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          (IT NBR SING)
          TNS
          PAST
          *TO
          (EARTH PREP INTO NBR SING)
          LOC
          (MILE QU
                (FORTY)
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    NIL)
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*(SETQ J (SUBST 'X (CADR VAL) VAL))
(S1 X (PLUNGE INSTR (IT NBR SING) TNS PAST *TO (EARTH
  PREP INTO NBR SING) LOC (MILE QU (FORTY) LOC
  (POINT PREP FROM DET THE LOC (START TNS PRPRT)
  NBR SING) NBR PL)) NIL)
*(TRY J)
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(S1 (IT PLUNGED INTO EARTH FORTY MILES FROM THE
  STARTING POINT) (PLUNGE INSTR (IT NBR SING) TNS
  PAST *TO (EARTH PREP INTO NBR SING) LOC (MILE QU
  (FORTY) LOC (POINT PREP FROM DET THE LOC (START
  TNS PRPRT) NBR SING) NBR PL)) NIL)
*(SPRINT VAL 1)
(S1 (IT PLUNGED INTO EARTH FORTY MILES FROM THE
      STARTING POINT)
    (PLUNGE INSTR
          (IT NBR SING)
          TNS
          PAST
          *TO
          (EARTH PREP INTO NBR SING)
          LOC
          (MILE QU
                (FORTY)
                LOC
                (POINT PREP FROM DET THE LOC
                  (START TNS PRPRT) NBR SING)
                NBR
                PL))
    NIL)
NIL
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Technical Note
Human Aspects of Computing

Henry Ledgard
Editor

A Human Factors Study of Color Notation Systems for Computer Graphics

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A human factors experiment was conducted that compares three color notation systems for use in computer graphics. Two of the systems (those in common use) represent colors as triples of real numbers in [0, 1]. The third system is based on natural language color categories in English. It was found that users of the natural language based system were significantly more accurate in specifying colors, despite the coarse granularity of that system as compared to the other two. This demonstrates that giving a user choice from a small set of values that are carefully chosen and based on human factors principles works better than providing a much larger and apparently more flexible set of values that are not based on such principles.

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1. Introduction

Human factors considerations have been shown to be helpful in improving the ease and accuracy with which software can be used [9]. The incorporation of natural

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language in the human interface has been demonstrated in many circumstances to improve usability. For example, one experimental study compared two semantically equivalent sets of text editor commands [7]. Despite the greater length of the natural language commands, fewer errors were made by the group using those commands than by the group using a more concise (and more typical) set of abbreviated commands.

Typical color graphics systems can realize up to the order of 4096 different colors. Part of the task of implementing an application for such a system is the specification of the various colors to be displayed so that a color actually displayed is as close as possible to the color visualized by the implementor. This must be done through the use of some *color notation system.* The authors have used natural language considerations in the design of a color notation system for use in a high level language for such applications [1, 2].

This color notation system, called the Color Naming System (CNS), draws on the user's familiarity with English color vocabulary. Psychological and linguistic principles were employed in selecting a set of terms which are based on the natural color categories used by speakers of English. It was hypothesized that this system would therefore prove superior to other color notation systems currently in use in graphics applications.

Most current graphics systems use a color notation system (the RGB system) that requires the user to specify a color in terms of its red, green, and blue primary components, which correspond to the intensities of the electron beams that excite red, green, and blue phosphors on a color CRT [4, 10]. Each color is, therefore, denoted by a triple of real numbers in the interval [0, 1], thus naming a potentially unlimited number of colors. A shade of yellow might be [0.73, 0.63, 0.05] in the RGB system. Although it is necessary for most hardware systems that a color be represented in these terms internally, it is obvious after a few attempts to specify the colors of arbitrary objects that this system is rather poor from a human factors point of view.

Another commonly used system (the HLS system) is a considerable improvement over the RGB system. The HLS system represents an attempt to exploit the psychology of color perception by allowing the user to specify a color in terms of its hue, lightness, and saturation. These are perceptual, rather than physical dimensions. Specifications given in the HLS system are easily converted into RGB [10], and the system appears to be superior from a human factors point of view. Nevertheless, the HLS system still has major deficiencies. In particular, HLS shares with RGB the property that all colors are specified as triple of real numbers in [0, 1]. Hues are mapped onto [0, 1] according to their physical relationships and spacing. Unfortunately, this does not correspond to the way that speakers of English perceive hue spacing. The yellow referred to previously would be [0.142, 0.73, 0.93] in the HLS system.

Since a well-understood vocabulary of color terms already exists in English, it was hypothesized that the advantages of HLS over RGB could be enhanced by using familiar terminology in place of triples of real numbers. The CNS system was designed to employ the same psychologically sound dimensions as the HLS system, except that the values of each dimension are coded linguistically instead of numerically. The CNS system was designed as a language feature for the initial specification of colors. The application of techniques such as shading, highlighting, etc. may be easier in a continuous system such as HLS. It is simple, however, to convert from one notation to another automatically when necessary.

2. The CNS System

CNS is based on the color lexicon of the Inter-Society Color Council and the National Bureau of Standards [8] which is widely used in areas such as textile color and paint specification. The ISCC–NBS system has been modified to remove inhomogenities in the lexicon, and to make the syntax more regular and thereby easier to learn and to parse. A formal summary of the CNS syntax can be found in the Table I. An informal description follows.

A CNS color description consists of up to three components. First, a lightness term may be chosen from *very dark*, *dark*, *medium*, *light*, and *very light.* If the lightness attribute is omitted, *medium* is assumed. Second, one of four saturation levels can be selected: *grayish*, *moderate*, *strong*, or *vivid.* If the saturation term is omitted, *vivid* is assumed. Finally, a hue name is specified.

Thirty-one chromatic hue names are formed from seven generic hue names; *red*, *orange*, *brown*, *yellow*, *green*, *blue*, and *purple.* These terms, together with *black*, *white*, and *gray* constitute the basic color terms of English [3], with the sole omission of pink which is easily understood as light red. It should be noted that these generic hue terms are not physically spaced, but rather are based

Table I. Syntax of CNS.

⟨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⟩ | ⟨half way hue⟩ | ⟨quarter way 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

Note: Only hues which are adjacent on the generic hue circle can be combined to form halfway and quarterway hues.

upon psychological and linguistic considerations. For example, *brown* is actually redundant, being a dark orange, but must be included because speakers of English perceive it as a separate color. The chromatic hue names are formed from the generic hues by using adjacent names on the generic hue circle to modify each other, denoting halfway hues, and with the suffix*ish* to denote quarterway hues. The generic hue circle is the circular list: red, orange (or brown), yellow, green, blue, purple, and back to red. Examples of hue names are *yellowish green*, *yellow-green*, and *greenish yellow*. Examples of complete color specifications are *medium strong yellow* (the example used previously), and *light grayish red-orange*. All color names constructed in this manner are syntactically correct, even though some of the colors so named may not be physically realizable on a particular display.

The achromatic (neutral) colors, necessarily having a zero saturation, are denoted with up to two components. The achromatic colors are *black*, *very dark gray*, *medium gray*, *light gray*, *very light gray*, and *white*.

In total, the CNS system generates only 627 color names. Of these, 480 can be realized with the glossy pigment samples used in this study. Furthermore, since brown derivatives are other names for orange derivatives, the CNS system can name only 340 distinct colors that are realizable with glossy pigment samples. Despite this coarse resolution, users were more accurate with the CNS system, as discussed below.

3. The Experiment

A human factors experiment was performed to determine the relative accuracy with which colors could be specified by persons with minimal training with each of the notation systems RGB, HLS, and CNS. Each of the 37 paid volunteers, recruited from juniors and seniors in the computer science program at Florida International University, were randomly assigned to learn one of these three systems. Training consisted of reading a 1500 word description of the assigned color notation system (each prepared by the same author, with the same number of examples) followed by a series of six practice trials in which the subject described color samples in the assigned notation system. After each training response, the subject was told the correct answer.

Following training, each subject was shown the same sequence of 20 color samples from the Macbeth Color Checker Color Rendition Chart. The subjects were asked to give a specification for each sample in the assigned notation system. The set of samples contained a wide variety of hues including two grays; saturation and lightness also varied in the samples. Subjects were not given feedback about the accuracy of their responses. Complete details of the methodology and results are reported in [1].

Table II. Mean Distance in NBS Color Difference Units.

Naming System	Mean Distance	s
RGB	5.97	2.82
HLS	4.24	1.67
CNS	2.88	1.22

Table III. Results of Newman–Keuls Pairwise Comparison Tests.

Comparison	r	q_r	p
RGB vs CNS	3	8.24	<0.01
RGB vs HLS	2	4.62	<0.01
CNS vs HLS	2	3.62	<0.05

4. Results

For each response the distance was computed between the color that the subject *should have* described and the color that the subject's response would actually generate. The greater this distance (measured in NBS Color Difference Units[1] [5]), the less accurate the response. A 3×20 two-way analysis of variance was performed, with notation system as a between-subjects factor and color sample as a within-subjects factor. The effect of notation system was statistically significant, $F(2, 34) = 16.62$, $p < 0.001$, indicating that the means of the three notation system groups were significantly different. The results are shown in Tables II and III. Further discussion and analysis of the results can be found in [1].

5. Discussion

These results confirm the expectation that the psychologically based HLS system would be easier to use than the physically based RGB system, and that the natural language based CNS system would, in turn, be even better. It is noteworthy that in the CNS system, each of the dimensions of hue, lightness, and saturation is divided into a relatively small set of discrete regions. Although one might expect that this coarse discretization of the color space would necessarily result in a loss of accuracy, in fact, the opposite was the case. Furthermore, the CNS subjects were at a disadvantage since it was impossible for their distance scores to be zero even if all answers were correct. This is because the test colors did not lie at the centers of CNS regions whereas the distances were computed to those central points.

In sum, the results of this experiment confirm the importance of human factors considerations in software development. In this instance, it has been shown that giving a user choice from a small set of values that are carefully chosen and based on human factors principles can produce better accuracy than providing a much

[1] "One NBS Color Difference Unit is equivalent to about 2.5 Munsell hue steps at chroma/1 to 0.10 Munsell value step, or to 0.15 Munsell chroma steps. Difference of one NBS unit or less can usually be disregarded in commercial transactions." [6, p. 318].

larger and apparently more flexible set of values that are not based on such principles.

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A Study of Superfluity in Storage Hierarchies

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Many current computer systems typically utilize a hierarchy of two or more different storage mechanisms to provide main storage with adequate speed and capacity. Such storage hierarchies automatically transfer pages of information between levels in order to service the storage references generated by an executing program. During a single residence period of a page in the first level of the hierarchy, it may be that a number of words in this page are unreferenced and therefore superfluous. This paper develops a measure of superfluity, and shows how superfluity varies with the pattern of storage references generated by the executing program, and the hierarchy configuration parameters of page size, first level capacity, and replacement algorithm. The results of an experimental study are described which indicate that the measure of superfluity is an indicator of storage hierarchy performance, and could conceivably be used to dynamically optimize its operation.

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