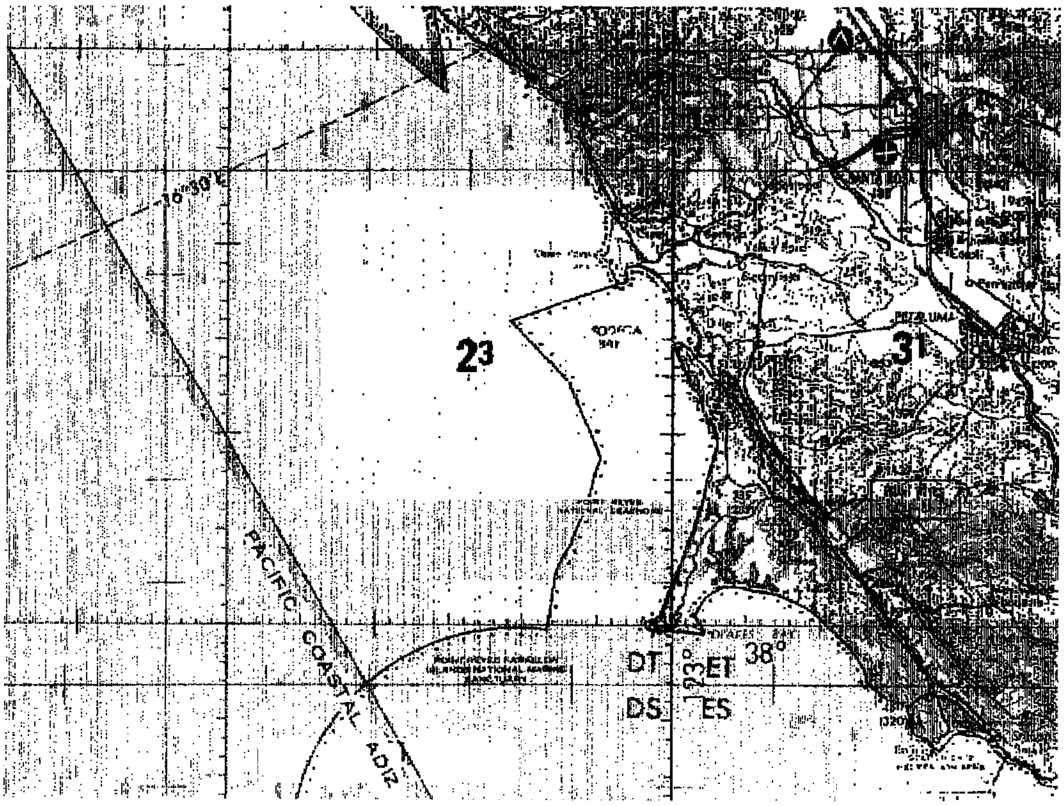

Fig. 7 — The 8-6-5 algebraic palette illustrating enhanced noise

of data is compressed with the resulting palette, it is uncertain whether or not the user-selected data set will provide enough color variability for all of the image data that will eventually be processed with the respective palette. However, although algebraic palettes provide more color variability, they tend to enhance the noise in the image data and, in some cases, reduce the integrity of the data. Since each method has its own benefits and drawbacks, the authors decided to try a hybrid method that incorporates attributes of both the median-cut algorithm and the algebraic method. This hybrid would first utilize a representative sampling of colors from an appropriate set of image data (using the median-cut algorithm) while also incorporating a greater variety of colors that could be used for data that are dissimilar to the original baseline data set (using a technique that is related to the previously discussed algebraic method; Jacobsen and Bender 1989).

The first step in generating an improved color palette with the hybrid method is to implement a color palette that was generated with the original median-cut algorithm as a preliminary palette. Some of the entries in this preliminary palette must be eliminated to make room for additional colors that will be generated algebraically. We have observed that many of the color palette entries established by the median-cut algorithm are very close to one another in perceived color. A metric was defined to eliminate a number of these similar-looking color palette entries and, thus, free enough slots in the color palette to add more color variability without losing any colors that are significantly distinguishable from one another in the original palette.

HUMAN COLOR PERCEPTION

An examination of the human visual system contributes to a more effective determination of hue similarity and, therefore, a successful definition of the desired color-reducing metric. The following points were taken into consideration during the development of this metric:

• Studies in human color perception show that the human eye can perceive approximately 350,000 colors (Foley and Van Dam 1982), so 19 bpp are required to accurately represent all perceivable colors. However, the colors in CAC palettes are limited to 8 bpp, so less than one-tenth of 1% of all perceivably different colors can be used to create an appropriately sized color palette.

• Other studies show that the human eye is much more sensitive (Fig. 8) to red and green light than to blue (Overheim and Wagner 1982).

• Most of the colors in the source (ADRG) image data lie relatively close to the achromatic axis, thus eliminating the need for heavily saturated reds, greens, and blues in the palette.

The very nature of color perception is purely subjective. Five members of the MDFF project performed a study in color perception. These individuals were asked to compare a color from a preliminary median-cut palette to scaled versions of the reference color, side by side. A reference color for each hue was compared against its same-hued scaled color (one red vs. another red, blue vs. blue, green vs. green). In this study, a color is considered to be in the red hue if its hue calculation based on the hue-lightness-saturation algorithm (Graphic Standards Committee 1979) is between 0° and 120°. Similarly, a color is considered in the green hue if its hue calculation falls

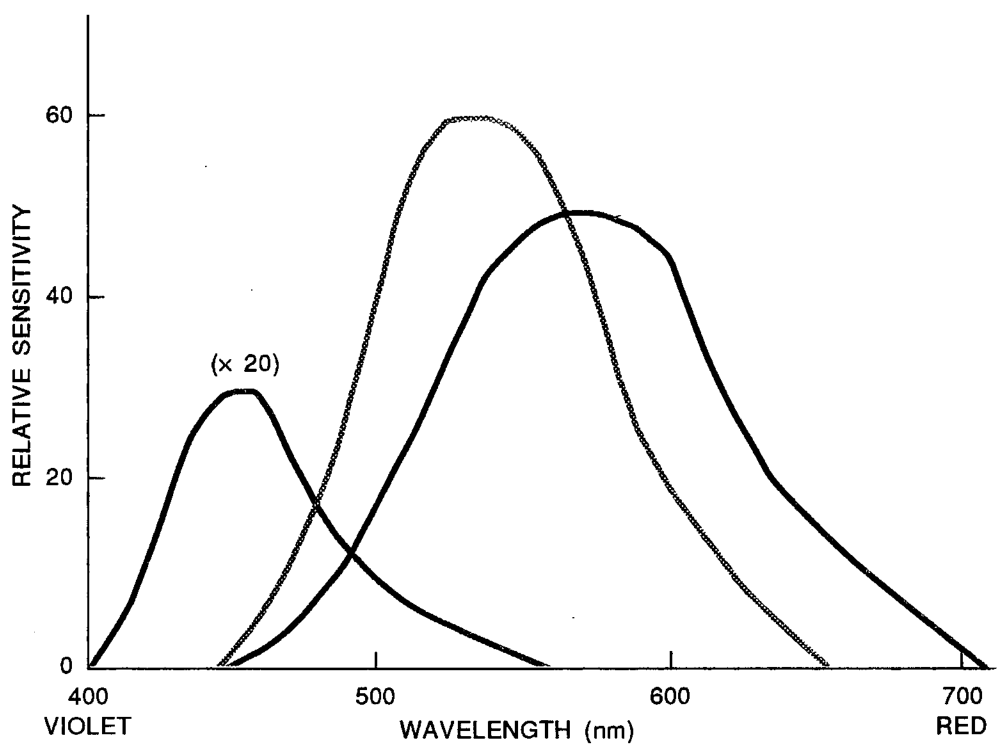

Fig. 8 — Response characteristics of the eye (Fig. 17.16 from Overheim and Wagner (1982))

between 120° and 240°, and the blue hue if its hue is between 240° and 360°. If any scaled color had a perceivable difference from the given reference color by any observer, the squared euclidean distance $[(R-R')^2+(G-G')^2+(B-B')^2]$ between the two colors was recorded. Once data were compiled for each hue, an average of the recorded distances was computed (see Appendix). The resulting metric is the average-squared euclidean distance, within each hue, that is used to eliminate similar colors from a given palette. The average-squared euclidean distance values for each hue, as computed from this study, are as follows: red = 66, green = 85, blue = 300. Applying this three-dimensional RGB metric to a color palette generated with the median-cut algorithm eliminated approximately 26% of the median-cut palette's entries (Wyssecki and Stiles 1982).

HYBRID COLOR PALETTE METHOD—COLOR GENERATION

The next stage in the hybrid process, such as the algebraic method mentioned previously, selects new and distinct colors to fill the now-empty slots in the preliminary palette. For each existing entry in the palette, a triangle is formed between that entry's color (in RGB space) and its two closest entries (in euclidean distance) within the same hue. In other words, blue-hued entries are compared only against other blue-hued entries; green-hued entries are compared only against other green-hued entries, etc. In Fig. 9, pixels 1, 2, and 3 are triangulated, and the centroid of the resulting triangle is test pixel *P*. If the distance between *P* and each of the three points is greater

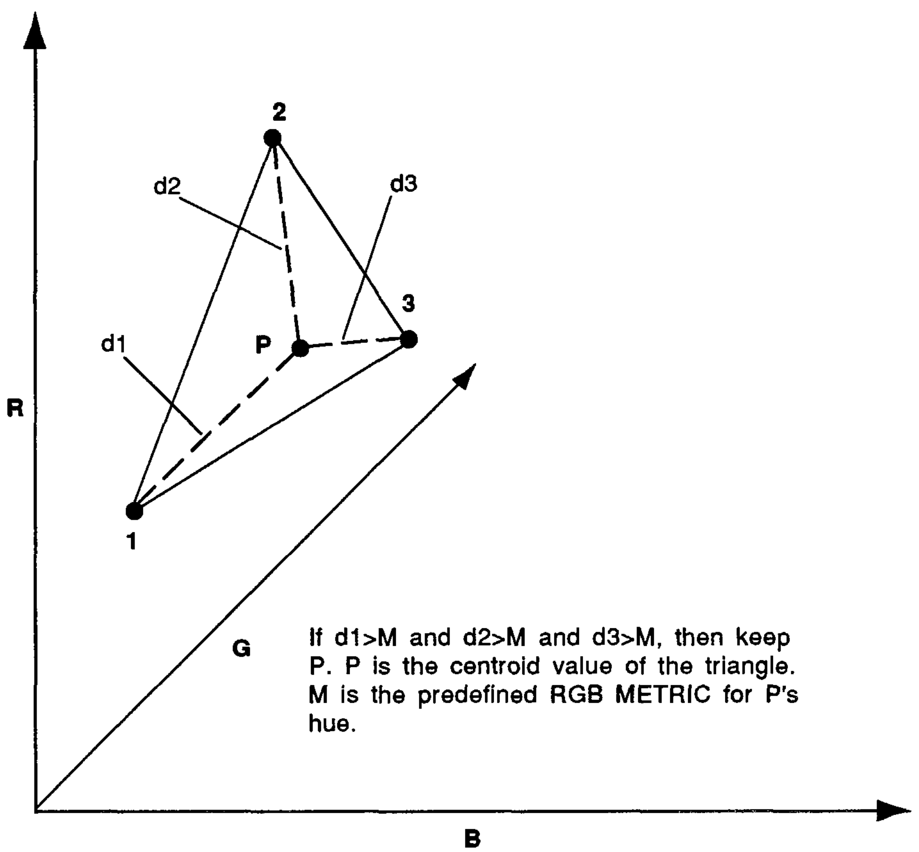

Fig. 9 — Selection of additional palette colors using geometric method

Table 2 — MSE Comparison of Median Cut, 8-6-5 Algebraic and Hybrid Methods

Codebook	Median Cut	8-6-5 Algebraic	Hybrid
1	58	173	59
2	54	176	54
3	59	167	59
4	161	185	89
5	968	210	219
6	62	193	63
7	51	199	52
8	54	189	55
9	216	200	73
10	788	240	300
11	87	234	91
12	82	237	85
13	49	213	47
14	188	268	156
15	582	268	324
16	159	308	173
17	156	305	176
18	40	253	31
19	206	293	226
20	550	248	347
MSE/CB	228.5	228.95	133.95

than the metric for that hue (i.e., 66 for red hues, 85 for green hues, and 300 for blue hues), then the centroid's RGB value is added to the color palette. If empty palette slots remain after this triangle method has been used, the process is repeated and includes the additional palette entries that were created in the first pass of this procedure. If empty slots still remain, then algebraic "seed" values are added from the eight corners of RGB space. Once the seed values are added, any remaining palette slots are filled using the triangle formula iteratively. Since the seed values are distant from the achromatic axis (where most of the source ADRG colors tend to lie), these seed colors tend to enhance very low or very high intensity colors without introducing additional noise. Also, the RGB metric still holds when adding these geometric colors. Therefore, ample spacing is provided within RGB space, thereby damping the effects of additional noise being introduced. This hybrid process produced the color palette used to correct the image shown in Fig. 6a (Fig. 6b) (Gordon and Abramov 1988).

The reasons behind this "geometric" method are the following: any desired colors that are bypassed by the median-cut algorithm are likely to be close to the colors in the baseline data set, which, in turn, are colors that lie relatively close to the achromatic axis. The method described here tends to add colors that, while significantly different from existing palette colors, are nevertheless apt to be similar to the source map colors. The final palette is composed of the initial colors, which were selected by the median-cut algorithm, whose distances from one another were greater than the given metric, plus the geometrically generated values. Table 2 presents the mean-square error (MSE) for an ADRG image, subdivided into sections called codebooks, that was compressed with three different palettes: a palette that was generated with the median-cut algorithm; a palette that was generated with the 8-6-5 algebraic method; and a palette that was generated with the hybrid technique (median-cut algorithm plus geometric method). The MSE for a 256 × 256 image is calculated as follows:

$$\frac{1}{3XY} \sum_{X=1}^{256} \sum_{Y=1}^{256} [R(x,y) - R'(x,y)]^2 + [G(x,y) - G'(x,y)]^2 + [B(x,y) - B'(x,y)]^2$$

where R, G, and B represent the RGB values of a pixel in the precompressed image, and R', G', and B' represent the RGB values of a pixel in the color-compressed image.

Table 3 — MSE Values for Fig. 6b

Method	MSE
Median	161
Algebraic	185
Hybrid	89

CONCLUSIONS

The hybrid method of color palette generation adequately produces a variety of colors that are present in a large set of image data for which only a relatively small, and not completely descriptive, subset of data is available. This method establishes a preliminary color palette with the median-cut algorithm; the base palette is then reduced by eliminating those colors that are considered to be nearly indistinguishable from other palette colors. Finally, the palette entries that were eliminated by the palette reduction process are then filled with new colors that are generated by a geometric method. The geometric method selects colors that are likely to be representative of the original image but that are not contained in the preliminary palette. Three distance metrics (one for each hue) were established and applied to this geometric method of color selection: red = 66, green = 85, and blue = 300. These numbers were derived by an in-house study, and they correspond with published results from the referenced studies in human color sensitivity. Figures 6a and 6b provide a comparison between a median-cut palette and its hybrid equivalent. The MSE values for the image in Fig. 6b are shown in Table 3.

In general, when a source image contains significantly more colors than the desired compressed image, some color loss during compression is inevitable. The establishment of a representative color palette is crucial to preserving the visual integrity of a digital image during color compression. The hybrid method of color palette generation combines the best aspects of the median-cut algorithm and a geometric method of color selection, reduces overall distortion in the image, and maintains color integrity.

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APPENDIX

TABLES

For the purposes of this study, red hues were defined to lie between 0° and 120° on the hue circle; green hues between 120° and 240°; and blue hues between 240° and 360°.

Determination of RGB Metrics for Color Palette Reduction

RED HUE (0°–120°)

				Distinguishable	
Euclidean Distance^2	R	G	B	Yes	No
0	233	104	14	0	5
10	236	105	14	0	5
20	237	106	14	0	5
30	238	106	15	0	5
40	239	106	14	0	5
50	238	109	14	0	5
61	239	109	14	2	3
70	239	109	17	3	0
80	241	108	14	–	–
90	240	109	18	–	–
98	240	111	14	–	–
Metric Calculation = [2*61 + 3*70]/5 = 66					

GREEN HUE (120°-240°)

				Distinguishable	
Euclidean Distance^2	R	G	B	Yes	No
0	134	154	141	0	5
10	137	155	141	0	5
20	138	156	141	0	5
30	139	156	142	0	5
40	140	156	141	0	5
50	139	159	141	0	5
61	140	159	141	0	5
70	140	159	144	0	5
80	142	158	141	3	2
90	141	159	145	1	1
98	141	161	141	1	–
Metric Calculation = [3*80 + 1*90 + 1*98]/5 = 85					

BLUE HUE (240°-360°)

				Distinguishable	
Euclidean Distance^2	R	G	B	Yes	No
0	64	51	126	0	5
50	69	56	126	0	5
100	74	51	126	0	5
150	74	56	131	0	5
200	74	61	126	0	5
250	77	60	126	0	5
300	74	61	136	5	–
350	79	61	131	–	–
400	64	71	126	–	–
450	69	71	131	–	–
500	74	71	126	–	–
Metric Calculation = [5*300]/5 = 300					