Culture and Cognition: What is Universal about the Representation of Color Experience?

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ABSTRACT

Existing research in color naming and categorization primarily reflects two opposing views: A *Cultural Relativist* view that posits color perception is greatly shaped by culturally specific language associations and perceptual learning, and a *Universalist* view that emphasizes panhuman shared color processing as the basis for color naming similarities within and across cultures. Recent empirical evidence finds color processing differs both within and across cultures. This divergent color processing raises new questions about the sources of previously observed cultural coherence and cross-cultural universality. The present article evaluates the relevance of individual variation on the mainstream model of color naming. It also presents an alternate view that specifies how color naming and categorization is shaped by both panhuman cognitive universals and socio-cultural evolutionary processes. This alternative view, expressed, in part, using an *Interpoint Distance Model* of color categorization, is compatible with new empirical results showing divergent color processing within and across cultures. It suggests that universalities in color naming and categorization may naturally arise across cultures because color language and color categories primarily reflect culturally modal linguistic mappings, and categories are shaped by universal cognitive constructs and culturally salient features of color. Thus, a shared cultural representation of color based on widely shared cognitive dimensions may be the proper foundation for universalities of color naming and categorization. Across cultures this form of representation may result from convergent responses to similar pressures on color lexicon evolution.

KEYWORDS

Categorization, color naming, perceptual variation, cognitive universals.

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Introduction

Since the 1960's research on cross-cultural color categorization has primarily involved a debate between theorists that promote Universalist explanations and those advancing Cultural Relativist explanations. Cultural Relativism suggests that color categorization and naming is due largely to learned language associations and perceptual learning specific to a given culture (Kay & Kempton 1984, Saunders & van Brakel 1997, Davidoff, Davies & Roberson 1999, Roberson, Davies & Davidoff 2000). Universalists, on the other hand, emphasize panhuman uniformity in the perceptual processing of color as the basis for color naming coherence within and across cultures (Kay, Berlin, Maffi & Merrifield 1997, MacLaury 1997, Kay, Berlin & Merrifield 1991, Hardin 2005). Although some researchers have argued that blends of these two different perspectives are most appropriate for modeling color-naming phenomena (Dedrick 1998, Jameson & Alvarado 2003a, Paramei 2005, Jameson 2005a), it is nevertheless clear that since Berlin & Kay (1969) the Universalist perspective has carried the greatest explanatory weight in cross-cultural color naming and categorization research (see Kay 2005, Kay & Regier 2003).

Recent empirical evidence on the perceptual processing of color sheds new light that may help bridge an explanatory gap separating culturally derived factors from those based on perception. This evidence includes: (a) proof of considerable variation in color processing among individuals in the same culture, and (b) new results on important cross-cultural differences in color naming and categorization. These new findings raise the following questions: First, if divergent color processing exists among individuals within a culture, what is the basis for within-culture coherence in color-naming? Second, are the processes that produce within-culture coherence also the basis for observed similarities in color naming and categorization across cultures?

Here it is proposed that *both* cultural and cross-cultural color naming coherence are due to convergent evolution of color lexicons in the context of similar psychological and social demands. Here we present a psycho-social framework for mapping color language with color percepts which explains how individuals in different cultures might develop similar ways of communicating about color experience. While the framework shares some features with existing color-naming theories, it differs by specifically suggesting that *cognitive features* of the shared cultural representation of color are the proper universals in color naming and color categorization. These universal cognitive features are incorporated in a model of Interpoint Distance relations among color sensations, and provide an alternative approach to understanding color categorization and naming coherence (Jameson & D'Andrade 1997). Because this explanation emphasizes different features of psychological color processing for evaluating color-naming phenomena, it permits novel empirical hypotheses about color naming phenomena both within and across cultures.

In addition to introductory and concluding statements, this article includes four sections. Section 1, *Intracultural Variation in Color Perception and Cross Cultural Studies of Color Cognition*, reviews recent evidence showing important individual differences in color processing occurring within ethnolinguistic societies. Section 2, *The Psychological Processing of Color and Inherited Color Perception Differences*, discusses the consequences of such intracultural variation for cross cultural color naming research, including analyses of how color perception differences relate to the ways individuals learn color lexicons and perceptual color categories. Section 3, *Cross cultural Universality in Color Naming and Categorization*, focuses on an alternative explanatory framework including the Interpoint Distance Model of color categorization, and relates the proposed alternative model to existing research. Section 4, *Applying the Framework to Explain Cross-Cultural Color Naming Phenomena*, briefly discusses applications of the proposed framework.

Intracultural Variation in Color Perception and Cross Cultural Studies of Color Cognition

There is little question that perceptual, linguistic, social and pragmatic factors all play a role in the cognitive processing of color (Dedrick 1998, Schrillo 2001). Nevertheless, the most widely accepted explanation of both cross-cultural color naming universalities and, implicitly, color-naming consensus within cultures, argues that panhuman similarities in color vision processing create uniformity in color salience, and this alone gives rise to color naming universals across cultures (Kay & Maffi, 1999).

Kay & Regier (2003) argue that the prevalence of 11 or fewer *basic color categories* across a wide range of linguistic societies is grounded in perceptual processing similarities derived from human visual processing.[1] Kay & Regier's "universality hypothesis" (2003 p. 9085) suggests that perceptual processing similarity across individuals derives from the primacy of Hering's opponent colors (Red-Green, Yellow-Blue, Black-White), and that this is the basis for widespread cross-cultural agreement with regard to color lexicons, color categories, and color category best-examples (called '*focals*'). They conclude:

> (i) there are clear cross-linguistic statistical tendencies for named color categories to cluster at certain privileged points in perceptual color space; (ii) these privileged points are similar for the unwritten languages of nonindustrialized communities and the written languages of industrialized societies; and (iii) these privileged points tend to lie near, although not always at, those colors named red, yellow, green, blue, purple, brown, orange, pink, black, white and gray in English. (2003, p. 9089).

Asserting that *privileged points in perceptual color space* are the basis for a robustly shared lexicalized color code requires that with-language comparisons of individual data demonstrate strong inter-individual agreement on such "privileged points" (or even restricted *regions*) in color space. However, in many empirical tests, such agreement across subjects is not typically found.

For example, Kuehni (2001, 2004) convincingly showed that the location of unique hues[2] (UH) differs considerably across individuals and groups of individuals, and that such variation is quite significant for monochromatic lights, yet smaller for reflective surfaces (pp. 61-63). Specifically in a study using Munsell surface samples to isolate unique

[1] Throughout this article 'Basic Color Term' (or BCT) theory refers to the research program of Kay and colleagues (Kay & Regier 2003, Kay and Maffi 1999, Kay, Berlin, Maffi & Merrifield 1997, Kay & McDaniel 1978, Berlin & Kay 1969) and their related articles.

[2] Unique Hues are pure red without any trace of yellow or blue; pure blue without any trace of green or red; and pure green and pure yellow, free of any traces of other colors.

hue appearances, he suggests "it is apparent that when two color normal individuals look at a reflecting sample under identical conditions of viewing, they may not experience the same color. For unique hues . . . the individual differences can be up to 4 Munsell 40 hue steps" (Kuehni 2001, p. 63). Such results accord with similar individual differences in color category mappings described throughout the work of MacLaury (1997, 2005), as well as unique hue variation show by others (e.g., Webster, Miyahara, Malkoc & Raker 2000).

In this issue, Kuehni (2005a) extends his study to color naming universals, finding (1) wide variation across individual unique hue settings in different empirical settings, (2) no uniformity in perceptual distances covered by unique hue ranges, and (3) emphasizes the inherently problematic practice of (i) deriving universal category "foci" and "elemental hues," and (ii) comparing such "privileged points" across ethnolinguistic groups (cf., Jameson 2005a, Alvarado & Jameson 2005).

Variability in 'focal' color choices was also seen in a recent cross-cultural comparison by Webster et al. (2002) who compared color judgments of observers in India and the United States. For these groups, selections of color best exemplars were found to produce similar BCT category partitions, yet with different, systematically shifted, category best exemplars across the two groups tested. The groups' unique hue selections also differed. These results point to subtle differences in the ways color category focals vary across ethnolinguistic societies.

Other empirical research has confirmed the lack of a distinctly privileged BCT salience in color-naming (Alvarado & Jameson 2005, Jameson & Alvarado 2003a), as it varies across native-language speaking individuals within-culture (Sayim et al. 2005), and as it varies across ethnolinguistic groups (Jameson 2005a, Jameson & Alvarado 2003b, Alvarado & Jameson 2002). Lin, Luo, MacDonald, & Tarrant (2001a, 2001b) found cross-culturally varying focal appearance salience. Roberson, Davies & Davidoff (2000) found non-universality of color focal or centroid exemplars. Similarly, Sturges and Whitfield (1997) found no convincing differences between basic "landmark" hues (Hering's Black, White, Red, Green, Yellow & Blue color opponents) and the other BCT categories typically identified as universal (i.e., Purple, Orange, Pink & Brown), following upon the earlier failed verification of the cognitive primacy of Red, Green, Yellow & Blue (Whitfield 1981).

Given these results an argument against the universality hypothesis could reasonably assert that uniformly shared privileged perceptions are not likely to be the basis for the observation that 'named color categories cluster' across different ethnolinguistic societies. This raises an interesting question: If privileged perceptual salience is not the basis for BCT prevalence across ethnolinguistic societies, then what is? The answer to this question requires an examination of the relationships between individual perceptual color experience, individual color categorization and naming, and shared color naming systems.

The Psychological Processing of Color and Inherited Color Perception Differences

One way to clarify how individual color experience interacts with color naming behaviors is to examine color-naming in individuals with impaired color vision, so-called *color blind* subjects. Color perception deficiencies, like color-blindness, are genetically inherited via the X-chromosome. This explains the greater incidence of male color blind observers compared to females. Males have one X-chromosome, females have two, and as a result males have a greater chance of expressing color vision deficiencies due to a defective or anomalous gene.

In color perception and categorization research a standard practice is to exclude individuals with color vision anomalies and deficiencies from the groups of subjects judging color categorization tasks. Typically this omits approximately 2% of deficient dichromat males (who express only two of the three typical retinal photopigment classes) and approximately 6% anomalous males (expressing a shifted photopigment class). Standardized tests of color perception (e.g., Ishihara 1987) ease identification of color vision deficiencies. This practice of excluding deficient subjects is useful because it serves to intentionally normalize the behavior assessed, thus allowing for more precise development of a "normative" model. However, it also deprives us of data for understanding how individual color experience is mapped to a culturally shared linguistic code. When such subjects are excluded, one cannot compare the cognitive processing of observers with impaired color perception to those with normal color perception.

For example, Jameson & Hurvich (1978) showed that dichromats use dissimilar names for colors that are perceptually similar to them, but dissimilar to unimpaired observers. The finding suggests that dichromats can use color names in a manner congruent with trichromat naming while experiencing incongruent perceptual experiences.

Separate perceptual and linguistic representations among dichromats were also shown by Shepard & Cooper (1992) who derived color word and color appearance similarity structures for dichromat, normal and blind subjects. Shepard and Cooper's Figure 2 (1992, p. 100) compared the structure of color appearance similarity and the structure of color word similarity. It shows that the dichromat lexical representation closely resembles the one produced by trichromat observers, whereas the structure of the color appearance representation differed in ways that reflected the known perceptual deficit. Indeed, Shepard and Cooper show that some congenitally blind individuals (i.e., about 50% of their sample) produce roughly the same structural mapping of the color lexicon as trichromats, even though they have never experienced color sensations. Similar results were found earlier by Marmor (1978). Such results support the suggestion of separate perceptual and lexical representations.

Taken together, Shepard and Cooper (1992), Marmor (1978), and Jameson and Hurvich (1978) results suggest that a shared similarity structure for lexical knowledge can develop in the absence of perceptual experience. Such results underscore the importance of differentiating perceptual and semantic content when modeling and testing the cognitive representation of color (Dedrick, 1997); and suggest that even dramatic perceptual differences do not preclude a shared intracultural understanding of color categories and color naming, because the perceptual and the semantic representation of color are separate, and in many ways different (Johnson, Pavio & Clark, 1996, Roberson, Davidoff & Braisby 1999).

Dichromat Observers

Mappings between perceptual and cognitive representations for three different observer groups help illustrate the implications for models of shared color naming: Figure 1 depicts some color perception relations for a dichromat observer. Analogous to the familiar *CIE* chromaticity diagram,[3] Figure 1 schematically shows (at left) a triangular slice of uniform *brightness* from a three dimensional color appearance solid consisting of vertices Red, Green and Blue, and an implied perpendicular dimension of *lightness-darkness* through the central white point. Within the triangular color plane a miniaturized schematic of a region of color appearance space is shown. On the right of Figure 1 is an enlarged view of that same region. Figure 1 also presents two expressions giving perceptual and naming relations for a dichromat observer. Recall that dichromats confuse (or cannot distinguish) some colors that normal color vision observers (*trichromats*) see as different. Such a deficiency is stylized in Figure 1 by the solid *confusion lines* appearing within the color appearance triangle. Empirical results show that appearances located between two of these confusion lines in the triangle are perceptually indistinguishable for the dichromat. Note in the miniaturized view at left, a grayish area of the space represents three *reddish* color samples (labeled A, B, C in the enlarged view), and a more distant area shows a *bluish-green* sample labeled X.

Note that all four samples (A, B, C and X) lie between the heavy lines indicating that when viewed as isolated samples none of these appearances would be perceptually differentiated by this hypothetical dichromat. Thus the relation defining the dichromat perceptual experience is given by:

$$X \approx B \approx A \approx C,$$

which states that X, B, A and C are all perceptually indistinguishable.

As mentioned earlier, the dichromat may not perceptually distinguish these samples, but he still possesses the *shared naming relations* of normal trichromats. Thus, the dichromat linguistic relations for these stimuli may be different and distinct from the perceptual construct given by expression (1). The shared naming relation is given by:

$$X \neq B \approx A \neq C,$$

[3] CIE is the *Commission Internationale de l'Eclairage*, or the International Commission on Illumination.

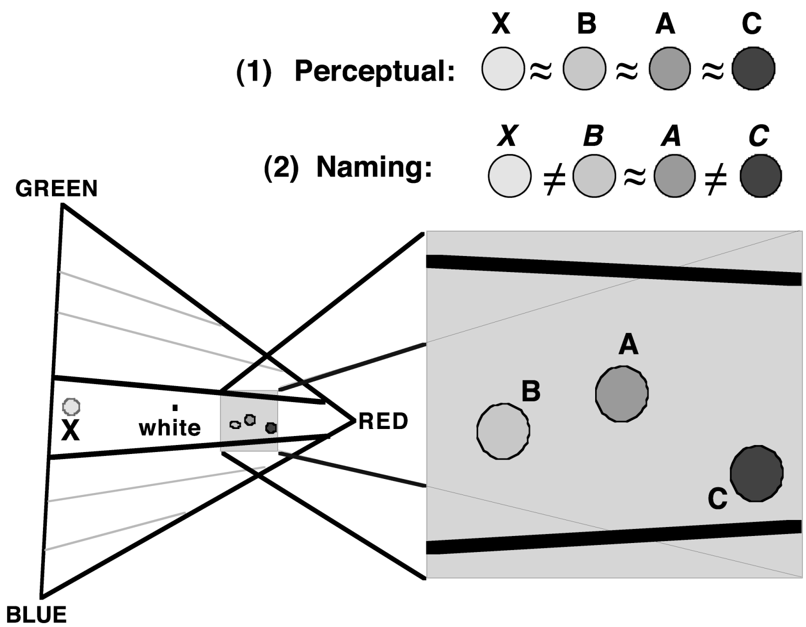

Figure 1. Grayscale schematic of an area of dichromat color perception. Different (1) perceptual and (2) naming relations are proposed. The dichromat confusion regions shown by solid lines are generalization of confusion loci empirically identified by D. Farnsworth (see Wyszecki & Stiles, 2000).

which specifies that B and A are similarly named (denoted "≈"), and X is named differently (denoted "≠") from B and A, as is C.

The implication of this hypothesized separation between perceptual and linguistic representations is that a dichromat's cognitive representation of color is in some ways more complicated than that of a trichromat, as described later. For a dichromat there must exist two considerably different mappings – one for color appearance, and a second for the structure of linguistic relations as prescribed by a society's trichromat majority. It also implies that some dichromats are aware that some of the colors that look the same to them map on to different labels in the shared lexicon. Conversely, it would appear that dichromats may learn that color communications can reflect a specificity that they cannot appreciate perceptually, even though other observers might do so.[4]

The existence of shared lexical representations, distinct from color perception representations, partially explains why dichromat observers can be undetected in everyday social interactions with trichromats. This suggests a highly cognitive (albeit apparently automatic) meta-awareness about one's own color experience compared to others in the culture. Thus, dichromats are not as disadvantaged as one might imagine from their color matching behavior – they understand that trichromats perceive *red* and *green* as opposing categories, and in everyday interactions they are only at a disadvantage for naming when they have no other cues except color properties to help differentiate two items within their confusion classes.

Trichromat Observers

Figure 2 shows a grayscale schematic for trichromat color perception and linguistic relations. As in Figure 1, a miniaturized region of *reddish* color appearances within the triangular plane is enlarged on the right side of Figure 2. The circles marked A, B, and C define three color samples from that outlined area. In the enlarged view an outlined ellipse centered on stimulus A defines an area of color space containing colors that *match* sample A.[5] Figure 2's hypothetical trichromat observer will not distinguish appearance A from appearance B because A and B both occur within the same equivalence-class ellipse. In general, colors within such ellipses are phenomenologically "the same" or "a match" even though they are physically different in spectral composition (called "metameric" stimuli by psychophysicists). Also in Figure 2 are color appearances C and X. Appearance C is categorically similar to A and B but would not be considered a perceptual "match" to A because it lies outside the equivalence class ellipse defined for A. By comparison, X is a bluish green sam-

[4] Although not all color vision impaired observers are aware of their deficit.

[5] Depicted ellipses are not empirically determined, and, for illustrative purposes, are not drawn to scale.

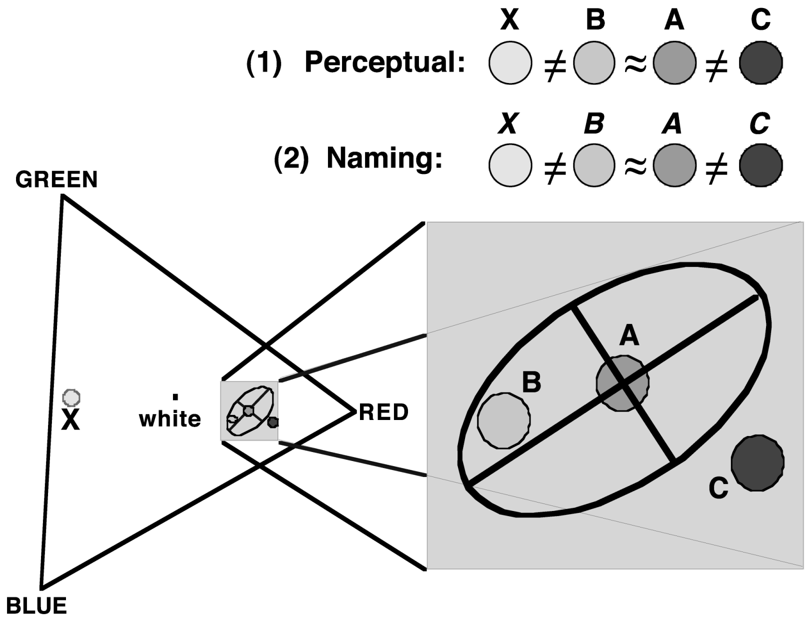

Figure 2. Grayscale schematic of an area of trichromat color perception proposing identical (1) perceptual and (2) naming relations.

ple, distant from the reddish color category of A, B and C. Thus, X is far removed from A's perceptual match ellipse. Accordingly, the trichromat perceptual relations for these colors are described by:

$$X \neq B \approx A \neq C,$$

which specifies that B and A are perceptually indistinguishable, and X is distinguishable from B and A, as is C.

Figure 2 describes the trichromat *perceptual relations* for these four stimuli and the *shared naming relations* for the stimuli's lexical labels. For trichromat observers, in general, lexical relations are identical to perceptual relations when color differences are large, even though the shape and size of equivalence-class ellipses will vary somewhat across individuals and will be non-uniform in size across color appearance space. This differs from Figure 1's dichromat observer for whom large color differences may be undetectable perceptually, but present linguistically.

Although the trichromats perceptual and linguistic relations are identical for large color differences (Figure 2), they need not be identical for smaller color differences. Thus, separate underlying perceptual and naming relations are also postulated for trichromat observers, observable for some color comparisons but not others. Consistent with research on shared color naming systems, for both dichromats and trichromats the same commonly shared color naming relations can exist irrespective of differences in color perceptual relations.

We can extend also Figure 2's perceptual and lexical relations for *normal* trichromat observers to *anomalous* trichromats. These are trichromats with one or more shifted retinal photopigments causing systematic differences in the observer's perceptual equivalence classes. For smaller perceptual color differences the correspondence between linguistic and perceptual relations should deteriorate more rapidly for anomalous trichromats.

The analyses above suggest different ways that variation in perceptual experience might interact with color naming in familiar observer groups formed by inherited color perception abilities. Such variation need not impact the sharing of linguistic color relations within an ethnolinguistic group. The examples presented support the assertion that color category naming universals within and across ethnolinguistic groups are not attributable to shared privileged perceptual salience across individuals (Jameson & D'Andrade 1997, Jameson & Alvarado 2003, Jameson 2005a). Rather, across all three observer types discussed (dichromats, anomalous trichromats and normal trichromats), irrespective of their differences in perceptual relations, named color categories may cluster due to the sharing of the same normative linguistic relations.

Although modeling the processes underlying color naming in deficient and anomalous observers is informative, skeptics may argue that models of color naming universals should not be expected to explain variation arising from perceptually deficient observers. However, as our earlier review shows, there is good evidence of large normal variation in the psychophysical determination of Hering *privileged points in perceptual color space*, suggesting crucial and substantial differences even among normal observers. Such normal variation produces heterogeneity in the assumed privileged perceptual salience across individuals. Yet much cross-cultural color naming research report results aggregated over individuals (e.g., Kay 2005). This data reduction practice obscures individual differences of the kind reviewed earlier in Section 1. Such observer variation, and some of the empirical consequences for color categorization and naming, are now presented.

Retinal Tetrachromat Observers

Other interesting forms of *normal* observer variation exist (arising from the inheritance of additional variants of photopigment opsin genes). Recently these have been shown to correlate with color naming behaviors and may provide further insight into the relations linking perceptual variation and shared color naming systems.

As mentioned earlier, the genes for color vision are located on the X-chromosome. Molecular genetics and psychophysics research have recently shown more color vision phenotype variation among "normative" observer groups than previously believed to exist. This variability stems from several, normally occurring, allelic variants of X-linked opsin genes: the medium-wavelength sensitive (MWS) and long-wavelength sensitive (LWS) opsin genes. The genes for the shortwavelength sensitive cone pigments are not X-chromosome inherited and S-cone defects are not common phenotypically. When allelic variations for these photopigment classes occur at certain positions on the genetic array they give rise to shifts in spectral response sensitivity which, in turn, impact color perception (Winderickx, Lindsey, Sanocki, Teller, Motulsky & Deeb 1992, Asenjo, Rim & Oprian 1994). The range and variety of photopigment variants is surprising, and unanticipated by color vision models that historically postulate only three "normal" pigments. It implies that in some populations initial retinal color processing is almost certainly more varied than originally anticipated by three photopigment theories.

For example, although the actual incidence of phenotype expression remains uncertain, it is known that a considerable percentage of Caucasian females have the genetic potential to express four classes of retinal photopigments (Sharpe, Stockman, Jägle & Nathans 1999, pp. 39-40).[6] Regardless of the actual magnitude of this genotype's frequency,

[6] Indeed, phenotype expression of multiple photopigment variants is perhaps made more interesting due to recent findings of incomplete X-inactivation in gene expression (Carrel & Willard 2005).

individuals who retinally express four photopigment classes have been shown to exist and are called "retinal tetrachromats" (Jameson, Highnote & Wasserman 2001). Still debated is whether post retinal processing of the signals from additional cone classes allows significant color perception variation, and whether it is variation that is not available to retinal trichromats. If such results were shown, such observers could be referred to as "functional tetrachromats." Jameson, Highnote & Wasserman (2001) discuss the conditions for *weak* and *strong* forms of tetrachromacy, and argue that functional tetrachromacy does not necessarily follow as a consequence of retinal tetrachromacy. For functional tetrachromacy (or *strong tetrachromacy*) to occur, more than three neural processing channels, or a different form of higher order color processing, may be needed to process the various color signals originating from retinal tetrachromacy. Cases of *weak* tetrachromacy have been found (i.e., Nagy et al. 1981), as has one case of *strong* tetrachromacy (Jordan & Mollon 1993). Evidence found by several recent empirical studies suggests that, although the causes remain uncertain, the genetic potential to express more than three cone classes correlates with differences in behavior such as color categorization, naming and similarity (discussed below). The existence of functional tetrachromacy is still debated and requires additional demonstration. However, regardless of the abundance of demonstrations of strong or weak tetrachromacy, the mere existence of retinal tetrachromats classed among normal trichromat groups presents an additional opportunity to analyze the relations between individual perceptual color experience and shared color naming systems.

Similar to earlier analyses, Figure 3 illustrates hypothesized perceptual and linguistic consequences for a retinal tetrachromat. It depicts one perceptual equivalence-class region potentially available to a retinal tetrachromat for comparison with that described earlier in Figure 2 for a trichromat.

As in Figures 1 and 2 the same small region of reddish color appearance is expanded on the right of Figure 3. This hypothetical tetrachromat equivalence-class region is centered on sample A. Note that its size is somewhat smaller and shifted compared to that shown for the trichromat observer in Figure 2, suggesting that an individual with four classes of retinal photopigments may experience some shifted or compressed

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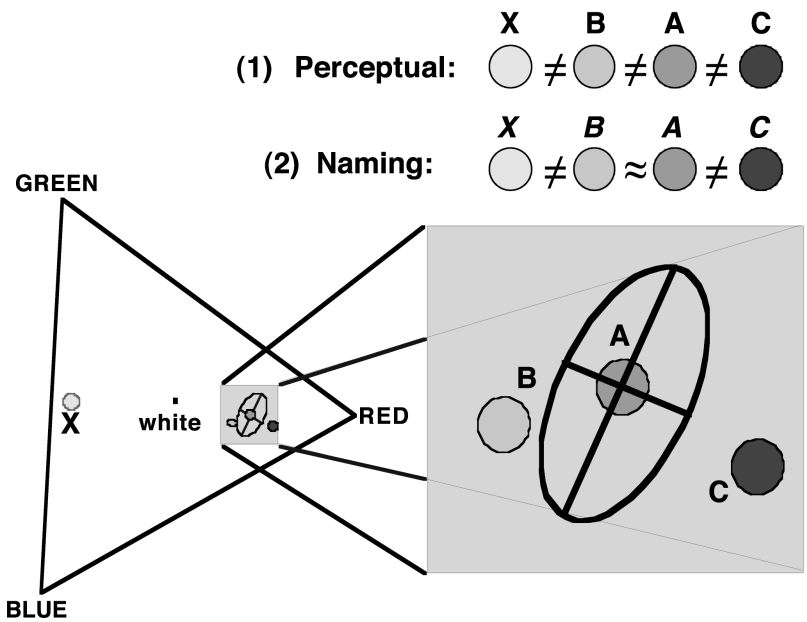

Figure 3. Grayscale schematic of an area of hypothesized retinal tetrachromat color perception with differing (1) perceptual and (2) naming relations.

equivalence-class contours compared to a trichromat (generalized from Jameson, Highnote & Wasserman 1998, 2001).[7]

The hypothetical retinal tetrachromat perceptual relations are described by:

$$X \neq B \neq A \neq C,$$

implying that appearances A, B, C, and X all differ perceptually. In contrast to Figure 2's trichromat, this hypothetical retinal tetrachromat can distinguish between sample A and B. Like Figure 1's dichromat,

[7] As in Figure 2, Figure 3 equivalence-class ellipses are drawn larger than actual size and are strictly for illustrative purposes.

however, the retinal tetrachromat makes use of a shared color lexicon influenced by the society's trichromat majority, namely:

$$X \neq B \approx A \neq C.$$

Retinal tetrachromats may be capable of more specificity than is reflected in this simple illustration, including greater lexical specificity than is found in their culture's color lexicon, and greater numbers of categorical distinctions than are agreed upon by trichromats in their society (Jameson et al. 1998, 2001). Of course, the trichromat also perceptually resolves more color distinctions than are represented by the lexicon (compared to a dichromat with *less* perceptual specificity). However, while a society's color lexicon may be adequate as a trichromat color communication code, it may be inadequate, or lack sufficient specificity, for tetrachromat observers.

As with dichromats, tetrachromat observers may learn to accept and comfortably use a comparatively imprecise mapping of color appearances to color language and categories. A retinal tetrachromat child developing in the company of trichromats may learn color categories primarily by discovering that groups of objects that appear different in color to the child are consider as color-matched by other people. After reliable exposure to these learning experiences such an observer could develop a personal definition of color similarity that says: "Color *matching* denotes when two things have *almost the same* color appearance to me, although other people report seeing them as identical." In this example, the retinal tetrachromat's cognitive construct of a color-match differs from (and is perhaps more flexible than) a trichromat's. The net result is that potential disagreements of color labeling among individuals with varying perceptual abilities are minimized. How tetrachromat perceptual relations can differ from linguistic relations, and how they vary from a trichromat norm, is clarified by some recent color-naming behavior results, which are now described.

Color Naming Behaviors Correlated with Potential Retinal Tetrachromacy

The trichromat and dichromat analyses described earlier follow directly from a well-established empirical literature. New empirical results justify the tetrachromat analysis. Psychophysical discrimination paradigms have primarily produced evidence of weak tetrachromacy (Nagy et al. 1981, Jordan & Mollon 1993, Jakab & Wenzel 2004). While the details are beyond the scope of the present article, there are good reasons why some psychophysical techniques might not register strong tetrachromat perception that may be possible under more naturalistic viewing circumstances (see Jameson et al. 2001 for a discussion). Nevertheless, Figure 3's suggestion that tetrachromats show subtle color perception equivalence-class variation is consistent with existing psychophysical findings on such observer.

In contrast, assessing cognitive judgments under more naturalistic viewing circumstances (e.g., color similarity, color categorization, and color naming), show correlations between retinal tetrachromat genotypes and differences in color behavior (Jameson et al. 1998, 2001, Jameson & Wasserman 2002, Jameson, Bimler & Wasserman 2005a, 2005b, Sayim, Jameson, Alvarado & Szeszel 2005).

For example, Jameson et al. (1998, 2001) found that females with retinal tetrachromat genotypes experience differences in color perception that are substantially different from normal female trichromat controls. Briefly summarized, Jameson et al. used a task in which subjects delineated categories in a diffracted spectrum subjectively appearing as a luminous "rainbow," (Jameson et al. 1998, 2001). They hypothesized that the ability to perceive and delineate bands of chromatic difference along the spectrum was a function of perceiving noticeable differences in spectral wavelengths. Such differences were expected to covary with the number of retinal photopigment classes possessed. As hypothesized, their results showed significant covariation of tetrachromat genotypes with increased spectral delineation behavior.

Table 1 shows that the number of spectral bands a subject delineates systematically varies with the number of photopigments a subject is presumed to express (Jameson et al. 2001). Classification of subject partition (1.) is inferred strictly from the genotype analysis determining heterozygote and is probabilistically linked to the four photopigment phenotype. Partitions (2.), (3.) and (4.) are based on results from both genotype tests and color vision screening tests. Partition (2.) is a sub partition of group (3.). As expected from trichromatic theory, dichromat individuals (in this case protanopes) delineate fewer chromatic bands than trichromats (Student's t-test, two-tailed distribution, two sample equal variance $p < .05$ on rows 4 and 3). Male trichromats ($n = 22$) were not significantly

Table 1

Means of Individual Median Spectral Delineations for Four Subject Partitions

Subject Partition	M	SD	n
(1) Females with four photopigment genes (opsin gene heterozygotes)	10.0	2.96	23
(2) Trichromat Females	7.6	1.80	15
(3) Trichromats (Females and Males)	7.3	1.93	37
(4) Dichromat Males	5.3	1.53	4

different from female trichromats (n = 15) in the mean number of chromatic bands each group delineates ($p = .44$). Significant difference ($p < .01$) was found between the number of bands delineated by females with retinal tetrachromat genotypes (or *heterozygotes*) and trichromats (males and females) subjects (partitions 1 and 3).

The most stringent test of this hypothesis, ruling out the possibility that the result is due to gender differences in socialization, is provided by comparing female trichromatic "controls" with females possessing the genes for retinal tetrachromacy. As seen in rows 1 and 2 of Table 1, the number of bands observed between the two female groups is significantly different ($p < .01$). Overall, Table 1 indicates a systematic relationship between the observed number of bands delineated by subjects and the number of photopigments they are presumed to express. These results suggest that higher order color experience for retinal tetrachromat females is more complicated than "normal" trichromatic color vision; or, less conservatively, that some females show signs of tetrachromacy.[8] As expected given their color vision deficiency, dichromat participants were found to delineate far fewer chromatic bands (about 5) compared to the other subject participants.

Jameson, Bimler & Wasserman (2005a, 2005b) also found support for a tetrachromat perceptual difference by comparing color vision assessment results between individuals possessing retinal tetrachromat genotypes and individuals with three-gene trichromatic genotypes. Novel multidimensional scaling analyses revealed that one popular standardized

[8] Although whether it is classified as a weak or strong form of tetrachromacy is unknown.

color perception test, the Farnsworth-Munsell 100 Hue Test (Farnsworth 1943), identifies some retinal tetrachromat individuals (who otherwise exhibit above average color discrimination) with a non-normative diagnosis. These findings suggest that such tests may not appropriately capture the non deficient perceptual variation that tetrachromat individuals experience. Detailed analysis reveals that performance in the red to green region of color space seems to underlie the test's misclassifications of these otherwise normal color observers. When the test is used as a screen to eliminate subjects with color perception defects (as is the common practice), such misclassifications would result in the omission of these non-defective retinal tetrachromats from the "normal" subject sample tested (Jameson, Bimler & Wasserman 2005a, 2005b; Jameson & Wasserman, 2002).

Sayim, Jameson, Alvarado & Szeszel (2005) assess cognitive color behaviors of retinal tetrachromats. They examine triad similarity for colormetrically controlled color samples and color names for local and global color stimulus sets, finding that some behavioral measures differentiate those possessing retinal tetrachromat genotypes from trichromatic genotype controls. Analyzing females separately from males, they find that measures of group agreement and consistency increase with opsin genotype complexity, and L-cone dimorphisms seemed instrumental in the behavioral differences. They found that among eight subject groups examined, only the L-opsin gene heterozygotes were above criterion on all consensus and matching measures evaluated. Sayim et al. (2005) also present strong evidence supporting the distinct perceptual and naming relations hypothesized in Figures 1–3.

Due to the X-linked nature of opsin genotype inheritance, a number of existing findings showing gender differences in color naming and categorization behaviors (too extensive to review here) can be viewed as consistent with, if not indirectly supporting, the suggested link between opsin genotype and color behaviors (as suggested by Bonnardel et al. 2002). In addition, some neuroscience evidence suggests that inherited photoreceptor variations are linked to reorganization of human cortical maps. Baseler, Brewer, Sharpe, Moreland, Jägle, & Wandell (2002) show that "molecular alterations in the genes encoding the cone photoreceptors have profound consequences for visual experience. The abnormal visual experience, in turn, changes cortical reorganization" and suggests that there exists "a close coupling among genetics, experience and brain development" (p. 368). In light of this, considerations of tetrachromatic processing made possible through normal retinal photopigment variation seem justified and important.

Additional indirect support exists by analogy to specific patterns of color vision inheritance found in non-human primates (Bowmaker, Mollon & Jacobs 1987) and the existence of other tetrachromatic species (Thompson, Palacios & Varela 1992). Color perception variation among "normal" observers is too substantial to support the construct of *panhuman uniform color processing salience* as the basis for color-naming similarities across cultures. It seems clear that color-naming theories need to explain how substantial intra-cultural differences in perceptual color experience can exist alongside inter-cultural similarities in color naming and categorization. Below a framework for developing alternative explanations for such findings is suggested.

Individual Variation and Intra-Cultural Naming

Given the above mentioned findings, color naming research must explain the processes by which generalizations of the perceptual relations shown in Figures 1, 2, and 3 are reconciled by a society's shared naming system, given each cultures' frequency and distribution of observer-types as they influence a society's shared color naming system. The above analyses of different observer types help towards this goal, and illustrate the usefulness of hypothesizing different cognitive levels of color representation.

The suggested perceptual representation is an individual's idiosyncratic perceptual similarity structure. The suggested linguistic representation is the shared cultural color lexicon and color category similarity structure. A cognitive mapping function links the two representations. This flexible linking function – called a *cognitive color-naming function* (Jameson & Alvarado 2003a) – accommodates the discrepancies between a dichromat's color equivalence class relations and those of trichromat individuals. For individuals this color-naming function should be robust in its mapping of large color differences to color categories for both normal and anomalous trichromats, but it should be comparatively less robust for mapping small color differences (especially near boundaries) to categories for such groups (Sayim et al., 2005, Kay & Kempton 1984).

Such a naming function may also play a role in mapping a retinal tetrachromat's construct of color matching with the equivalence class relations of trichromat peers, and play a role in other individually varying representations involving color compatibility, color preference, color memory.

In addition to focal and unique hue variation reviewed earlier, the fact that intra-culturally there is considerable variation even in the number of colors perceived by individuals in different perceptual groups (e.g., dichromats, trichromats & anomalous trichromats) and among observers from the same group, strongly suggests there must be considerable intra-cultural variation in the mapping of color percepts to language categories. Nevertheless, individuals from different groups use color lexicons in similar ways (Shepard & Cooper, 1992; Jameson & Hurvich 1978). This raises an interesting puzzle in color naming research. If the potential for individual variation in color perception is common, and the perceptual consequences are, in some cases, substantial, then why is intra-cultural agreement common in everyday color naming and categorization? Two features implied by separate lexical and appearance representations further address this question.

Two Essential Features of Intra-Cultural Color-Naming Systems

Earlier it was suggested that learning experience and social forces help smooth out color-naming discord potentially arising from perceptual differences among members of a culture. Two essential features implied by this are (1) development of individual color naming relations concordant with society's *stable color-naming system*, and (2) a tendency for *linguistic charity*, or flexible discourse, among members of a society (Jameson & Alvarado 2003a).

Practically speaking, as a communication code a **stable** color-naming system should in part aim to optimize color communications among members of a culture. However, in societies where observers vary, as described here, optimal coding can be variously defined. For example, two extreme forms of optimal coding are plausible.[9] The *majority rule* form

[9] The actual criteria met by, or form of, the coding system is unknown because no detailed evolutionary model of color naming system emergence exists that specifies the

is where the system optimally codes for interactions among majority members and the minority members comply with the majority rule system. Alternatively a *polymorphic system* may suboptimally code among majority members and suboptimally code among minority members, but optimally code for interactions within the polymorphic society. Both forms can produce stable solutions.[10] Note that actual ranges and frequencies of color perception variation found in some human societies seem more compatible with the development of stable polymorphic systems, but the main assumption here is that for a given society examined, some form of stable color-naming system exists.

Given a stable color-naming system, feature (1) suggests it is essential that individuals acquire naming-function mappings for indexing color in their personal color similarity space in accord with the *lexical entries of the stable system*; and that individuals share, by communicating with members in their society, the relational structure of that system in ways that reinforce and maintain the stable communication code. The clear purpose of the cognitive color-naming function in this scenario is to strive for maintenence of a shared naming-system equilibrium despite individual variation in perceptual representation or other naming idiosyncracies.

Essential feature (2) is a social mechanism. Social mechanisms contribute to the stability of naming-system equilibria when individuals converse intra-culturally about color appearances that are valuable or salient in cultural interactions. Here the social mechanism is *linguistic charity*

dynamics driving the solutions. For a given language it could resemble one of these extreme forms or it could resemble any form in the gradient between the extremes described.

[10] The evolutionary dynamics underlying the emergence of a stable color naming system are not understood or have not been described in sufficient detail. One might argue that color naming systems reflect a code optimized for a large trichromat majority, forming a "normative" or "modal" color naming system (e.g., based on color perception from a purely hypothetical standard normal observer model). While this *majority rule* approach is intuitively appealing, the empirical validity of this suggestion has not been shown, and results from simulated color-naming system evolution suggest that different stable color-naming solutions emerge across different *cultures* of observers, all based on the same standard normal observer model (Steels & Belpaeme 2005). Such results are consistent with analyses of evolutionary dynamics which typically find paths of many stable equilibria vary due to incidental events and features (e.g., the starting state of the system) resulting in the emergence of very different stable naming systems.

(Putnam 1988, Jameson & Alvarado 2003a, 2003b) which occurs in interpersonal interactions when individual variation about the meanings of specific words are subordinated to maintain a coherent overall meaning and the need to communicate. Thus, while relatively minor differences in color-naming mappings are acknowledged from time to time, for the sake of facilitating communication they are frequently disregarded on the basis of *linguistic charity*.[11] Like the rest of language, color language is subject to the demands of pragmatic communication. If disagreements about subtle differences in color seriously prohibited social commerce, or were to produce undesired consequences (e.g., ingestion of poisonous mushrooms), then those differences would be marked by social salience, and would be accommodated in the language through redundant coding, modifier embellishment, and so forth. Practically speaking, this semiotic feature of the color-naming phenomena is essential for shared, stable color-naming systems because it effectively minimizes the effects of individual variation on the shared representation of color lexicons, allowing shared lexical relations to reconcile to some extent individual differences in perception.

In sum, these essential features help explain why individual variation in color perception does not impede intracultural agreement in everyday color naming and categorization. The next section extends this analysis to cross-cultural naming and categorization.

Cross cultural Universality in Color Naming and Categorization

Given intra-cultural variation in individual color perception and color representation, what explains existing empirical results showing cross-cultural color universality in the naming and categorization of color (e.g., Kay 2005, Kay & Regier 2003)? Briefly, it is proposed that universalities in color lexicons and categories arise from commonalities in the ways different cultures evolve their color naming systems. Some of these com-

[11] The degree of linguistic charity observed will clearly depend on a number of factors such as the age differential of two conversants, social status differences, and its use is expected to vary across societies (c.f., Gatewood 1983).

monalities follow from the psychological processing of color using universal cognitive heuristics that regularize color naming across cultures. Socio-cultural components also influence the ways cultures differently evolve color naming systems. Both types of components are described below, but first some rationale for an alternative framework is presented.

An Organizational Framework for Individual and Cultural Color Categorization and Naming

An organizational framework (abbreviated "*framework*" below) is proposed for explaining individual and cross-cultural color naming phenomena. This framework includes a psychological model of color category partitioning based on interpoint-distance relations among category exemplars, called the Interpoint-Distance Model (or *IDM*). The framework also specifies pragmatic and socio-cultural components that dynamically interact with the IDM.

Overview

The proposed framework is based on the idea that there are two important universalities in color naming and categorization. First, different societies approach the problem of how to communicate about color in similar ways due to cognitively natural universals. Color-naming system features are most similar across cultures when (1) color is universally accessible and becomes constrained in similar ways across cultures, and (2) when socio-cultural constraints are similar. When constraints imposed by (1) and (2) differ, two cultures color-naming systems can differ. Second, individuals in a given ethnolinguistic society share a common cognitive representation of their culture's color lexicon. The shared representation differs in important ways from each individual's personal cognitive representation. Individual representations of personal perceptual similarity are linked to the shared cultural representation by a cognitive color-naming function.

Psychological emphases of the framework are addressed by the IDM. These are: (1) color category partitions are based on salient cognitive dimensions, (2) emphases of brightness, saturation, and secondarily hue seem, in the absence of other possible influences, most general and universal as perceptual bases for color lexical codes, (3) dimensional salience arising strictly from culture, language and environment also shape color lexicon evolution and are subject to similar partitioning heuristics as salient cognitive dimensions. Influences of the sort emphasized in (3) seem to be of secondary importance to aspects of lexicon development linked to brightness and saturation salience.

As described below, the framework is not a specific theory of color-naming, rather it is an empirically justified way to organize and explain color-categorization and naming phenomena, and can be applied to develop models of color naming universals.

Relevance to Existing Theories

Although significant progress has been made by existing color-naming research, a new theoretical framework is needed for several reasons. First, while much of the color-naming literature emphasizes the prevalence of cross-cultural color naming universals, actual color-naming phenomena vary considerably across cultures. Second, socio-cultural influences on naming differ greatly across cultures, and the most widely accepted model of color naming does not aim to incorporate such influences in its theory (e.g., Kay & Regier 2003). While such variation remains unexplained it hinders the needed development of a *comprehensive* theory – one that incorporates physical, psychological and cultural influences – to explain both cross-cultural similarities and variation.

Third, based on an extensive literature, it seems likely that color-naming systems evolve in different ways, to meet varying cultural needs.[12] This presents an additional challenge for all theories of color-naming because even if a candidate theory captures some languages' color-naming universals, that same theory may not adequately explain naming universals found across color-naming systems arising from different evolutionary paths or shaped by differing socio-cultural influences. Thus, to additionally account for cross-cultural commonalities one needs a broader theoretical framework.

[12] Empirical results (Roberson, 2005) and computer simulation also indirectly support this suggestion (Steels & Belpaeme 2005).

The proposed framework and its accompanying IDM aims to identify and explain common cognitive dimensional emphases across different color-naming systems, and organize the factors underlying color categorization and naming phenomena by making explicit the general principles that give rise to different color-naming systems across cultures. In this approach, once various partitioning paths to color-naming are specified, the possibility exists that languages that cluster along similar paths can be understood, which in turn may reveal a general theoretical structure for color naming. In this sense the framework itself is not a color categorization theory *per se*, rather it provides a justified method for explaining empirical results arising from multidimensional phenomena and for developing appropriate color-naming theories. Exactly how the framework differs from existing theories is elaborated in its description below.

The present framework and IDM does not aim to displace existing theories of cross-cultural color categorization. The Universalist perspective that argues in support of the wide-spread prevalence of eleven or fewer *basic color terms* across cultures seems useful for summarizing empirical phenomena arising in a number of studied languages (Kay & Regier 2003, Kay 2005), even though other BCT theoretical components such as universal "focal" colors and privileged basic color salience constructs are problematic. Similarly, the Cultural Relativist perspective is not discordant with the present framework – indeed, aspects of this framework incorporate relativistic influences to explain and organize the phenomena. Nor does the framework in any way exclude constraints or influences imposed on color categorization by human color vision processing (discussed in earlier). Instead the framework combines the strengths of these existing views with multivariate analyses of differences and commonalities seen in the cross-cultural color naming research.

Components of the Framework

Briefly, the framework proposes the following ideas:

(1) All societies face the same highly constrained problem – how to partition and name color appearances – yet solutions to this problem can arise along different paths.

(2) Major constraints on this problem include environmental and visual processing properties, and cognitive and socio-cultural influences, all of which contribute dimensions for partitioning.
(3) To the extent that constraints differ, dimensional emphases can differ, and partitioning solutions can differ. Solutions can also follow different paths when different dimensional emphases exist despite similar constraints on the problem.
(4) Solution similarity is optimized across societies when both constraints and dimensional emphases are similar. This optimization is driven by highly prevalent, possibly universally salient, cognitive principles and heuristics.

The framework characterizes how these ideas depend on the interplay between psychological processing components and socio-cultural components. Thus, empirically robust color-naming tendencies seen within and across cultures are, in part, a consequence of the adoption of specific universal cognitive heuristics. These heuristics arise because they are best suited to solving a problem occurring across all individuals in all cultures – how best to lexically partition and label color space. These heuristics can be seen in the ways different ethnolinguistic groups similarly solve (by convergent evolution), the communication problem of labeling color experience in a socially optimal manner.

*Psychological Components and the Interpoint-Distance Model (*IDM*) of Partitioning*

What general cognitive principles underlie the processes by which many cultures seem to similarly subdivide and label color space? Central to the framework is the IDM which proposes that color space partitioning is regularized by salient cognitive dimensions and universal naming heuristics. The IDM assumes there are minimal dimensions (e.g., brightness, saturation and hue) that are appropriate bases for partitioning an idealized color space. This assumption accepts that certain properties of color space are important regardless of whether the signal is a self luminous light or a non self luminous surface reflectance (Judd, 1973, p. 65).

Human visual processing gives rise to continuous dimensional constructs or cognitive gradients (e.g., brightness) that produce ranges of normal variation in the individual processing of stimuli. Despite individual variation in the processing of such cognitive gradients, such dimensions are good prospects for widely shared constructs. Thus, while enough individual variation exists to preclude the determination of universally salient "focal" colors and uniform category boundaries (discussed above), visual processing constraints nevertheless support, in part, color partitioning based on dimensional structures that are shared across observers.

Regarding the partitioning of dimensional stimuli, Garner (1974) describes a general cognitive principle used by subjects when classifying such stimuli. He suggests that a general form of classification learning is seen when a subject partitions total sets of stimuli, or stimulus domains, into subsets or classes in which all stimuli are alike in some way, while at the same time all different from stimuli partitioned into the other classes (p. 97). Garner states that ". . . the subject classifies the stimuli so that he maximizes the perceived differences between classes while at the same time maximizing perceived similarities within classes" (p. 98). In Garner's (1974) theory, this heuristic approach to stimulus similarity is widely seen throughout human cognitive processing under categorization tasks. The IDM assumes that the kind of dimension similarity relations described by Garner are the universal cognitive basis for color categorization (see Jameson 2005a).

In addition to the partitioning of specific dimensions, three principles bear on the relational structure and cognitive organization of categorized color appearances. As applied to an idealized three-dimensional color appearance space, these are:

(1) Polar opposition or symmetry among category best-exemplar interpoint distances.
(2) Regularized category area, or a tendency toward equal sized category areas.
(3) Category area symmetry, or a balanced relational structure among categories.

These principles imply that during development of a naming system, newly identified category best exemplars tend to be optimally distant from existing best exemplar regions in each culture's idealized perceptual color space. The polar symmetry principle (1) in conjunction with regularized category area (2), in essence, leads to uniformly distributed category structures across the entire stimulus space, regardless of the number of color categories a language manifests. Asymmetrically or irregularly distributed category structures do not represent a reasonable lexical mapping of the stimulus space. Such mappings of color lexicons to color space are not common, and, indeed by IDM principles, asymmetrically distributed mappings should only occur when lexicalization of the space is based on pragmatic demands, such as when specific socio-cultural needs arise.

As with other multidimensional information codes, a consequence of encoding color categories based on this optimized interpoint distances idea is that *initial* lexical partitions based on a given dimension's interpoint-distances will constrain subsequent partitions based on other salient dimensions. For this reason, partitioning sequences are greatly determined by those color dimensions initially deemed most salient by those determining the lexical code.

Also, optimal information code partitions defined on a given dimension in isolation (e.g., brightness), may not be identical to the optimal brightness code partition defined when an additional dimension of information is present (e.g., saturation). This is especially the case for interdependent – or *integral* dimensions – for example, saturation and brightness which perceptually covary. In general, the IDM formulates color lexicon development as a dynamic process dependent on both information encoding considerations (represented by the interpoint-distance heuristic) and dimensional salience (including both widely shared cognitively salient dimensions and culturally specific salient dimensions).

An important distinction is made by the IDM with regard to the geometry underlying partitioning. The IDM emphasizes some geometrical considerations that are not based on a metric, and thereby do not support strictly Euclidean interpoint distances between color category exemplars. In addition, the cognitive dimensions and rules of the IDM do not use any sort of uniform cognitive distance metric because inhomogeneities across each dimension's perceptual ordering are likely, and the corresponding cognitive orderings are unclear. For this reason a metric across the cognitive space is difficult to construct even though it may exist. The IDM's essential features are that salient dimensions and polar opposites are emphasized in the space, yet the details of how these dimensions trade-off with each other need to be specified. Even in the absence of metric distances the IDM captures relationships central to color category partitioning (e.g., polarity) in which Euclidean distances or other geometric distances need not be used to define the representation. And despite its non-metric feature, the IDM is consistent with modeling color in a way that is intermediate to a metric geometry (assuming trade offs between dimensions) and a topological space. In this way it contrasts with many models of color representation (e.g., Romney, Moore, Batchelder & Hsia 2000) that are formulated in terms of the metric distances arising in similarity representation data.

IDM heuristics implicitly model the ways ethnolinguistic societies reach common solutions for partitioning and labeling culturally relevant color appearances, and through different dimensional emphases societies can develop solution variants. This approach has several advantages over perspectives based strictly on a pan human universal color vision phenomenology. First, it capitalizes on the naturalness of universal cognitive dimensions and the influences of polarity and symmetry, which in this case at least, can be described as universal principles of cognitive organization. Second, pressures to regularize and balance the spatial area of category partitions strive for an efficient information code. Third, it allows for shared cultural agreement to serve the role of defining a normative system of color categories and a lexicon. Fourth, the perspective is not strictly deterministic, but can accommodate shifts in cultural salience of color appearances.

Socio-Cultural Components

Pragmatic constraints can impose both cross-cultural differences and similarities on color naming. For example, differences in color naming systems will arise due to color appearances imbued with culturally specific value; variation in environmentally prevalent and salient colors; and existing linguistic structures for naming other naturally occurring categories and object attributes. The forces which shape a culture's color lexicon development and maintenance differ from those that affect an individual learning an established naming system. In the existing literature these two processes have not been clearly differentiated.

Some of the framework's socio-cultural influences on color-naming include:

(1) Emphasis of pragmatic dimensions (such as livestock hyde colors, or edible/inedible color continua),
(2) Appropriate representational specificity (consistent with a society's color use, and with other similarly salient category structures in language),
(3) Distribution, frequency and relative importance of different perceptual groups within a society,
(4) Compatibility with existing linguistic structures commonly found in a culture's language.

Through such influences societies develop color naming systems that accord with the pragmatic importance of color language as a communication tool, by way of naming categories that minimize individual and interpersonal confusion in an information theoretic manner (c.f., Dedrick 1997; Freyd's 'shareability,' 1983; Jameson & Alvarado 2003a). Examples of socio-cultural dimensions and constraints are provided below.

Convergent Evolution of Color-Naming Systems

Under the cognitive and socio-cultural constraints described, many cultures converge on similar solutions to the problem of how to collectively name color appearances. Three aspects of color experience make this convergent evolution possible.

First, color is a stimulus domain that is both universally accessible and universally regular, compared to stimulus domains with features that vary cross-culturally (e.g., categories of creatures or cultural artifacts). Second, the dimensionality of color appearance space is relatively constrained compared to most other stimulus domains, with appearances continuously vary across a few specifiable dimensions (e.g., Shepard, 1994); the physical properties of visible light are relatively uniform; and the human visual response to light is constrained.[13] Third, all cultures'

[13] Setting aside for the current discussion the important finding that the dimensionality of color appearance space increases dramatically under contextualized viewing (Mausfeld & Niederée 1993; Niederée, 1993), and that surface viewing condition complexity precludes a strictly three dimensional structure for color appearance space (Maloney 1992).

color lexicons and color representations arise through similar psychological components, to solve the common problem of how to organize and label culturally salient color perceptions.

Considering these constraints, emergence of similar color categorization systems is analogous to a widely accepted principle in biology known as adaptive convergent evolution. Convergent evolution states that two animal species can independently evolve similar features to solve similar environmental problems. So, for example, the red tube shape flowers of many plants independently co-evolved to optimize pollination by hummingbirds; or the need to excavate insect food sources forced independent evolutions of a probe shaped snout in the Giant Anteater (South America), Giant Armadillo (North America), Spiny Anteater (Oceania) and the Giant Pangolin (Africa). Extended to cross-cultural color naming systems, convergent evolution suggests that various pressures presented by cognitive, socio-cultural, and environmental constraints produce similar problems that lead cultures to find similar solutions. The pragmatic uses of color language place substantial constraints on color lexicon evolution. For a color naming system to be viable it needs to be a useful code for the majority of the speakers of the language. Such constraints force a culturally shared color naming system towards a shared stable representation irrespective of individual variations in representation that might arise due to diversity in perceptual observer types (such as dichromacy). Linguistic charity (Putnam, 1988; Jameson & Alvarado 2003a) also contributes to the adoption of a shared stable model of lexical representation (despite its possible inappropriateness for some observer types). This pragmatic principle implies that errors or ambiguity in the mapping of a color term to color appearances near category boundaries, may be forgiven by speakers of the language. Such ambiguity is linked to the probabilistic assignment of appearances to lexical categories, but is socially tolerated as a non-fatal obstacle to successful color communication. Thus, a culturally shared stable solution constitutes a good color naming system, and such solutions evolve in the context of demands from the psychological and socio-cultural components described.

Implications of the Framework

Some important corollaries that follow from the above framework are:

(1) Best-exemplars float with dynamic category formation, similar to MacLaury's "floating foci" (1997a, p. 25). Discussed further in *Regularized Category Structures* below.

(2) Fuzzy category boundaries arise, in part, due to variation in individual perceptual response to dimensional continua, which is consistent with Kay & MacDaniel (1978). Differences in category boundaries occurring among observers from the same culture present no critical obstacle to interpersonal communication due to linguistic charity and fuzzy-set mappings of the color naming function (see Putnam 1988, Dedrick 1997 pp. 154-159, or Jameson & Alvarado 2003a).

(3) Personal lexical similarity mappings may exist in addition to separate personal color similarity relations and shared lexical similarity relations. Personal lexical similarity relations can differ from shared lexical similarity.

(4) Category partitions depend on chromatic biases and the distribution of colors in appearance space. IDM partitions of visible color space greatly depend on the stimulus domain under consideration, and partitions are expected to vary as stimulus domain variation impacts color differences inherent in the spatial extent of categories represented across color order systems.

(5) The framework implicitly suggests a clear separation between individual naming processes and a culture's path to evolving a stable color-naming system.

Support for the Framework and the IDM

This section briefly summarizes empirical support for features of the proposed framework and the IDM. Although full discussion of each feature is beyond the scope of this article, mention of cognitive and cultural influences from the literature is provided.

Individual Cognitive Influences

Polar opposition. The cognitive principle of **polar opposition** is central to the emergence of the first few category partitions within a color appearance similarity space (c.f., Garner 1974). For gradient stimulus dimensions the most cognitively natural partition is a stimulus continuum bisection forming two similarly-sized partitions with polar opposite central exemplars. A universally natural partition of *brightness* produces a dark/light polarity. Polar opposition is a construct commonly discussed in color phenomenology. For example, Hardin (1988) advanced "polarity" as a significant subjective criterion in color processing, although his formulation differs from that proposed in the IDM, primarily due to his implied linkage between subjective opponency and visual processing opponency (Hardin 2005).

Symmetry. A related cognitive tendency, a preference for **symmetry**, is also a central partitioning influence in the IDM. Symmetry is realized in color appearance similarity space through category best-exemplar placement and is reflected in the spatial extent of category areas. Psychophysical studies indicate that the processing of visual symmetry is specifically enhanced in the human brain as shown by fMRI activity in human visual cortex (Sasaki et al. 2005).

Salient cognitive dimensions. The cognitive constructs of polar opposition and symmetry operate on the **salient cognitive dimensions**. Keil & Kelly (1987) discuss how this arises from perceptual experience:

> Even in the earliest stages, children do not select all the logically possible features or dimensions that could conceivably be used in a computation of overall similarity. Universally shared constraints could make some features more salient than others in organizing a domain and thus it is only within this subset of features that the shifts . . . [in category membership] are occurring. In addition, broad structural constraints on conceptual structure may be at work throughout the period during which knowledge differentiates and shifts away from early exemplar bound representations. . . . If early representations were completely based on overall similarity relations without any guiding constraints that laid down a skeletal conceptual framework, it is difficult to see how knowledge acquisition could proceed so successfully and quickly in the first place. . . . therefore consider it essential that the developmental changes [and learning] . . . be viewed against a backdrop of constraints and predispositions that provide a kind of trellis within which the vines of categorical structure are able to differentiate (p. 508).

Jameson (1997b) has also emphasized that color-naming research often inappropriately overlooks dimensional salience differences in multidimensional representations of color similarity.

In general, perceptual regularities that are widely shared across observers will most substantially influence dimensional saliences in color similarity structures. Three cognitive dimensions mentioned earlier are brightness, saturation and hue. Brightness and saturation are considered by psychologists to be universally salient and perceptually integral dimensions (i.e., they perceptually covary). The latter feature makes their separate roles in color category development and naming more difficult to untangle compared to the role played by the perceptually separable dimension of hue (Garner, 1974). The present framework emphasizes individual brightness and saturation constructs and this differentiates the IDM from some existing approaches (e.g., Shepard, 1994), and theories that presuppose that Hering color salience drives color perception and categorization (Kay & Regier 2003).

Two reasons for an emphasis on brightness and saturation constructs are: (1) brightness and saturation are more widely shared than hue (as discussed below), and (2) greater simplicity of brightness as a perceptual dimension. Brightness and saturation are both polar dimensions (light-dark, pale-strong) that are clearly marked for magnitude, whereas hue is more complex. Brightness and saturation match other dimensions such as size and loudness, making them different from hue. Both Goldstone (1998) and Smith & Sera (1992) discuss why feature values ordered on a single dimension make for the simplest topological imprinting. A de-emphasis of hue may seem counter-intuitive given the subjective appeal of hue as *the* defining attribute of color. However, due to individual perceptual variation, hue is actually the dimension for which individual differences should be the greatest intra-culturally. This secondary emphasis on hue is further justified by the idea that cultures' color nomenclatures are based on commonly shared salient properties of color experience as opposed to properties that are idiosyncratically salient. Hue as a dimensional circumplex obscures the actual relationships among colors in color appearance space (see Young 1975, p. 159, or Rapoport & Fillenbaum 1972), and as Boynton (1997) suggests: "... there is no chromatic plane in OSA space that includes all of the basic colors. Yellow, Orange and Pink simply do not exist at the lower lightness levels, and Purple, Brown and Red are absent at higher lightness levels" (p. 147). Thus, as a salient visual processing dimension a hue circumplex differs fundamentally from brightness and saturation dimensions because it is an irregular connected contour that does not exist as a smooth plane in color space. Koenderink (2000) illustrates an alternate representation to the typically characterized hue circumplex of surface color (see also http://www.phys.uu.nl/~wwwpm/Talks/jk-ecvp 2000.php).

This idea of dimensional emphasis was applied in the IDM analyses of composite category structures to explain how Green and Blue might linguistically form a single category, or be alternatively partitioned further into hue categories (Jameson, 2005a), and to clarify the existence of two distinct glosses for blue in Russian (Paramei 2005, Jameson 2005a).

Regularized category structures. Cognitive features of color dynamically interact to produce a regularized relational structure consisting of cognitively similar inter-point "distances" among formed categories and category best-exemplar regions. From an information processing standpoint, a relational structure with equally spaced category best-exemplars minimizes cross-category confusions within and between individuals when category names are used as a communication code (c.f., Garner 1974). Even with variation in color appearance similarity space across individuals, lexicalized categories with similarly spaced best-exemplar regions maintain an unambiguous information code. The existence of these hypothesized interpoint distance relations is supported by the empirical results of Smallman and Boynton (1990, 1993). Their results show that individual search performance using color codes that are personalized structure-preserving rotations of a group modal category structure, is as good as (or better than) search performance using color codes derived from the actual modal categories. Finding that color codes from an individually rotated structure are better than a familiar, shared, group encoding suggests the code's informational value relies greatly on the regularized relational structure among encoded category best-exemplars (as opposed to widely shared regions of perceptual salience, as typically explained).

Results of Kuehni (2001) and Paramei (2005) also suggest that some larger areas of idealized color appearance space that are not yet lexically represented are likely candidates for emergent categories (also suggested by Boynton, 1997, pp. 144-145). Note, that emergence of a new category in an existing naming system forces the best-exemplar regions and boundaries of existing categories to *float* and redistribute in a way that maintains a regularized relational structure among encoded categories given the inclusion of the new category.

Shared Cognitive Influences

Universally shared dimensions. Widely shared, cognitively salient, dimensions are the most likely bases for the initial partitioning and naming of color appearance space. However, dimensional salience is expected to vary across individuals, at a minimum, as a function of color perception variation (e.g., dichromats' hue dimensions differ compared to trichromats). Despite considerable observer group variation in a given population, uniformly shared cognitive dimensions that are similarly experienced across observer types do exist. These are brightness and saturation, and, to a lesser extent, hue.

Evidence of the robustness of brightness and saturation over hue in naming-tasks is provided by Jameson and Alvarado (2003b) and Alvarado and Jameson (2002). They demonstrate empirically that despite observed differences between Vietnamese and English in terms of modifier use and monolexemic color naming, both language groups showed similar mappings for "light" and "dark" modifiers, and for saturation modifiers (i.e., glosses for "bright," "fresh" and "moderate"). This shows that the brightness and saturation lexical mappings agree in Vietnamese and English, whereas hue term mappings do not.

The IDM differs from most color-naming theories by its emphasis on brightness and saturation, and a secondary emphasis on hue. This de-emphasis of hue is indirectly supported by results showing large average "foci" variation across cultures, and an unsupported linkage between opponent color unique hue positions and "foci" (Kuehni, 2005b). In addition, D'Andrade and Egan (1974) showed that brightness and saturation are more cognitively salient than hue. MacLaury (1992, 2005) argued that brightness is essential in the partitioning of some languages. A de-emphasis of hue, subordinate to brightness and saturation dimensions, is compatible with existing explanations for observed yellow/green and yellow/green/blue category partitions (Casson, 1997, Casson & Gardner, 1992). Gellatly (1995) reviews other sources supporting the present emphasis of brightness and saturation. These findings support the suggestion that while hue categories and best exemplars may vary cross-culturally, brightness and saturation may be linguistically represented more consistently across languages. One reason for this may be that compared to hue they are simpler dimensions (as discussed earlier).

Note that while the IDM identifies brightness and saturation as strongly universal cognitive dimensions for color space partitioning, the framework does not exclude possible variations on brightness and saturation partitioning. For example, warm/cool partitions are seen in a number of societies and may naturally arise as an approximation to a brightness partition, or as a partition arising from the dual application of the brightness and saturation dimensions. By IDM theory such a partition may be expected early in a society's color lexicon development, prior to the separate differentiation of polarity for the brightness and saturation dimensions. Given the prevalence of warm/cool partitions cross-culturally, it may reflect a popular alternative to initial partitions of brightness and saturation dimensions. For languages with warm/cool distinctions, the framework aims to separately model such lexicons from those with initial lightness dimension partitions.

Also note that the IDM allows partitioning of shared culturally-salient dimensions as naturally as those perceptually based cognitive dimensions described above. Some of these are described in the next section.

Cognitive processing and shared color-naming systems. Davidoff suggests that judgments of color naming and color appearance are based on distinct cognitive mechanisms (Davidoff, 1991). Neurophysiological evidence supporting the existence of distinct representations is found in populations with selective deficits for either color naming or color perception, whose capacity for color processing nevertheless remains unimpaired (e.g., Roberson, Davidoff & Braisby, 1999, Chao & Martin, 1999). Cases of color anomia exist where individuals can discriminate colors but not name them. In such individuals color naming is apparently dissociated from the perceptual representation of color (Davidoff 1997, Davidoff & Ostergaard 1984, Davidoff 1991). In studies of unimpaired subjects' categorical perception of color it has been shown that although both visual and verbal codes can be employed in color recognition memory, categorical perception is only found when subjects made use of verbal coding (Roberson & Davidoff 2000). Based on these results, Roberson and Davidoff suggest that categorical color perception primarily requires verbal codes. Such studies demonstrate instances where color perception is dissociated or represented independently from color semantics, which is consistent with the separate cognitive representations proposed earlier.

Culturally Specific or Pragmatic Influences

A considerable literature exists on the pragmatic aspects of individual linguistic processing and human communication (e.g., Morris 1946, Grice 1957, 1989, Lewis 1969). Such research presents the idea that lexical coding systems, in part, develop with an aim of effective communication. This work supports the present framework's emphasis on color lexicons as efficient communication codes, and the practice of *linguistic-charity* in discourse. Efficient shared color-naming arises from a culture's communication pragmatics. In addition to language pragmatics, a large number of studies report culturally-specific influences on color-naming (cf. Saunders & van Brakel, 1997).

Pragmatic and culturally defined dimensions. Compatible with the warm/cool dimensions mentioned above, the IDM permits partitioning of color appearance space based on dimensions that are strictly pragmatic or culturally defined. Culturally specific influences and dimensional biases are seen in many cultures (Jameson, 2005a). For example, Roberson (2005) describes a color dimension defined strictly by an edible-to-inedible leaf continuum as the basis for Berinmo partitioning and naming of greenish and yellowish color appearances. Numerous similar examples exist. Lewis (1969) discusses language as coding conventions, and color-naming is just one such conventional system. Critics argue that pragmatic or culturally specific dimensions are less compelling compared to those derived from color perception, but there is no inherent reason why such pragmatic dimensions could not serve equally well, or additionally, as a basis for color lexicon development. That a number of languages use pragmatic dimensions is justification for studying these alternative ways of color space partitioning. The framework accommodates color space partitioning on the basis of cultural dimensions because the empirical data suggest they play an important role in many languages. For cases where several societies emphasize the same pragmatic or social dimension (e.g., *freshness-to-dessicatedness* in some cultures), IDM dimensional analyses may reveal these as plausible alternative cognitive universals for color-categorization and naming.

Linguistic structure. Recently Davidoff, Davies, Roberson (2000) and Roberson (2005) empirically demonstrate that invariance of color-naming response is strongly associated with language structure, and they emphasize a need for research to acknowledge linguistic relativity in color naming. They argue that linguistic structure and language processing are not properly considered in the widely accepted approaches to color-naming and are indeed a large component (if not the main component) affecting color naming systems across cultures.

As mentioned earlier, Jameson and Alvarado (2003b) demonstrate the effects of culturally specific linguistic structures on color naming. In addition, they empirically show that Boynton and Olson's (1987) results support the salience of specific category exemplars as universally mapped to basic color terms, occur only under the empirical constraint of a monolexemic naming paradigm, and disappear when the monolexemic constraint is removed. While monolexemic color names were originally emphasized by Berlin and Kay's theory (and have been prevalent in color naming research due to their methodological simplicity), they do not represent the lexicon-to-appearance mappings found in the context of everyday communication in some languages. For example, Vietnamese, and other languages which rely heavily on modifier use as a general linguistic construction, appears to use more modifiers in conjunction with basic-color stem terms (see Alvarado & Jameson 2002, Jameson & Alvarado 2003b).

By organizing and modeling cross cultural color naming as phenomena shaped by several different influences (i.e., dimensions emphasized, pragmatics, linguistic constructions common to each language, etc.), the framework permits the identification and explanation of commonalities that may occur at some levels (e.g., dimension emphasized) even though two culture's color naming systems may differ strictly due to varying features in the two culture's languages (i.e., a tendency for high use of *modifier+stem* constructions versus a low-use tendency). Formulated in this way, different influences can be empirically assessed for their contribution to cross-cultural universality.

Category complexity. Based on efficiency principles from Information Theory, color categories should not vary considerably in complexity across color appearance space. In an efficient code, encoded concepts are distinct, general and carry relatively unambiguous semantic values.

When two or more lexical items are similarly complex and regularize the distances between encoded exemplars, this improves the likelihood that semantic confusions will be reduced when speakers of the language use the code to converse about color.

Thus, irregularly shaped categories should not co-exist in a system with otherwise regularly shaped categories. The IDM would not predict a partition of a single, large, salient category which spanned color regions glossed by appearances of, say, *Black, Brown, Red, Orange* and *Yellow*, co-existing with several smaller but categorically distinct salient category partitions each glossed by category labels *Indigo, Blue, Aqua, Turquoise, Green*, and *Chartreuse*. Such color space structures would not represent an efficient lexical encoding of the stimulus space (Garner, 1974). Asymmetric mappings of lexicons to stimuli of the sort just described are not often found in the world's languages, except when highly idiosyncratic pragmatics effect color salience (i.e., the unique color of a highly poisonous food).

Distribution of observer groups in a society. Observer types (dichromat, trichromat, etc.) have been found to vary in frequency within different cultures. Such variation in observer group frequency raises another potential cross-cultural influence on color-naming. If a society's shared color-naming system depends on the members of the community, and that community is highly heterogeneous with respect to individual color perception abilities, then (all else being equal) the color-naming system will likely differ from that of a community of homogeneous individuals. For an expansion of this idea see Jameson's (2005) comment on Steels & Belpaeme (2005). Further, if some members of society have greater social influence, then these member's naming behaviors can exert a stronger influence on the shared color-naming norm.

One example of impact possible from inherited perceptual abilities is described by Oliver Sacks in *The Island of The Color Blind and Cycad Islands* (Sacks 1997). Sacks reports on a population from the Caroline Islands in Pacific Micronesia. He describes cultural practices and "color-naming" in a society in which many individuals share monochromacy or congenital achromatopsia. The consequences of this photopic vision defect are extreme sensitivity to light, color blindness and very poor visual acuity. Appropriately, emphases in achromotopic "color-naming" include elaboration on descriptors for shadows and lights, dull and shiny finishes, qualities of transparency, and visual texture. Such emphases resemble the pragmatic specialization seen in the color naming of livestock-based societies with typical frequencies of normal trichromats and anomalous observers. Thus, Sack's achromatopes dramatically illustrate that cultural practices (e.g., night fishing) and cultural artifacts (e.g., color-naming systems) adapt to accommodate perceptual phenotypes.[14]

Steels & Belpaeme (2005) present computer simulation results for artificial societies of agents learning to categorize and name color. They imply that *non-random* variation in the distribution of observer types in a society is likely to give rise to different paths, and different equilibria, for developed color-naming systems (see Jameson 2005b). By analogy, color-naming systems from different human societies comprised of homogeneous observer groups might be expected to evolve different paths to stable color naming solutions, similar to that seen for societies with **systematically varying** heterogeneity of observer groups.

Cultural variation in color salience. Finally, support for the IDM partitioning principles also comes from the observed prevalence of Basic Color Terms (BCTs) in many cultures, notwithstanding enormous variation in "landmark" exemplar salience and "focal" salience across individuals and cultures. Jameson & Alvarado (2003b) tested the salience of basic color appearances and their link to basic color terms. They showed empirically that important features of the cognitive color naming-function are highly task dependent, and that the naming function does not exhibit reciprocity in the empirically derived mappings that link color appearances to the color lexicon. In a study of three language groups (monolingual Vietnamese, bilingual Vietnamese-English, and monolingual English speakers), they found that while BCTs are used most frequently to describe a wide array of color samples, they are not uniquely mapped to specific category exemplars across the groups. Further, while certain color samples show high agreement in naming for each group, the terms showing such agreement differ across the language groups tested. Several other studies have shown failures of "landmark" color salience. If color naming was simply determined by universal neural processing, or by uni-

[14] See Sacks (1997) for further description of the cultural knowledge and mythology developed by the Micronesia achromatopes.

versally shared phenomenal salience, then such failures of "foci" salience should not occur across cultures. Such failures are seen frequently when naming is assessed using methods that employ appropriately strong tests of salience constructs.

Applying the Framework to Explain Cross-Cultural Color Naming Phenomena

Typologies on Dimensional Constructs

The cognitive heuristics and principles in the present framework can be applied to color-naming systems cross-culturally to develop specific color naming theories. Specific theories (as opposed to a general theory) are necessary because the emphasis of different dimensions in different cultures will produce different category partitions.[15] The initial strategy is to group color-naming systems that appear to share similar dimensional emphases. For example, some unwritten languages clearly emphasize a warm/cool dimension, or a color space dimension representing freshness. Grouping color lexicons based on such dimensions – irrespective of differences imposed by additional, sometimes idiosyncratic, culturally relative dimensions – may lead to natural typologies of color lexicons for further comparison.

When dimensional similarities are not immediately obvious, an alternative may be to examine dimensional similarities among languages sharing common, or neighboring, "stage" designations in the Berlin, Kay, Maffi & colleagues theory (Kay et al. 1997, Kay & Maffi, 1999). The practice of classifying languages at different evolutionary "stages" groups languages with similar naming-system features and specifies color lexicons that are likely to have similar dimensional emphases. This particular use of BCT staging is not promoted by the Kay et al. theory, nor is grouping by *dimensional similarity* a discussed goal of BCT theory. By comparison, the present approach disregards the assumption of the BCT

[15] Not ruling out the possibility, however, that specific theories may themselves show general patterns.

evolutionary hierarchy as a fixed sequence, and suggests using BCT stages only as a guide for exploring the shared principles underlying grouped color lexicons.

For example, "Stage I" languages may share a warm-cool dimension (Kay, Berlin, Maffi & Merrifield 1997). "Stage V" languages seem to be differentiated from lower stages by a hue dimension emphasis. Thus, existing progress made by organizing color lexicons into stages may advance the identification of lexicons grouped by shared dimensional constructs.

Other stages of the Kay and colleagues' theory may not easily reveal dimensional emphases, because the dimensions are subtle or idiosyncratic (such as the dimensional emphases found in the nomenclature of Sacks' society of rod monochromats). The framework would predict, however, that languages with similar dimensional bases for naming will have greater similarity across their color-naming system measures (i.e., best-exemplar placement, partitioned categories, structural complexity of glossed categories, categorical perception, naming consensus, etc.) These are empirical questions that need to be addressed by applying the present framework in comparisons of existing color-naming results.

When groups of languages with common dimensional emphases are identified, it may be possible to specify, for example, a shared basis for the presence of empirically observed composite categories such as blue-green (*grue*). Moreover, as dimensional analyses become more specific within color-lexicon groups, culturally relevant dimensions may be revealed, helping to specify the extent of such cultural influences on color-naming systems. For example, different linguistic systems may include a non-differentiated grue (blue or green) category because they also rely upon liberal modification of stem terms as a commonly shared feature across languages (Jameson 2005a). Such analyses present an alternative way to investigate how color naming and categorization in languages with similar linguistic features are similarly impacted by cultural influences. Examinations of this sort permit consideration of known cultural influences – a task that is otherwise not easily accomplished using accepted models in the color-naming in the literature.

Comparisons across Grouped Languages using Framework's Heuristics and Principles

Irrespective of dimensional emphases, one prediction of the IDM and its framework is that the lexicalization of idealized color appearance space should reflect principles stated in the IDM psychological model (i.e., polar opposition, category symmetry, category area uniformity). Provided color similarity data exists for lexicons clustered in a group, this can be explored by representing each lexicon's color-categorization data in separate multidimensional scalings and evaluating the correspondence of category areas, boundaries, and best-exemplar regions. Such comparisons would improve upon analyses typically done using the Mercator projection stimulus (Kay & Regier 2003) that depicts a restricted gradient of Munsell Value and Hue dimensions, and no real Chroma gradient. In some cases, dimensional scaling solutions may require rotation when embedded in an approximation of color appearance space (e.g., a CIE L*a*b* space) to clarify patterns in the data (e.g., Moore, Romney & Hsia, 2002). Thus, after identifying language groups based on shared dimensional emphases, application of the IDM psychological model can be used to predict the optimal interpoint-distance relations for named categories and exemplars among similarly grouped naming-systems.

In theory, for each cluster of similarly grouped color lexicons there should be a general IDM solution (based on the known shared dimensions that underlie partitioning) and each language should express category boundaries and best-exemplars that approximate those seen in a general IDM solution for the group. To the degree that a specific language's IDM solution does not resemble the general IDM solution expected for that particular cluster of grouped lexicons (a group of warm/cool lexicons), then further dimensional emphases (including socio-cultural influences) should be explored.

Given sufficient dimensional analyses of this sort it should be possible to verify or disprove some of the IDM Framework's proposed cognitive universals, and demonstrate that natural variation in dimensional emphases does not undermine color-naming universals. However, in such analyses the present framework only expects to probabilistically account for existing color-naming phenomena, and predicts the existence of "special case" color-naming systems (i.e., those that are difficult to typologize and explain) as inherent in the color-naming empirical phenomena.

Conclusion

The framework and IDM presented explicitly identify universal cognitive mechanisms and socio-cultural influences impacting color categorization, and, as an approach for understanding specifics of color-naming variation, accord in many ways with existing theories. While the framework identifies universal features inherent in the phenomena, it does not provide a universal solution by which all cultures accomplish the task of labeling color appearance. Although the intended lack of specificity in this approach may be seen as a drawback, it reflects the challenge that essentially there exists no single fixed universal process, or simple basis, by which all cultures develop systems to partition and name color experiences. Nevertheless, there are a great number of different universal features inherent in the phenomena, and understanding the ways each culture employs these universal features gives the most comprehensive and reasonable basis for color naming theory.

The organizational framework and the IDM proposed here benefit greatly from existing research and theory. Some features the IDM includes were discussed by Dedrick (1997) including, communication accuracy and codability, socio-cultural pragmatics of color communication, color appearance dimensional salience (e.g., brightness, saturation and hue). The present perspective differs from existing approaches in four key respects: (1) it de-emphasizes the importance of the hue dimension (crucial in color-salience based explanations); (2) the IDM emphasizes color space area irregularities attributable to variation on brightness and saturation dimensions (previously described by Jameson & D'Andrade, 1997); (3) IDM partitioning operates from a generalizable abstraction of color appearance space (similar to Davidoff's, 1991, Internal Color Space) rather than from a specific color order system (i.e., Munsell, OSA, or other surface color space; or a CIE light mixture space); and (4) the framework differentiates the development of a culture's color naming system from the process by which individuals acquire and use a that color naming system.

The ideas presented here are not intended to replace the contemporary models of Kay and colleagues, but rather are offered as an alternative modeling framework that builds upon the observed regularities in color-naming phenomena. The IDM provides a realistic basis for explaining the prevalence of Berlin and Kay's basic color categories, as well as issues that have historically challenged BCT theory (for example, *grue* & yellow green category prevalence, individual variation, cultural contributions to naming, etc.). It also accommodates the essential contributions of culture and language that Davidoff and colleagues and other moderate cultural relativists correctly advance, as aspects of color-naming phenomena that theory must take into account. The IDM accommodates research results illustrating within- and cross-cultural variation (e.g., MacLaury 1997), and the suggestion that color similarity can alternatively be based on perceptual or language-based criteria is compatible with suggestions that perceptual and linguistic representations are distinct (Dedrick 1997, Roberson, Davidoff & Braisby 1999).

The present framework's explicit de-emphasis of the widely popular panhuman salient Hering colors as the basis for color naming universality is not a return to a culturally relativistic Neo-Whorfian perspective in which language determines perception (Whorf 1956). Rather, the proposed IDM perspective and the framework aims to reintroduce, in a substantial way, the role of culture and cognitive processing into the cross-cultural study of color naming and color categorization phenomena. The IDM perspective described accords with a cognitivist view of the products of shared cultural ideas (D'Andrade, 2001) and with the general approach of defining cultural meaning systems as shared cognitive representations (Romney, Boyd, Moore, Batchelder, & Brazill, 1996, Romney & Moore, 1998). Through these considerations, the aim has been to provide a balanced perspective that achieves a more comprehensive understanding of this complex phenomena.

In view of the considerable individual variation in color perception, cross-cultural *cognitive universals* are the most likely basis for observed color-naming universality. Such universals can be appropriately used by color naming theories as descriptive constructs, and they correct the unnecessarily narrow theoretical emphasis on panhuman uniform color phenomenology seen in existing models. Similarly, incorporating *cultural universals* as an explanatory factor in the study of color naming universality makes for more comprehensive modeling of phenomena in which different societies similarly categorize and name color.

The present account of color naming and categorization rests on a clear separation between processes that produce a culture's color lexicons, and processes by which individuals learn and reinforce color lexicon equilibria. Understanding that these aspects are distinct while shifting the explanatory emphasis as suggested here, will lead to a clearer understanding of the linkages between culture, color cognition and language, and color signal neural processing.

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