An English-based color notation system, designed for computer graphics applications, proved easier to learn and more accurate than quantitative systems.

A New Color-Naming System for Graphics Languages

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Recent reductions in hardware cost have caused the price of color raster CRT systems to drop considerably. As a result, such display systems are becoming more common. They are being used, and will be increasingly used, in applications written by programmers who are not specialists in the technology and technique of computer graphics. These programmers should not be required to learn the technical details of such devices as Z-buffers or digital scan converters. Nor should they be required to learn the technical details of colorimetry.

High-level languages and systems can free these users from the need for specialized knowledge of color raster display technology in much the same way that earlier generations were freed from such details as printer timing and spacing control. An ideal system would allow a programmer to write an applications program for use with a color raster display, without having to master the mathematics of coordinate geometry.

The work described here is part of a Florida International University project to design and implement just such a high-level language. One facility necessary in this language is a system for the specification of colors, or a color notation system. A recent study showed that users of a text-editing system performed better if they used commands based on English phrases.[1] With the hypothesis that the same would be true for a color notation system for use in a graphical language, we developed and tested such a system.

Existing color notation systems

A programmer can choose from a menu, from a palette displayed on a raster CRT, or from a color atlas (e.g., a set of paint chips of different colors). But it is best if he can specify color without access to a terminal as he writes the program, and without special materials such as a color atlas. A color notation system should allow a programmer to specify a color easily and to write a program that produces a color as close as possible to the one he visualized. The system should be easy to learn and should have an adequate set of colors. Here, we describe and evaluate a number of color notation systems, some designed for computer graphics, and others for noncomputer applications.

The RGB system. The color parameters of most monitors may be used as a color notation system. The RGB system,[2,3] specifies a color by indicating the intensities of the primary colors red, green, and blue. If the intensities are expressed as numbers between 0 and 1, the color space is a cube, and a color is represented by a triple of coordinates between 0 and 1, as shown in Figure 1. The RGB system was chosen as one of two optional standards by the Graphics Standards Planning Committee.[4]

This color notation system is familiar to many, as it represents the most commonly used additive primary system. Nevertheless, it is somewhat counterintuitive in sev-

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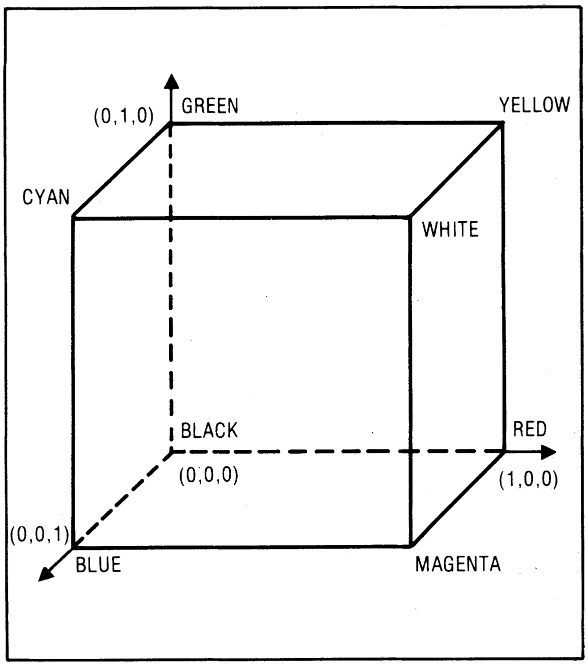


Figure 1. The RGB color space.

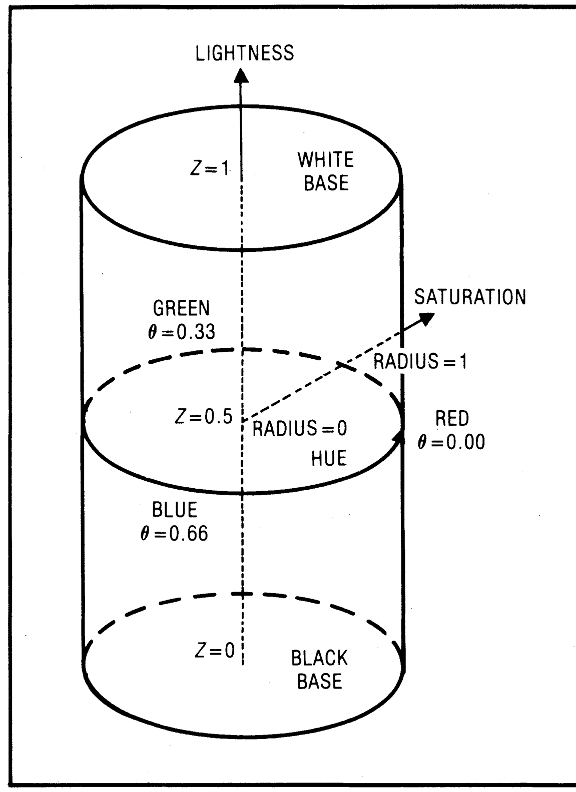


Figure 2. The HSV color space.

eral ways. For one thing, most users are accustomed to thinking in terms of subtractive color mixing, in which the usual primaries are red, blue, and yellow. Consequently, some re-education is necessary in order to understand that, for example, a mixture of red and green produces yellow in the RGB system, rather than the brown produced by mixing pigments. Further, although this system is attractive for its simplicity, it is not easy to use. This can be illustrated by trying to decide what ratios of red, blue, and green should be combined to produce the brown color of a wooden desk top. The weakness of the RGB system of color notation has been pointed out elsewhere.[2,5]

The HSV system. The other color notation system selected as an optional standard by the Graphic Standards Planning Committee is the HSV system.[2,4] In this system, each color is considered to be a pure hue modified by a saturation and a value (i.e., lightness). The color space is represented by a right circular cylinder (or, optionally, a double cone) and a color is defined in terms of cylindrical coordinates. The radial coordinate (normally between 0 and 1) corresponds to saturation, with the maximum attainable saturation at a radius of 1. The Z coordinate corresponds to lightness. Therefore, the bases of the cylinder are black (at $Z=0$) and white (at $Z=+1$). Hues are represented by the angular (theta) coordinate. Thus, the pure hues are on the surface of the cylinder at $Z=0.5$ (halfway between maximum and minimum lightness) and at maximum saturation. If the angular component is expressed as a fraction of an entire revolution around the hue circle, a color is represented by a triple of coordinates between 0 and 1, just as in the RGB system, normally organized in a circle (counterclockwise) with red at $\theta=0$, green at $\theta=1/3$, and blue at $\theta=2/3$. The cylindrical HSV color space is shown in Figure 2.

The HSV system is often preferred over the RGB system because algorithms such as those for shading and highlighting are more easily expressed in terms of modification of lightness and saturation than in terms of modification of the red, green, and blue components of a color. The HSV system also offers greater ease of properly specifying hues. To do so, however, the user must either have a hue circle available or have experience in converting an imagined pure hue to the proper spot on the interval (0-1). Although the HSV system is considerably easier to use than RGB, specifying all colors properly is still rather difficult for an inexperienced user. For example, as in the RGB system, how to specify the brown of a wooden desktop is not obvious.

The Munsell system. The Munsell color system[6,7] of notation is widely used in noncomputer applications where the precise specification of color is necessary, such as in the production of paints, fabrics, etc. It is often used as a standard, complemented by sample books,[8] which include precisely controlled samples of about 1500 different colors. The Munsell system is similar to the HSV system, in that a color is represented by hue, saturation (called "chroma"), and lightness (called "value"). A typical Munsell color description might be 5.0 RP 4/2, where 5.0 RP represents the hue (in this case, a red-purple), 4 represents the chroma, and 2 represents the value. This system is not well suited for programming languages because it is not systematic. It is also not very easy for the inexperienced user, but is useful as a set of color standards, and was used as such in the study we conducted as part of our project.

The IQY system. The IQY system[9] is used in broadcast color television signals, as recommended by the National Television Standards Committee. It uses three hypothetical primaries which are chosen to satisfy the particular requirements of the broadcast signal to represent a color. In particular the Y primary (called "luminance") contains all of the brightness information, and is thus suitable for use in displaying a color transmission on a monochrome television set. The output to the CRT must be in IQY form to drive a standard broadcast monitor. The system is not attractive at all from a user's point of view—it is certainly not intuitively clear.

The CIE system. In 1931, an international committee (Commission Internationale de l'Eclairage) designed what has become known as the CIE colorimetry system.[7,10] This system, which, like the IQY system, is based on three hypothetical primaries, is used for most serious work in colorimetry. Certain theoretical considerations make the CIE system well suited for such work, but, like the IQY system, it is intuitively unnatural, and difficult to learn. Because the various color standards we used were described in the CIE system, we used it as an intermediate form in analyzing the data in our study.

Dictionaries of color. Unfortunately, English words and phrases used to name colors constitute a large and ill-structured system. Maerz and Paul pioneered in listing color terms in their *Dictionary of Color,*[11] which contains over 3000 English color names. The National Bureau of Standards has published a dictionary of color names in general use and in use in specific fields, such as interior decorating, biology, textiles, dyes, paint, plastics, geology, and philately.[12] This dictionary contains some 7500 different names, from *abbey* (a strong violet) to *Zuni brown* (a medium brown), and includes such little-known terms as *orseille* (a moderate purplish red) and *feuille* (deep orange). It is obvious that this set is unsystematic, sometimes esoteric, and unsuitable for use in a computer language.

The ISCC-NBS lexicon. The National Bureau of Standards, following the recommendations of the Inter-Society Color Council, developed a lexicon of names for 267 different regions of the color space. This lexicon[12] employs English terms to represent values along three dimensions of the color space: hue, lightness, and saturation. There are five discrete lightness values (*very dark, dark, medium, light,* and *very light*) and four discrete saturation values (*grayish, moderate, strong,* and *vivid*). Three shorthand terms denote combinations of lightness and saturation (*brilliant, pale,* and *deep*). Twenty-eight hue names are constructed from a basic set consisting of *red, orange, yellow, green, blue, violet, purple, pink, brown,* and *olive.* Certain pairs of these can be concatenated to denote intermediate hues. For example, *yellow* and *green* can be paired to form *yellow green,* but somehow not *green yellow. Red, blue, violet, purple,* and *pink* cannot be paired in this way with their adjacent hues at all.

Another way of defining intermediate hues in the ISCC-NBS lexicon is by using the suffix *-ish* in a modifier-modified hue pair. For example, *greenish blue* is a blue with a small amount of green in it. There are many exceptions to this rule, however. For instance, *violet* and *olive* can be neither modified nor modifier; *orange* and *pink* cannot be used as modifiers; *red* modifies *orange, purple,* and *brown,* but in turn is modified only by *purple.* In addition, achromatic names can be combined with chromatic hue names—again, with no systematic syntax; *blackish red* is valid, but not *blackish brown.*

The main problem with this system from a user's point of view is that there is no simple rule to determine which hue terms can be paired, can modify or be modified, and in which order they must appear. In order to use this system, one needs either the list of 267 distinct names, the 31 color name charts, or the set of ISCC-NBS centroid colors.[12] The load on the casual user's memory is too great for this system to be easily used.

The CNS color-naming system

General principles. In attempting to design a color notation system that would be suitable for the users discussed above, we found it obvious from introspection that a system based on commonly understood English morphemes* would be easier to learn and to use accurately than a more artifical, numerically based system. (In fact, we discussed the possibility of basing the system on the one that almost all US users have learned—the system used to name children's crayons.) To meet users' needs, the most nearly adequate of the existing color notation systems is the ISCC-NBS lexicon. Since the terms are constructed from common English words, their referents are presumably well understood. Thus, the semantics of this system are not likely to cause difficulty. As mentioned in the previous section, however, its syntax is extremely difficult to learn. To simplify the syntax, it was necessary to provide a hue name structure that follows a few simple, systematic rules. To this end, a new color naming system—CNS—was designed.

CNS generic hues. The terms for lightness (*very dark, dark, medium, light,* and *very light*) and saturation are taken directly from the ISCC-NBS nomenclature, with the omission of the shorthand terms *brilliant, deep* and *pale.* The hue terms, however, are only loosely related to those of the ISCC-NBS system. Only the hues which lie on the color circle are used (*red, orange, yellow, green, blue,* and *purple*) with the single addition of *brown. Violet, olive,* and *pink* are omitted. *Pink* is easily recognized as a light red and does not lie on the pure color circle. The terms *violet* and *olive* do not distribute in the English language like the other color terms used. For example, neither can take the suffixes *-ish, -er,* or *-est* as the other color terms can. Therefore, they are not included. The only CNS generic hue name which is not on the pure color circle is *brown* (dark, desaturated orange), included because, unlike other nonpure colors such as maroon and navy, brown is not perceived as being qualitatively simi-

*A morpheme is a minimal unit of meaning in a language. Root words and suffixes are examples of morphemes in English.

lar to its pure counterpart, which is saturated, bright orange.[13] Consequently, we felt that the inclusion of brown would be important to the descriptive power of CNS.

The complete set of generic hue names used in CNS is *red, orange, brown, yellow, green, blue* and *purple*. This set of seven chromatic hue names, with the addition of the achromatic terms *black, white* and *gray,* matches 10 of the 11 "basic color terms of English," as listed by Berlin and Kay.[14] Pink is the only basic color term excluded, as explained above.

CNS syntax. In CNS, all adjacent hue terms may modify one another according to the following rules:

(1) Two generic hues joined by a hyphen denote a hue exactly halfway between the two generic hues specified.

(2) If a color one-quarter of the way between two adjacent generic hues is desired, the farther hue is the modifier, appearing first with the suffix *-ish*, and the closer hue is the modified, appearing second.

Thus both *green-blue* and *blue-green* denote a color halfway between *green* and *blue. Bluish green,* on the other hand, denotes a hue one-quarter of the way from *green* to *blue,* and *greenish blue* denotes a hue one-quarter of the way from *blue* to *green*. This grammar generates a total of 24 different chromatic hue names:

red
orangish red (*brownish red*)
red-orange or *orange-red* (*red-brown* or *brown-red*)
reddish orange (*reddish brown*)
orange (*brown*)
yellowish orange (*yellowish brown*)
orange-yellow or *yellow-orange* (*brown-yellow* or *yellow-brown*)
orangish yellow (*brownish yellow*)
yellow
greenish yellow
yellow-green or *green-yellow*
yellowish green
green
bluish green
green-blue or *blue-green*
greenish blue
blue
purplish blue
blue-purple or *purple-blue*
bluish purple
purple
reddish purple
purple-red or *red-purple*
purplish red

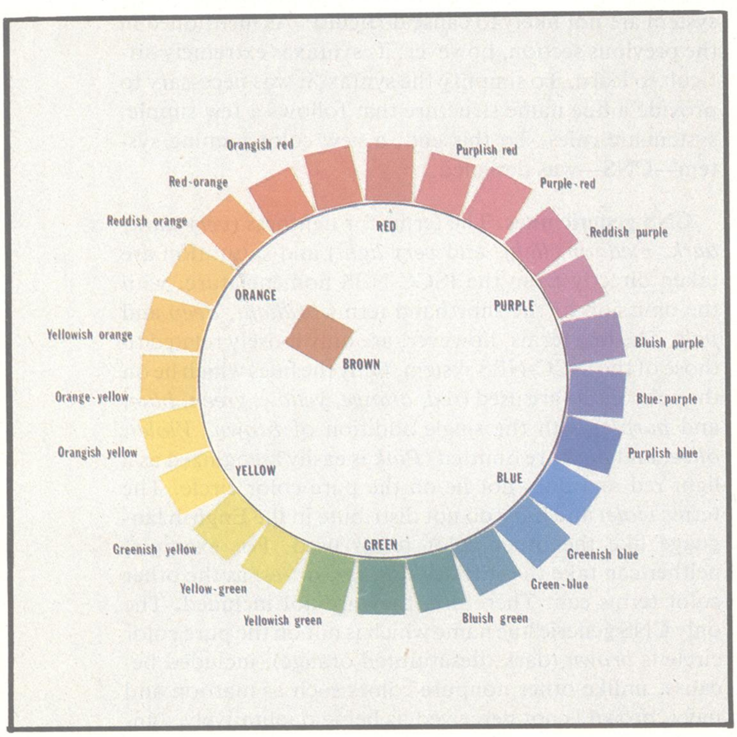


Figure 3. CNS medium vivid colors. (Generic hues are labeled inside the circle. Quarterway and halfway browns are omitted for clarity.)

Seven additional names can be generated by substituting the term *brown* for the term *orange*, as shown parenthetically.

Chromatic colors found within the color solid can be specified with the designators for lightness, saturation, and hue. Either lightness or saturation designators can be placed first. For instance, a color may be called *medium vivid bluish green*. If the lightness designator is omitted, a *medium* lightness is assumed. If the saturation designator is omitted, *vivid* is assumed. Thus, the following color names are synonyms: *medium vivid bluish green, vivid medium bluish green, vivid bluish green, medium bluish green,* and *bluish green*.

The medium vivid colors corresponding to most of the chromatic hues are shown in Figure 3. Only the halfway and quarterway browns have been omitted for clarity. The generic hue names are shown on the inside of the hue circle, and the halfway and quarterway hue names are shown on the outside of the hue circle. The division of the color space for a fixed hue (greenish blue) is shown in Figure 4, with the best example named by each CNS name indicated with an asterisk.

Finally, the terms for the achromatic (neutral) colors are *black, white,* and the color terms formed by combining an optional lightness attribute with the achromatic hue name *gray*. Thus, the achromatic colors are *black, very dark gray, dark gray,* (*medium*) *gray, light gray, very light gray,* and *white*.

The syntax of CNS (a formal description appears in the appendix) is orthogonal with respect to the three terms of a color specification. All possible combinations are syntactically correct, although some syntactically correct combinations may not be realizable. For example, if a color is very light or very dark, it cannot be fully saturated. Only colors of intermediate lightness can be vivid. The maximum possible saturation of a color decreases as it becomes light or dark. This is the reason for the common description of the color solid as a sphere or double cone, rather than as a cylinder.

Hue terms in English are not used uniformly with respect to saturation and lightness.[15] *Orange* is commonly used to designate only medium-light, high-saturation colors; colors of the same hue but of low lightness and saturation are termed *brown*. The correspondence between CNS color names and actual colors is consistent with this usage.

Scope. The five lightness terms, four saturation terms, and 31 hue terms of CNS combine to produce 620 chromatic color names. Adding the seven achromatic color names produces a total of 627 separate color names. As mentioned before, however, some of these colors may not be realizable.* Only 480 of these 627 colors can be found, for example, in the 1976 glossy finish edition of *The Munsell Book of Color.*[8] Furthermore, since brown derivatives are merely other names for orange derivatives, there are in fact only 340 distinct colors in the Munsell book that are nameable in CNS. Nevertheless, the study reported below showed that users achieved considerably higher accuracy with CNS than with RGB or HSV. Presumably, this is due to the naturalness of the CNS system.

Limitations. The CNS system does not, in itself, provide a good basis for a computational color space, because it is not easy to describe an algorithm for shading, highlighting, or the like in this system. Rather, the CNS system should be considered a mechanism for naming color literals and constants. In an application requiring computed color values, the computation can still be carried out in the RGB, HSV, or any other apppropriate system, once the initial values have been determined. One might thus specify a color to be initially *medium moderate brown* and then apply an algorithm that recomputes its saturation and/or lightness.

The study

In order to evaluate the ease and accuracy of the use of the proposed color naming system by new users, we conducted a human factors experiment in which each subject was trained in one of the three systems (RGB, HSV, or CNS) and then tested for accuracy in naming color samples in that system.

Subjects and materials. Thirty-seven undergraduate students from the computer science program at Florida International University served as subjects. All had passed a color vision test.

The following six color samples were selected for training trials from *The Munsell Book of Color,* to cover a wide variety of hues, lightnesses, and saturations: 5R 5/8, 5G 4/2, 5B 6/8, 10P 8/4, 10PB 3/2, and 5Y 8.5/10. These samples were mounted in a row on a gray background. The color samples for test trials consisted of 20 of the 24 samples on the Macbeth Colorchecker[16] color rendition chart. The following color samples, each isolated by a gray mask, were presented in this order: (1) neutral 6.5, (2) neutral 3.5, (3) blue, (4) green, (5) red, (6) yellow, (7) magenta, (8) cyan, (9) orange, (10) purplish blue, (11) moderate red, (12) purple, (13) yellow green, (14) orange yellow, (15) dark skin, (16) light skin, (17) blue sky, (18) foliage, (19) blue flower, and (20) bluish green.

* We have chosen to leave to the application programmer the decision whether to consider unrealizable colors as errors or to provide the closest realizable color.

Procedure. Subjects were tested in a room that received daylight illumination from a large window facing north. Artificial illumination was not used.

Subjects read a three-page description of the purpose and general procedure of the experiment; the description did not reveal the nature of any of the color systems. Each subject was then randomly assigned to learn one of the three color notation systems (RGB, HSV, CNS) and given a six-page description of the assigned system and a single summary page to read and later use as a reference during testing. At no time did a subject know the nature of the two systems to which he was not assigned, nor was he told the expected relative difficulty of his assigned system.

After reading the description, subjects responded separately to each of the six training samples by supplying a description in terms of their assigned color notation system. If a subject gave as a response a syntactically incorrect description (e.g., by using a value greater than 1 in the RGB or HSV systems or an invalid hue name in CNS), the experimenter solicited another response without indicating why the response was unacceptable. After a syntactically correct response, the experimenter revealed the true description.

After all six training trials were completed in this manner, the test trials began. These were presented by mask-

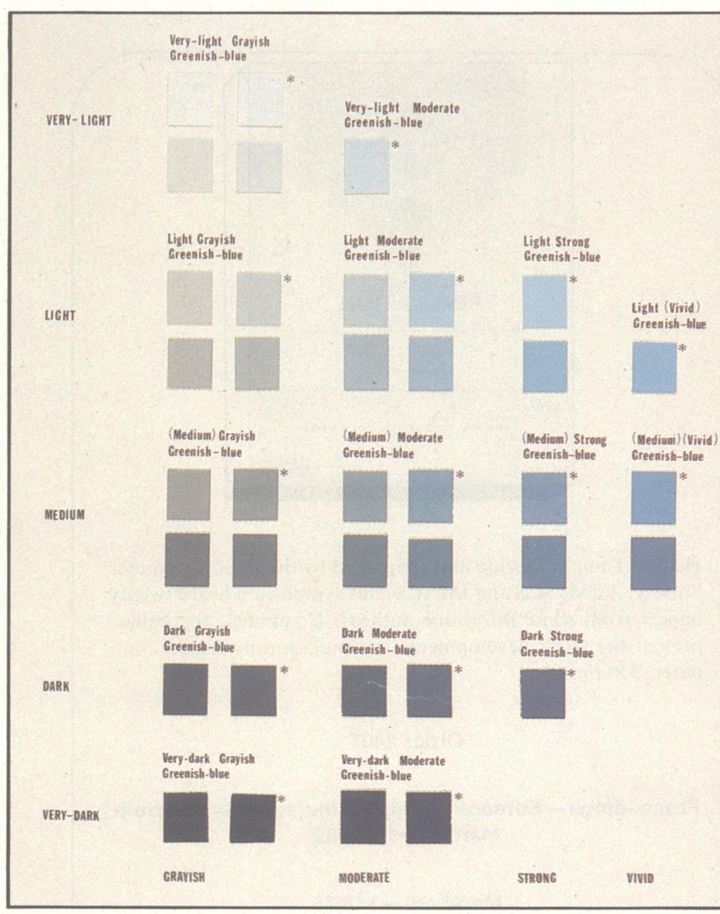


Figure 4. CNS division of hue *greenish-blue*.

ing all color samples except the current test sample on the Macbeth Colorchecker rendition chart. Subjects again were asked to revise syntactically incorrect responses. No feedback, however, was given concerning the correct description of the test samples. The entire session took from 30 to 75 minutes, with a mode of about 45 minutes.

Results. All responses were transformed into RGB, HSV, and CIE coordinates. The RGB and HSV responses were converted by means of standard algorithms and tables.[5,17] The CNS responses were converted in two steps. First, for each permissible color name, a single sample from *The Munsell Book of Color* was chosen to represent the color named. Then the CIE coordinates of that Munsell color were used to produce the RGB and HSV coordinates. The Euclidean distances between responses given and the correct responses were then computed in RGB, HSV, and CIE space. The distance in NBS Color Difference Units[18] was also computed. This nonlinear distance metric has been constructed to coincide with subjective judgments of the differences between colors. Although all four sets of distance data (RGB Euclidean, HSV Euclidean, CIE Euclidean, and NBS Color Difference Units) were analyzed, results will be reported only for the NBS metric, since all four analyses yielded equivalent results, and since the NBS metric is presented as a measure of psychological distance.

A 3×20 analysis of variance was performed: naming system (RGB, HSV, or CNS) was the between-subject factor, and color sample (the 20 test trials) was the within-subject factor. The main effect of naming system was significant:

$$F(2,34) = 16.62,\ P < 0.001.$$

This indicated that the three naming systems did differ from one another in terms of the accuracy of responses given by the subjects. The mean distance for the RGB condition was 5.97 (s.d. = 2.82); the mean for the HSV condition was 4.24 (s.d. = 1.67), and the mean for the CNS condition was 2.88 (s.d. = 1.22). Scheffé's test was used to compare treatment means for the three conditions. All pairwise comparisons were significant: RGB-HSV [$P < 0.05$], RGB-CNS [$P < 0.01$], and HSV-CNS [$P < 0.01$].

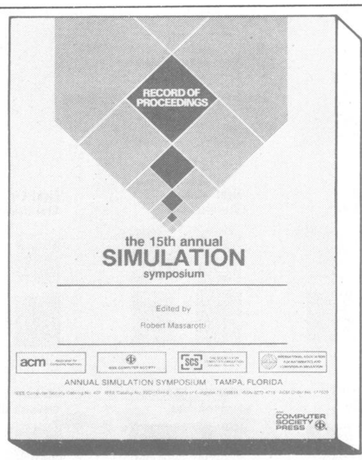
Conclusions. Obtaining better results from the HSV system than from the RGB system confirmed our intuition that our subjects could be substantially more accurate when the quantitative color notation system mirrored psychological rather than physical attributes of colors. Even greater accuracy was achieved, as we had hypothesized, by the subjects who used the English-based CNS system. CNS not only uses the same psychological dimensions as the HSV system, but it also allows responses based on a lifetime of experience with English color terms. Although this study did not measure the accuracy obtainable by experienced users of these systems, we felt that ease of learning by inexperienced users was a very important characteristic for any system; thus, this test was a valid way to compare systems.

The superiority of the CNS system is even more striking in view of its discreteness, with only 340 specifiable colors in the glossy sample domain used. Furthermore, a conservative method was used in scoring accuracy of responses made by subjects who used the CNS system. CNS responses were mapped onto the centers of the regions specified by the color names, but the ideal values were taken from the Munsell values of the color samples themselves, and not the centers of their regions. Thus, with CNS, optimal distance could not be zero unless all the samples shown to the subjects lay at the exact centers of color name regions—this was not the case. Therefore, this experiment underestimates the true superiority of the CNS system over the RGB and HSV systems.

The main advantage of a natural-language-based system like CNS is that users need not refer to menus or printed tables of values in order to make reasonable first attempts at selecting colors to be displayed. Although this capability was not tested in the experiment, we believe that users would undergo less trial and error with CNS than with one of the quantitative systems in successive attempts to converge on an acceptable color. ■

Appendix: syntax of CNS

The syntax is described in standard BNF. Nonterminal metalinguistic variables are enclosed by angular brackets. The meta-assignment ::= may be read as "is defined as." The symbol ¦ has the meaning of meta-or; square brackets denote optional occurrence of the enclosed construct.



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<color name> ::= <achromatic name> | <chromatic name>

<achromatic name> ::= [<lightness>] *gray* | *black* | *white*

<chromatic name> ::= <lightness> <saturation> <hue> | [<saturation>] [<lightness>] <hue>

<lightness> ::= *very dark* | *dark* | *medium* | *light* | *very light*

<saturation> ::= *grayish* | *moderate* | *strong* | *vivid*

<hue> ::= <generic hue> | <halfway hue> | <quarterway hue>

<generic hue> ::= *red* | *orange* | *brown* | *yellow* | *green* | *blue* | *purple*

<halfway hue> ::= <generic hue> – <generic hue>

<quarterway hue> ::= <ish form> <generic hue>

<ish form> ::= *reddish* | *orangish* | *brownish* | *yellowish* | *greenish* | *bluish* | *purplish*

Notes:

1. If <lightness> is omitted, *medium* is assumed.
2. If <saturation> is omitted, *vivid* is assumed.
3. <halfway hue> and <quarterway hue> define intermediate hues between two adjacent generic hues around the hue circle shown in Figure 3 of the article. The complete list of hue names is shown on page 40.

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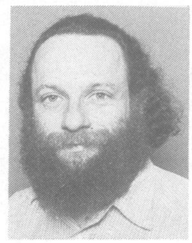

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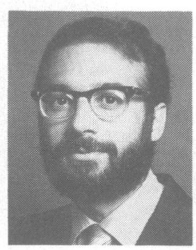

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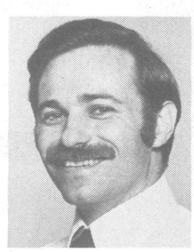

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