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THE INTERNAL STRUCTURE OF BASIC AND NON-BASIC COLOR CATEGORIES

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Kay & McDaniel 1978 have recently proposed a new method of distinguishing between basic and non-basic color terms, based on fuzzy set theory (Zadeh 1965). In the present paper, we report two empirical studies that test the effectiveness of the fuzzy set method for identifying basic color categories. It is found that the method fails to discriminate between basic and non-basic categories. It is argued on theoretical grounds that the method proposed by Kay & McDaniel cannot distinguish between basic and non-basic colors because its primary premise, that the two types of categories display different characteristic membership functions, is false. Some general conclusions about the structure of categories are offered.*

INTRODUCTION

1. Kay & McDaniel 1978 (hereafter K&M) have recently offered a formal model to describe color semantics and the evolution of color naming systems. The model employs the formalism of fuzzy set theory (Zadeh 1965) to describe the structure and interrelationships among categories within the color domain. The model is impressive in its ability to provide a coherent theoretical explanation for a number of disparate phenomena. The most important contribution of the model is that it provides a theoretical link between the physiology of color perception and universal semantic color categories. It also provides an excellent account of why some categories, such as GRUE, have multiple foci (hues judged as best examples). Prior to K&M's proposal, no satisfactory explanation of the phenomenon was available.

In addition, the model provides a new perspective on the nature of basic color categories. Berlin & Kay 1969 (hereafter B&K) had regarded basic categories as a set of eleven universal categories, each associated with a single focus in the color space. K&M argue that basic color categories are not all of the same type—as B&K had implicitly assumed. Rather, K&M propose that three distinct kinds of basic categories exist. Moreover, they suggest that there is no upper limit on the number of basic categories that can be encoded in a language, as B&K had presumed. K&M argue that it is merely an accident of history that no language now known possesses more than eleven basic color terms. They postulate that, as languages continue to evolve, some color terms that are presently non-basic will become basic. In addition, they argue that, at any given time, the same term may be basic for some speakers of a language and non-basic for others.

If the status of a color term as basic can vary over time and across individuals, it becomes important to develop an accurate method to identify whether or

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not a term is basic for a particular individual at a given time. K&M have proposed a procedure which, they postulate, will distinguish between basic and non-basic color terms. The method arises directly out of their fuzzy set-theoretic formalism, and has the desirable properties of being simple and straightforward to apply.

In this paper, we report the results of two empirical studies testing the validity of the method. In §2, we briefly review the criteria which B&K used to identify basic color categories. This is followed, in §3, by an overview of the K&M model of color semantics, and a description of the method they propose to distinguish basic from non-basic color terms. In §4, we present the results of two empirical studies that provide a direct test of the K&M method of identifying basic color terms. In §5, we conclude with some comments on the general nature of categories and category structure.

THE ORIGINAL BERLIN & KAY VIEW OF BASIC COLOR CATEGORIES

2. The color domain is a case where properties of the perceptual system have a powerful effect on which categories are formed. Severe constraints seem to apply both to the color categories that can be encoded by a language and the order in which the categories can be encoded.

B&K were the first to obtain evidence that the color categories encoded by a language are not arbitrary and culture-dependent, as had once been thought (cf. Gleason 1961). They studied the color naming systems in 98 languages, representing a wide range of language families. They were interested in the best examples (foci) and the boundaries of the basic color terms in each language. A term was considered basic if it met four criteria: (1) It was monolexemic. (2) Its signification was not included in that of another term. (3) Its application was not restricted to a narrow class of objects. (4) It was psychologically salient, as determined by such measures as the tendency to occur at the beginning of elicited lists of color terms, stability of reference across occasions of use, and occurrence in the idiolects of all subjects. If a particular color name met some but not all of the four requirements, then the following four additional criteria were used to determine whether the name was a basic-level one: (5) The name had the same distributional potential as previously established basic color terms. (6) A color name was suspect if it was also the name of an object characteristically having that color. (7) Recent loan words were suspect. (8) If lexemic status was difficult to assess, morphological complexity was considered.

B&K found that, while the boundaries of the basic color categories varied widely across languages, the foci were extremely similar. Across the 98 languages, the foci of the basic categories occurred in only 11 different regions within the color space. These regions corresponded to the areas where native English speakers locate the best examples of red, yellow, green, blue, black, white, orange, brown, purple, pink, and gray. B&K argued that the 11 regions where the foci occurred reflected a universal set of basic color categories.

B&K also noted severe limitations on the order in which the 11 universal color categories were encoded in a language. If a language contained fewer than 11 basic color terms, then the particular categories encoded strongly depended on the number of basic terms in the language. For example, on the available data, it appeared that if a language contained only two basic color terms, the color categories encoded would have foci corresponding closely to those of the English categories BLACK and WHITE. Languages that contained three basic color terms always encoded color categories whose foci corresponded to those of the English categories BLACK, WHITE, and RED. From such evidence, B&K argued that the evolution of color term systems involved the successive encoding of basic categories with single foci.

The conclusions of B&K have mainly been supported by subsequent work. However, the conclusion that basic color terms universally encode categories with single foci proved to be inaccurate: a number of basic color categories were reported with multiple foci. Thus Heider 1972a,b, who studied the two-term color naming system of the Dani, reported that speakers varied in where they placed the foci of the terms *mola* (white-warm) and *mili* (dark-cool). Similarly, GRUE, a term that covers the blue and green regions of the color space, appears to have two foci, corresponding to the foci of the English categories BLUE and GREEN (Kay 1975). This type of evidence led K&M to argue against the view that basic color terms reflect a set of 11 universal categories, each associated with a single focus. In addition, K&M question the assumption that color terms with similar foci reflect the same universal basic categories, even when the terms have very different extensions. They argue that an adequate model of color semantics should account for the extension of terms, as well as their foci.

THE KAY & MCDANIEL MODEL OF COLOR SEMANTICS

3. K&M have offered a detailed theoretical account of the structure and interrelationships among categories within the color domain. Their primary thesis is that color categories are strongly influenced by inherent properties of the visual system. They propose that color categories can be characterized by fuzzy set-theoretic membership functions (Zadeh), which assign to each color percept a value between 0 and 1, indicating degree of membership in the category. Basic color categories are assumed to be characterized by one of three types of membership functions. The first type is possible only for the six primary colors: red, green, yellow, blue, black, and white. The membership functions for these primary colors are assumed to be based on neuro-physiological processes. K&M provide substantial evidence that the membership functions for these primary colors correspond to neural response functions. The second type of membership function is possible for unions (combinations) of the primary colors. The membership functions for these categories follow the standard fuzzy set-theoretic definition of union: $f_c(x) = \text{Max}\,(f_{p1}(x), f_{p2}(x))$. That is, the membership value of a color percept in the color category C (formed from the union of the primary categories P_1 and P_2) will be the larger of the values corresponding to the color percept's membership in P_1 and P_2. For example, the basic color category GRUE, which occurs in many American Indian languages, is assumed to be formed through the fuzzy union of the membership functions of green and blue. Grue encompasses the color percepts in both the blue and green range, and the color typically exhibits two focal points: one near focal blue, the other near focal green. This is exactly as would be predicted by fuzzy union. The K&M model thus provides an excellent account of why the membership functions of colors like GRUE are bimodal.

A third type of membership function is formed by intersections of the primary colors. K&M note that the standard definition of intersection in fuzzy set logic is $f_c(x) = \text{Min}\ (f_{p1}(x), f_{p2}(x))$. That is, the membership value of a color percept in C is equal to the smaller of the values corresponding to the color's membership in P_1 or P_2. The standard fuzzy set intersection function is shown in Figure 1a. However, for two reasons, K&M consider this definition inappropriate for basic color terms which are derived from the intersection of primary colors. First, the definition has the result that no good examples of derived categories exist. Second, the definition implies that there is no hue sensation with a higher degree of membership in the category formed by the intersection than in the primary colors that intersect to form the new category. Thus in the case of orange (which is assumed to be derived from the intersection of red and yellow), the standard fuzzy intersection definition predicts that (1) no hue will be a really good example of orange, and (2) all hues that are examples of orange will be as good (or better) examples of both yellow and red. K&M argue persuasively that (derived) basic color categories formed by intersection of primary categories do not exhibit these properties. Therefore they propose that the correct membership function for basic color categories requires a scalar multiplication of the function produced by the operation of fuzzy intersection. Figure 1b shows the membership function for a category formed by intersection, after scalar multiplication is applied. For example, the membership function for orange (including scalar multiplication) is assumed to be $f_{orange}(x) = 2[\text{Min}\ (f_{red}(x), f_{yellow}(x))]$. Scalar multiplication is necessary in order to raise the degree of membership in the intersection category so that at least one color percept exists with a higher membership value in the intersection category than in either (any) of the categories that form the intersection.

K&M argue that, while the function obtained using the standard fuzzy set operation of intersection does not adequately model the membership function of derived basic color categories, it is a more accurate model of the membership function of non-basic categories. Specifically, K&M state that it is possible to have a continuum of membership functions for derived categories. One end of the continuum is marked by the standard fuzzy set definition of intersection; the other end is marked by the scalar multiplication function just described. Operationally, K&M consider a color category to be non-basic if all color percepts having a positive degree of membership in the derived category have at least as high a membership value in one of the primary categories from which the color is derived. For example, *lime* would be a non-basic color term if all color percepts that were examples of lime were as good (or better) examples of either yellow or green (the primary categories from which lime is derived). Otherwise, the derived category is considered basic.

If this analysis is correct, then basic and non-basic derived color categories

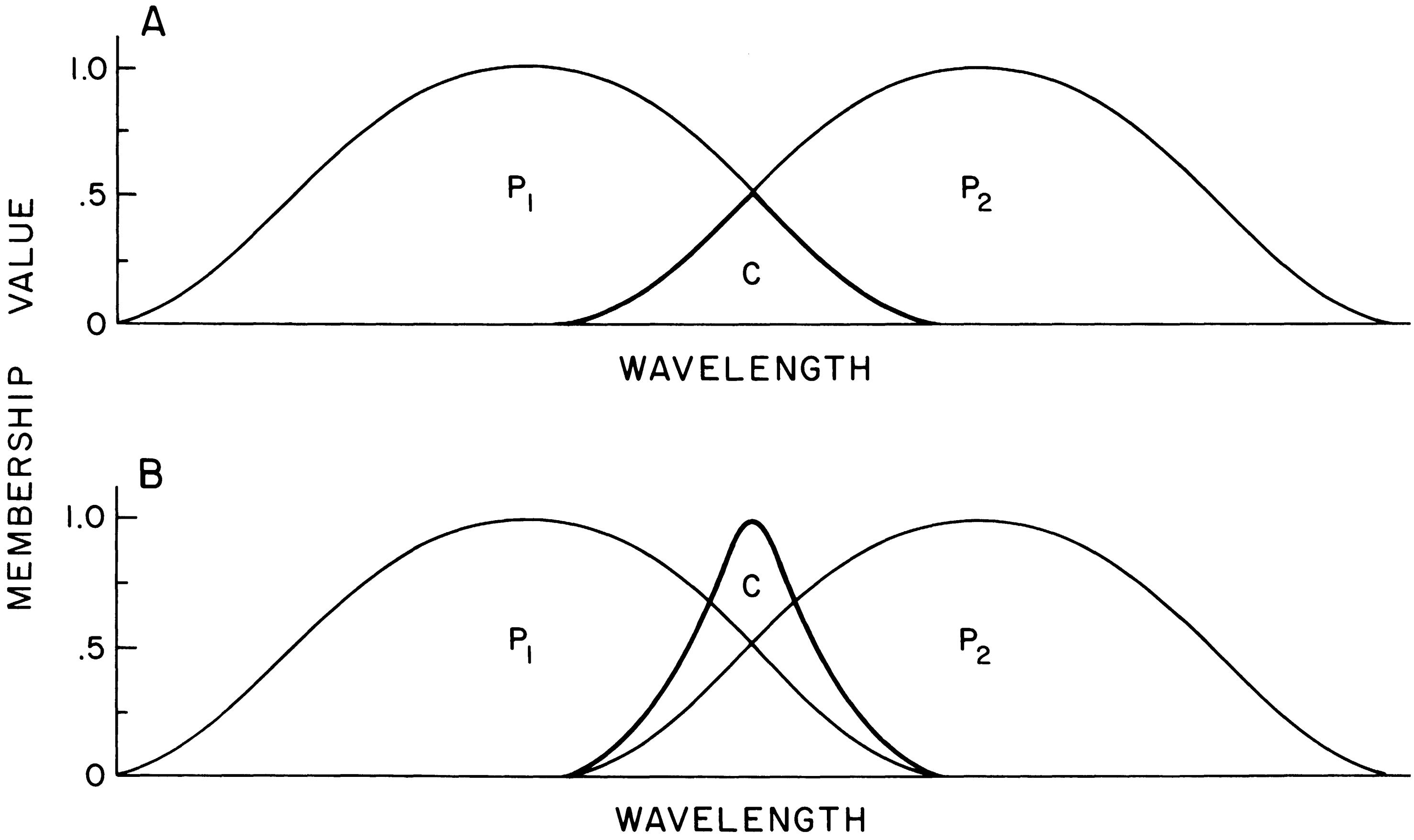

FIGURE 1. Theoretical membership function for category C formed by intersection of two primary colors P_1 and P_2. Figure 1a shows the standard fuzzy set membership function. Figure 1b shows the membership function after scalar multiplication has been applied.

have different characteristic membership functions; it should therefore be possible to determine whether a category is basic by examining its membership function. As K&M note (636), the question of whether a color category is basic reduces to the question of whether the category contains at least one member which has a higher membership value in the derived category than in either (any) of the primary categories which intersect to form the derived category. If there is such a member, then the category is basic; if not, then the category is not basic. That is, C, defined by the intersection of P_1 and P_2, is basic if and only if there exists at least one X such that $f_c(x) > \text{Max}\ [f_{p1}(x), f_{p2}(x)]$.

FUZZY SET LOGIC AND THE DETERMINATION OF BASIC COLOR TERMS: AN EMPIRICAL STUDY

4.1. APPLICATION OF FUZZY SET LOGIC METHOD. This analysis suggests a simple method by which to determine whether a color category is basic. One first needs to elicit the best example of the category of interest. Then the set of primary categories which intersect to form the category is established. To determine whether the category is basic, it is then only necessary to compare the membership value of the best exemplar in the category of interest to its membership value in the primary categories. The category of interest is basic if the best exemplar has a higher membership value in that category than in any of the primary categories that form the intersection.

If this fuzzy set logic method were an accurate predictor of basic color terms, it would be a valuable tool. The method is simple, and leads to a clear decision as to whether a color term is basic for a given individual. Moreover, it could be used to determine whether a color term is basic in cases where B&K's criteria for a basic term lead to inconclusive results. The fuzzy set method would be particularly useful in cases where a color term was basic for some speakers of a language but not others, since the method does not rely on the lexemic status of a term to determine if it is basic.

Unfortunately, K&M do not provide strong evidence to support the validity of the method. They provide no theoretical arguments for why a difference in characteristic membership function should be expected between basic and non-basic color categories. They suggest their method as a valid indicator of basic color categories on the assumption that an empirical relationship exists between whether a color term is basic and the type of membership function it displays. The success of the method relies entirely on the existence of such an empirical relationship. Since K&M provide little empirical evidence for such a relationship, the validity of the fuzzy set logic method of predicting basic color categories remains largely untested.

We decided to make an empirical test of the fuzzy set method, for two reasons. First, as stated above, the method could potentially aid in distinguishing basic from non-basic colors. Identifying which color terms are basic for a speaker is important. Basic colors are psychologically salient categories, and appear early in language acquisition, both synchronically and diachronically (B&K; Rinsland 1945). Second, the method makes an interesting claim about the nature of categories. K&M hypothesize that the membership function for non-basic colors assigns to all exemplars of the color a lower membership value in that category than in one of the primaries. This implies the existence of categories whose members all have a higher membership value in some other category—an interesting possibility, from a theoretical perspective.

4.2. METHODS OF ESTIMATING DEGREE OF MEMBERSHIP. To apply the fuzzy set logic method, a measure of degree of membership had to be selected. We chose to approximate the membership function for color categories with a goodness-of-example measure. In this section, we first explain why this measure was chosen. We then describe three alternative measures, and explain why they were not used.

Goodness-of-example is measured by having people rate, usually using a 7-point scale, different exemplars in terms of how good an example of the category they are. The ratings result in a graded distribution of goodness-of-example from best to worst example. For a number of reasons, we chose to use a measure of goodness-of-example to approximate degree of membership. First, although K&M specify no method for measuring degree of category membership, their examples of linguistic indicators show that they believe that degree of category membership is reflected by judgments of how good an example is of a category, or how representative the example is. Thus K&M equate being judged 'the best example of x' with having the highest degree of membership in the category x (623). Similarly, they argue that judgments of whether a color percept is a better representative of one category than of another reflect relative degree of membership in the categories (636). Consequently, a direct measure of goodness-of-example should reflect degree of membership.

In addition, goodness-of-example distributions have a number of desirable properties. One of the most important characteristics of the goodness-of-example function is that it provides an approximately continuous function from best exemplar to worst exemplar; this is in keeping with the type of membership function proposed for fuzzy categories by Zadeh (p.c.)

Three obvious alternative methods exist for measuring degree of membership, each of which has serious drawbacks. One method is to use hedge statements (Lakoff 1973). Participants are asked to select a hedge that describes how they feel an item is related to a category term. Their responses are then converted to numerical values which indicate degree of category membership (see Kempton 1978). This method allows a relatively continuous grading. However, the numerical values assigned by the experimenter are unlikely to give an accurate reflection of the membership values intended by the participants, particularly since the ordinality of the hedges is not reliable across individuals.

An alternative measure is dichotomous judgment: the elicitation of a 'yes' or 'no' response to the question 'Is X [color chip] Y [color name]?' Since dichotomous judgments are discrete, this function is not in the spirit of fuzzy logic, nor does it fit with K&M's suggestions. Dichotomous judgments could be used to approximate a continuous function, by combining judgments either across occasions or across participants. However, for the better examples the resulting function is less continuously graded (see McCloskey & Glucksberg

1978) than a function based on goodness-of-example. An additional problem with dichotomous judgments is that, when an item is judged as belonging to more than one category, it is impossible to determine the item's relative degree of membership in the different categories.

A third alternative measure is elicited naming. Participants could be asked to name each of the relevant color chips. Naming could be made to approximate a continuous function in the same manner as described for dichotomous judgments. However, a serious problem exists with elicited naming: since each color would be given only one name, no color could be assigned simultaneously to two categories. This means that, for any color chip that is a very good example of one category and a relatively poor example of another, it is likely that the chip would always be named by the category in which its goodness-of-example was better. Therefore this measure will often not detect category membership when goodness-of-example is very low.

4.3. THE EMPIRICAL STUDIES: STUDY 1. The purpose of our first study was to provide a direct test of K&M's method of identifying basic colors. This entailed testing the claim that any color percept judged an example of a non-basic color category should be judged at least as good an example of one of the primary color categories from which it was derived. We examined whether the method accurately distinguished basic from non-basic colors, for sets of terms for which we had a clear idea, based on other criteria, of whether the colors were basic (cf. §2).

4.31. PROCEDURE. To make these comparisons, it was first necessary to determine the best examples of each of the categories to be tested. Best-example judgments were elicited in the same manner used by B&K (except that a neutral gray background was used) and by Mervis et al. 1975. Each of the ten participants was shown the standard Munsell array of 329 color chips (40 hues by 8 brightness levels, plus a 9-chip achromatic series), and was asked to think of his idea or image of the best example of the color term to be judged, and then to point to the color chip that came closest to that idea or image. He was then asked to make second, third, and fourth choices. (If a participant did not think there were four good exemplars available, he was allowed to choose fewer.) Participants were asked to indicate if they were unfamiliar with any of the color terms. Each participant was asked to make best-example judgments for 22 color terms. These included the 11 basic terms that B&K had identified (black, white, red, green, yellow, blue, brown, purple, orange, pink, gray) and 11 additional terms that were considered non-basic according to B&K's criteria (peach, gold, jade, lime, turquoise, navy, violet, lavender, burgundy, maroon, rose). In this and in all subsequent studies, the Dvorine pseudo-isochromatic plates were used to screen participants for color blindness.

The three best examples of each color were determined, based on the participants' choices.[1] For each of B&K's basic color terms, good agreement was

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[1] The three best examples of each color category were chosen as follows. The chips selected as first or second best example by at least one person were determined. For each of those chips, the total number of people who chose the chip as one of their four choices was computed. The

found among participants as to which chips were most representative. Choices also corresponded closely to those made in the study of Mervis et al. Agreement on the best examples of seven of the remaining categories (peach, lime, navy, violet, lavender, burgundy, maroon) was also high. For the other four categories (gold, jade, turquoise, rose), agreement was low.

Based on the results of this preliminary study, eight of the putative non-basic color terms were selected for use in the main study. The three colors eliminated were jade (because disagreement on best examples was extremely high) and violet and maroon (because the best examples of these two categories corresponded to the best examples of purple and burgundy respectively). Four basic color terms were also included: green and blue (primary colors) plus orange and purple (non-primary colors).

Each of the 12 color terms was tested using a separate 9-chip array. The array consisted of the three best examples of the target category and the three best examples of the two basic color terms (according to B&K) immediately adjacent to the target color.[2] The colors included in each array are listed in Table 1. The nine chips were arranged randomly in a 3 × 3 matrix, with one inch between adjacent chips.

Target color	Other two colors on board		Colors tested but not on board	
			Chromatic	Achromatic
peach	red	orange	yellow	white
gold	orange	yellow	red	white
lime	yellow	green		white
turquoise	green	blue		white
navy	blue	purple	red	black
lavender	blue	purple	red	white
burgundy	red	purple	blue	black
rose	red	pink	blue	white
green	yellow	blue		
blue	green	purple	red	
orange	red	yellow		
purple	red	blue		

Table 1. Color terms tested in Study 1.

Each of the 20 participants was asked to make goodness-of-example judgments for each of the 12 boards. Participants were asked to rate each chip on a board in terms of how good an example it was of the target category and of each of the two adjacent basic color categories. If one of these categories was not a primary color, the chips were also rated for goodness-of-example in the

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three chips with the highest sums were considered the three best examples of the category. The criterion that at least one person should choose the chip as the first or second best example of the category was used to insure that the chips selected as best examples of the colors were considered the very best examples by some people. Nevertheless, 44 of the 45 chips selected using this criterion would have also been chosen had selection been based solely on the total number of people who included the chip as one of their four choices.

[2] The Munsell notations for the color chips used in all the studies reported here may be obtained from the authors.

closest primary color. For the putative non-basic colors, the chips were also rated for membership in either white (light hues) or black (dark hues). The color terms for which goodness-of-example judgments were obtained are listed in Table 1, separately for each board.

Participants were asked to use a 7-point scale in making their goodness-of-example judgments. A '1' indicated that the chip fit the participant's idea or image of the color named by the experimenter extremely well; a '7' indicated an extremely poor fit. Participants were told to say 'not a member', rather than indicating a number, if they felt that the chip was not an example, in even the slightest degree, of the named color. The boards were presented individually, in a different random order for each participant. Each time a board was presented, the participant was asked to rate each chip for membership in one of the color categories listed in Table 1. Thus, each board was presented once for each category to be tested. For example, the 'lime' board was presented four times: once for ratings for lime, once for yellow, once for green, and once for white. The order of ratings for each of the colors for a given board varied randomly across participants.

After the participant had completed all the goodness-of-example ratings, each of the 12 boards was presented again, one at a time. The experimenter pointed, one at a time, to the chips that the participant had given the lowest (best) goodness-of-example rating for each of the color terms tested for that board. For each chip, the participant was asked to choose which color term the chip best exemplified. (E.g., for *lime*, the participant was shown four chips: the ones he had rated as most representative of lime, yellow, green, and white respectively. For each chip, he was asked whether it was a better example of lime, yellow, green, or white.) These judgments were included in order to elicit directly ordinal judgments of typicality of the chips as examples of the different color terms.

4.32. ANALYSES AND DISCUSSION. In order to consider whether the color categories studied met K&M's criterion for basicness, we examined our data in three different ways. All three analyses indicated that virtually all the colors tested met K&M's criterion. We first examined the goodness-of-example ratings we had obtained, to determine whether the chip which received the lowest (best) rating for the target (tested) category was considered a better member of that category than of any (other) primary category. If a category met that criterion, then K&M would consider it to be basic. The data relevant to this test are presented in Table 2. Note that, for all the categories, almost all participants indicated that the best example of the target category was a better example of that category than of any (other) primary category. In order to test the data statistically, we performed a separate sign test for each color, comparing the number of participants whose data met K&M's criterion ('Target better' in Table 2) to the number of participants whose data did not meet this criterion ('Other better' and 'Both equal'). For all the colors except navy, significantly more participants met K&M's basicness criterion than would be expected by chance ($p < .05$).

Target color	Rating patterns[a]		
	Target better	Primary better[b]	Both equal[c]
peach	20	0	0
gold	17	2	1
lime	17	1	2
turquoise	16	2	2
navy	12	0	8
lavender	19	0	1
burgundy	15	0	5
rose	18	2	0
green	20	0	0
blue	20	0	0
orange	20	0	0
purple	20	0	0

Table 2. Goodness-of-example rating patterns for 12 color categories: Target vs. all other primaries.

[a] Numbers indicate how many participants (out of 20) provided judgments which fit the particular pattern.

[b] 'Primary better' indicates that the best example of the target category was rated a better example of one of the (other) primary categories tested.

[c] 'Both equal' indicates that the best example of the target category was rated as an equally good (but not better) example of one of the (other) primary categories tested.

We then formulated a revised version of K&M's criterion. According to this version, a color is considered basic only if its best example is considered a better example of itself than of any other basic color (as determined by B&K—including the basic colors that are not primary). This formulation imposes more severe constraints on which colors can be basic. It might result in fewer colors being considered basic, which would make the results conform better to our intuitions that few (if any) of the additional eight terms are in fact basic. The data relevant to this formulation are presented in Table 3. With the exception

Target color	Rating patterns[a]		
	Target better	Other better[b]	Both equal[c]
peach	20	0	0
gold	17	2	1
lime	17	1	2
turquoise	16	2	2
navy	12	0	8
lavender	17	0	3
burgundy	15	0	5
rose	14	4	2
green	20	0	0
blue	20	0	0
orange	20	0	0
purple	20	0	0

Table 3. Goodness-of example rating patterns for 12 color categories: Target vs. all other colors.

[a] Numbers indicate how many participants (out of 20) provided judgments which fit the particular pattern.

[b] 'Other better' indicates that the best example of the target category was rated a better example of one of the other categories tested.

[c] 'Both equal' indicates that the best example of the target category was rated as an equally good (but not better) example of one of the other categories tested.

of the data for rose, both formulations of the criterion yield virtually identical results. We performed the same type of statistical tests as just described for K&M's original criterion. For all colors except navy and rose, significantly more participants met the revised criterion than would be expected by chance ($p < .05$).

For the third analysis, we considered the ordinal data that we had collected at the end of our experiment. Because of the nature of our data collection procedures, we were only able to test the data using the revised formulation. (Note that any color which is basic according to the revised formulation would also be basic according to K&M's original formulation.)[3] This analysis is important because ordinal data provide the most direct test of K&M's hypothesis. The relevant data are presented in Table 4. We again analysed the data using sign tests. For all colors except rose, significantly more participants met the revised criterion for a basic color than would be expected by chance ($p < .05$).[4] Although we cannot test K&M's original criterion directly, we expect that rose would have met that criterion for basicness, since almost all the 'other better' responses were claims that the chip was a better example of pink (which is not a primary color) than of rose.

TARGET COLOR	RATING ORDER[a]	
	TARGET BETTER	OTHER BETTER[b]
peach	19	1
gold	18	2
lime	18	2
turquoise	17	3
navy	16	4
lavender	18	2
burgundy	18	2
rose	12	8
green	20	0
blue	20	0
orange	20	0
purple	19	1

TABLE 4. Ordinal goodness-of-example judgments for 12 color categories. Ratings are for the best-example chip of the target category.

[a] Numbers indicate how many participants (out of 20) provided judgments which fit the particular pattern.

[b] 'Other better' indicates that the best-example chip for the target category was considered a better example of some other color category.

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[3] Our ordinal data could not test the K&M formulation independently from the revised formulation, for the following reason. When participants were presented with the chip they had chosen as the best example of the target category, and were asked to indicate which color term it best exemplified, they could select one of three types of terms: the target color, a primary color, or a non-primary basic color. If they selected the target color, then the target category was basic according to either formulation. Similarly, if they selected a primary color, then the target color was non-basic according to either formulation. It was only in the third case that the status of the target color was indeterminate in relation to the K&M formulation. When a participant indicated that the chip best exemplified a non-primary basic color, no information was provided as to whether the chip better exemplified one of the primary colors than the target color. Since this is the relevant

The results of our analyses indicate that all twelve color categories studied, including the eight color categories classified as non-basic by B&K, display membership functions that are characteristic of basic categories within the K&M framework. In Figure 2, we present a graph of the estimated membership

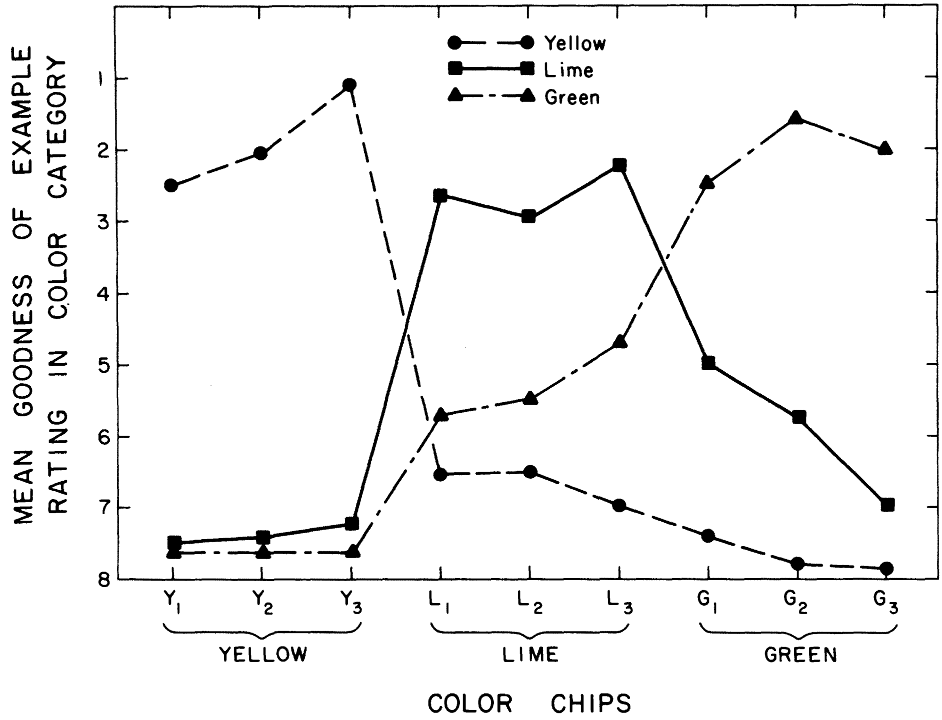

FIGURE 2.

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information by the K&M formulation, the response does not provide enough information to determine the status of the target category relative to the K&M formulation. The response does make the category non-basic, however, according to the revised formulation.

[4] We argue from the rating data that participants consider the chip that best exemplifies a non-basic color term to be a better example of that non-basic color than of any basic color. We base our argument on the fact that participants gave the chip a lower (better) goodness-of-example rating when judging it as an example of the non-basic color than when judging it as an example of a basic color. However, an alternative interpretation is possible: it may be that the participants were rating the chip relative to the other chips on the board. If this were the case, then the result that participants gave the chip a higher rating when judging it as an example of a basic term could have occurred because there were chips on the board that were better examples of the basic term (but no chips that were better examples of the non-basic term). Although the instructions urged participants to judge each chip in relation to the color category as a whole, rather than relative to the other chips on the board, the possibility of such a context effect on the rating task cannot be entirely ruled out. However, the ordinal data are not subject to this kind of context effect; they provide direct and unambiguous evidence that the participants in the study believed that the chip that best exemplified a non-basic color was a better example of that color than of any basic color. Thus the ordinal data support the interpretation we give to the rating results. In addition, the results of Study 1A provide further support for the conclusions drawn from Study 1. Those results are completely free from context effects, since in Study 1A the chips were presented one at a time.

function for 'lime', based on our data. This estimated membership function clearly resembles the membership function characteristic of basic colors (see Fig. 1b). K&M therefore would consider all these categories to be basic. Intuitively, however, we feel that only the four categories that B&K described as basic (green, blue, orange, purple) are actually basic.

In support of our intuitions, consider how the eight categories that we think are non-basic fare when tested according to B&K's original criteria for basicness. All meet requirements 1 and 3 (monolexemic label; use not restricted to a narrow class of objects). To determine whether the signification of these colors is included in any other color categories (criterion 2), the category judgments for the 20 adults in Mervis et al. were examined. Judgments were obtained for B&K's suggested basic terms. We believe that these judgments indicate that the significance of lime would almost always be included in green; that of navy would almost always be included in blue; and that of rose would almost always be included in pink. Further, the significance of peach and of gold would frequently be included in either yellow or orange, and that of lavender would frequently be included in purple. Only the significance of turquoise and burgundy would rarely be included in other color categories. Thus most of the colors do not meet the second criterion. The fourth criterion is that the category should be psychologically salient. One suggested measure of psychological salience is frequent and early appearance in elicited lists of color terms. When adults are asked to list color terms, B&K's 11 basic colors are named much more frequently than the additional eight terms we tested (see Battig & Montague 1969). Thus the eight additional colors appear to be less salient than B&K's 11 basic colors. Since the eight additional colors do not meet all of B&K's ideal characteristics, their four additional characteristics must be considered. All eight colors meet criteria 7 and 8; none is a recent loan word, and the morphological status of the terms clearly argues that they are monolexemic. We will not discuss criterion 5, since people's intuitions about the relationship of the distributional potential of the color terms under consideration, relative to that of the original 11 basic terms, undoubtedly vary widely. However, seven of the eight terms clearly do not satisfy criterion 6; all except lavender are also names for entities which characteristically have that color.

4.33. Study 1A. According to B&K's criteria, then, none of the eight putative basic colors are actually basic. One might, of course, argue in response that B&K's criteria are incorrect, and that we should therefore consider only K&M's criterion when deciding whether a category is basic. In reply to this suggestion, we offer data concerning two additional color terms: forest green and olive green. It is immediately obvious that neither of these colors meets B&K's criteria for basicness. Further, we think it intuitively obvious that any reasonable criterion for basicness should not yield these two colors as basic. In order to determine whether these two colors met K&M's criterion, we performed the simplest test possible. Sixteen adults were shown the best example of each of the two non-basic colors, one at a time. They were asked to rate each chip in terms of how good an example it was of the color green and of the appropriate non-basic color. The instructions were similar to the ones used in Study 1. Both the order in which the two chips were presented and the order in which the color terms were given was counter-balanced across participants.

As can be seen from the results presented in Table 5, virtually all the participants answered that the chip better exemplified the non-basic color being tested. This result clearly indicates that non-basic colors will be considered 'basic' according to K&M's criterion. The trend we are observing, in fact, implies that virtually every color will be considered basic according to K&M's criterion. This finding will be discussed further in our concluding section.

TARGET COLOR	RATING PATTERNS[a]	
	TARGET BETTER	GREEN BETTER
Forest green	13	3
Olive green	14	2

TABLE 5. Goodness-of-example rating patterns in Study 1A.

[a] Numbers indicate how many participants (out of 16) provided judgments which fit the pattern.

In summary, we have found that K&M's proposed method for distinguishing basic from non-basic color categories does not in fact distinguish the two types. This conclusion should not, however, detract from the major contribution which K&M have made to other aspects of color categorization. Two very important contributions are the formal description of color categories as continuous, rather than 3-valued (focal, non-focal, non-member), and the first theoretically interesting description of the structure of (diachronically) early color categories such as GRUE.

4.4. THE EMPIRICAL STUDIES: STUDY 2. In discussing the results of our first study, we argued that, even though all the colors we tested met the K&M criterion for basicness, only those originally identified by B&K as basic should be considered basic. The argument was based on two facts: (i) the additional colors we examined severely violated the B&K criteria; and (ii) it was intuitively obvious that many of these colors were not basic. The purpose of Study 2 was to gather independent, converging evidence that the B&K basic color terms are psychologically more salient than the additional terms we studied.

In Study 2, we examined two ways in which the basic color categories identified by B&K are treated differently from other color categories: ordering of color terms in hedge statements (e.g., loosely speaking, x is y) and use of one color as a reference point for another color (How similar is color x to color y?) These tasks were selected because they have been shown to reveal differences in the psychological salience of stimuli. Stimuli that are prototypical or otherwise psychologically salient tend to be placed in the Y (reference) slot of a hedge frame (Rosch 1975). In addition, subjective similarity between stimuli tends to be greater when the more salient stimulus is used as the reference point (Rosch 1975, Tversky 1977). Following B&K, we hypothesized that basic color categories should be psychologically more salient than non-basic ones. Consequently, we predicted that the basic terms identified by B&K should dominate the other terms in both these tasks. For hedge statements, the basic color should be assigned to the Y (dominant) slot. For the reference-point task, we predicted that pairs of colors should seem subjectively more similar when the non-basic color was compared to the basic (reference point) than when the basic color was compared to the non-basic (reference point).

4.41. PROCEDURE. In Study 2, we considered five of the eight non-basic color categories examined in Study 1: peach, lime, navy, lavender, and burgundy. Gold and rose were excluded because no color chip was rated as a good example of the color (mean goodness-of-example less than 3) in Study 1. (Note that this problem is caused by the array of color chips used, rather than by the nature of the particular color categories.) Turquoise was excluded because it would have been necessary to pair turquoise with blue, and navy had already been paired with blue (see Table 6).

We were interested in the dominance relations between these five target color terms and the five basic terms most similar to them. For each of the five target colors, a pair of color chips was selected. The pair included the best example of the target category and the best example of the basic color category that was most similar to the target category. The best examples were selected based on the goodness-of-example ratings obtained in Study 1. The pairs of colors used in Study 2 are listed in Table 6.

TARGET	EXPECTED DOMINANT
peach	orange
lime	green
navy	blue
lavender	purple
burgundy	red

TABLE 6. Color pairs tested in Study 2.

All 20 of the participants completed the reference-point task before the hedges task—because we felt that prior participation in the hedges task might bias the results of the reference task, but not vice versa. For the reference-point task, participants were required to make two sets of judgments: how similar the target color was to the basic color, and how similar the basic color was to the target color. In both instances, the second item serves as the reference point. In order to minimize the possibility that participants would remember their first response and simply repeat it for their second response, we also asked them to make similarity judgments for pairs of filler (distractor) colors. None of these colors was a good example of a basic color. The distractor pairs were chosen so that the similarity between the chips in a pair was approximately the same as that between the chips in the experimental pairs.

In the actual experiment, participants were asked to state how similar X (left chip) was to Y (right chip), using a 7-point scale, where 1 was defined as 'very similar' and 7 as 'not at all similar.' Participants first made judgments for five filler pairs; this served as a warm-up. They then were presented the five experimental pairs, mixed with five more filler pairs. Then an additional five filler pairs were presented, followed by the five experimental pairs (reversed in left–right ordering) mixed with five more filler pairs. The left–right position of the chips in the experimental pairs in the first and second presentation was counter-balanced across participants.

After the participant had completed the reference-point task, he performed the hedges task. The hedge statement, 'Loosely speaking, x is y' was written on a white index card. Participants were given each of the five experimental pairs, one at a time, and were asked to place the chips under the X and the Y in the order that seemed best to complete the statement.

4.42. ANALYSES AND DISCUSSION. To consider whether the basic color member of a pair dominated the non-basic member, we performed two sets of sign tests, one for the hedge data and one for the reference-point data. both sets of analyses indicated that the basic colors did dominate the non-basic colors with which they were paired. We first examined the hedge data by counting, for each of the five pairs, the number of times the basic color was assigned to the Y position vs. the number of times the non-basic color was assigned to that position. The data are presented in Table 7. Sign tests, performed separately for each pair of colors, indicated that, in all five cases, the basic dominated the non-basic color with which it was paired significantly more often than would be expected by chance ($p < .05$).

COLOR PAIR	COLOR ASSIGNED TO Y POSITION	
	BASIC COLOR	NON-BASIC COLOR
orange–peach	20[a]	0
green–lime	19	1
blue–navy	15	5
purple–lavender	19	1
red–burgundy	16	4

TABLE 7. Dominance as measured by hedge: 'Loosely speaking, x is y.'

[a] Numbers indicate the number of participants (out of 20) who placed the color chip in the Y position.

We examined the reference-point data by counting, for each of the five pairs, the number of times that the similarity of a pair was considered greater when the basic color served as referent vs. when the non-basic color served as referent. The data are presented in Table 8. We performed five separate sign tests, one for each pair, comparing the number of times the basic dominated

PREDICTED ORDER[a]	AGREE[b]	DISAGREE[c]	EQUAL[d]
orange–peach	10[e]	2	8
green–lime	5	1	14
blue–navy	9	0	11
purple–lavender	7	1	12
red–burgundy	11	1	8

TABLE 8. Reference points: Dominance data.

[a] The first term listed is predicted to dominate the second (if either dominates).

[b] 'Agree' indicates that similarity was greater when the basic color was the referent.

[c] 'Disagree' indicates that similarity was greater when the target color was the referent.

[d] 'Equal' indicates that rated similarity was equal in the two orders.

[e] Numbers indicate the number of participants (out of 20) whose data fit the given pattern.

the non-basic color vs. the number of times the non-basic dominated the basic. For all pairs except green–lime, the basic color dominated the non-basic significantly more often than would be expected by chance ($p < .05$).

In both tasks, the color terms identified as basic by B&K dominated the other colors. These results clearly demonstrate that the color terms we examined are not all of equivalent status. B&K's basic terms appear to be psychologically more salient. In light of the K&M model, one might expect that the primary basic colors would dominate all other colors (whether basic or non-basic), since the non-primary colors are considered to be formed from intersections of the primaries. If this were the case, it could explain the dominance patterns we obtained for the pairs green–lime, blue–navy, and red–burgundy. However, this explanation will not suffice for the dominance of orange over peach, or of purple over lavender: in these two cases, both members of the pair are non-primary. The dominance patterns obtained in these cases clearly reflect the basic vs. non-basic distinction.[5]

CONCLUSION

5. Categories are formed for a reason: to allow the members of a category to be considered equivalent for some purposes, while at the same time allowing members of that category to be differentiated from members of other categories. To serve this purpose best, the category representation (whether in terms of particular exemplars or of some idealized representation) should be such that it is highly similar to members of its own category, while at the same time being highly dissimilar to members of other categories. The best examples of a category are the members that are most similar to the category representation. Rosch & Mervis 1975 have shown, for a number of semantic categories, that the best examples of the category are the members which have the most properties in common with other members of the category.

In the case of color categories, the best examples (foci) appear to be strongly influenced by the psycho-physical properties of the visual system. Nevertheless, the degree to which a color percept is representative of a color category should be affected by how similar it is perceived to be to the other members of the category. With this premise in mind, we will explain why we believe the fuzzy set method proposed by K&M failed to distinguish between basic and non-basic color categories. The argument we will make is relevant to both perceptual and semantic categories. We claim that the best example of a category, to fulfill its function as category representation (or approximation to category representation), must be a better example of its own category than of any other category. (Under one particular circumstance, the best example

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[5] The methods used in Study 2 might form a useful basis for ordering color terms along a dominance continuum. The primary colors (which dominate all color terms formed by fuzzy intersections of them) would be at one end of the continuum. The basic colors which are formed by fuzzy intersections of the primaries would be near the middle of the continuum. These colors are dominated by the primaries which intersect to form them, but themselves dominate related non-basic colors. The non-basic colors (which are dominated by all related basic colors) would be at the other end of the continuum.

of a category may be an equally good exemplar of another category; this circumstance is described below.) Therefore, any formulation which depends on the best example of one category being sometimes a better example of a different category cannot possibly succeed.

In support of our claim, we present both empirical and theoretical evidence. We consider first the case of categories within a single contrast set (categories directly subsumed under the same super-category). The case is relatively straightforward, since very little overlap exists between categories within a single contrast set. (That is, very few members of one category are also members of another.) Those items which actually are considered members of more than one category within a contrast set are almost inevitably poor examples of all the categories. (E.g., 'beanbag chair' is a poor example of both 'chair' and 'cushion'; 'aqua' is a poor example of both 'green' and 'blue'. For further evidence, see Rosch & Mervis). Since the best examples of the categories are never members of contrast categories, there is no possibility that the best example of one category could be a better example of a contrast category.

The case of a super-category and the categories subsumed under it is more complicated because the best examples of the sub-categories are also members of the super-category; thus the potential exists for them to be better examples of the super-category. However, we argue on theoretical grounds that the best example of a sub-category will necessarily be a better example of its own category than of the super-category.

To present our argument most clearly, we will consider the relationship between the best example of a sub-category and the representation of a super-category (S) in three separate cases. In the first case, the sub-category (C_1) will be a poor example (highly unrepresentative) of S. In the second case, the sub-category (C_2) will be a middling example (moderately representative) of S. In the third case, the sub-category (C_3) will be the best example (highly representative) of S. (For example, S might be 'fruit', C_1 'coconut', C_2 'raspberry', and C_3 'apple'; or S might be 'red', C_1 'burgundy', C_2 'brick-red', and C_3 'fire-engine red'.) In all three cases, the best example of the sub-category will be highly similar to members of its own sub-category, and highly dissimilar to members of the other sub-categories; thus the best example will be highly representative of the sub-category (or may even serve as the category representation).

Consider first the best example of C_1. Since it is highly representative of C_1, and C_1 is a poor example of S, it will be highly unrepresentative of S. Thus it will clearly be a better example of C_1 than of S. Similarly, the best example of C_2 will be a better example of C_2 than of S. The situation becomes a little more complicated in the case of C_3. Since C_3 is the best sub-category of S, it is likely that the most representative member of C_3 will also be highly representative of S (perhaps its most representative member). In this case, we argue that one of two possible relationships will hold. The first is that the best example of C_3 will be a worse example of S; this would occur if a decrease in average similarity between the best example of a category and the members of the category leads to a decrease in representativeness of the best example. The average similarity between the best example of C_3 and the members of S will necessarily be lower than the average similarity between the best example of C_3 and the members of C_3 because of the greater variability among members of S (S contains C_1 and C_2 as well as C_3). Less plausibly, the best example of C_3 might be an equally good example of S. This would occur if differences in the average similarity between the best example of a category and the members of the category do not affect representativeness. In summary, then, the best example of a sub-category will always be a better example (or, for the best sub-category, at least as good) of the sub-category than of the super-category.[6]

The experimental results reported above demonstrate clearly that the K&M proposal fails to distinguish basic color categories from non-basic categories. One might ask whether the failure of K&M's formulation uniquely to identify basic color categories is caused by the particular formulation, or whether any simple formulation derived from fuzzy set logic would be problematic. We have identified two alternative types of formulation, and neither appears to be able uniquely to identify basic color categories. The first alternative is to derive another formulation which is different from K&M's, but which is still based on membership functions. Any such formulation would encounter the same difficulties as did K&M's, for the same reason: non-basic color categories display membership functions similar to basic categories. The second alternative is to distinguish basic from non-basic color categories on the basis of the fuzzy set-theoretic operations involved in deriving the categories. However, we have already seen that the same fuzzy set-theoretic operation (i.e. intersection) may result in either basic (e.g. orange, purple, pink) or non-basic (e.g. lavender, navy, lime) colors. Similarly, the number of primary colors or the types of primary colors (chromatic vs. achromatic) that intersect to form a category do not seem to distinguish basic from non-basic color categories. For example, when two chromatic primaries combine, they may form either a basic color (e.g. orange) or a non-basic color (e.g. lime). In addition, there are no theoretical reasons (either within or outside the K&M framework) to expect a principled relation between the number or types of fuzzy set operations involved and the basicness of a category.

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[6] The arguments we present depend on two assumptions. The first is that representativeness of a category member is a function of its similarity to the other members of the category. This assumption is consistent with proposals made by Rosch & Mervis and by Tversky. The second assumption is primarily relevant to semantic categories, where similarity between category members is a function of the number of attributes the exemplars share and the number of attributes that are distinctive (Tversky). For semantic categories, we assume that virtually the same set of attributes of an exemplar will be used to determine representativeness in a sub-category and in a super-category. Although there is no direct evidence available to support this assumption, the extremely high correlations between family resemblance and typicality which Rosch & Mervis obtained for super-categories suggest that the assumption is not unreasonable. Since the measure of family resemblance employed by Rosch & Mervis was based on all the attributes listed for the exemplars, the high correlations suggest that virtually all the attributes of an exemplar contribute to how representative it is of a category; consequently, the attributes of an exemplar used to determine representativeness in a sub-category and in a super-category should be more or less identical.

Our argument has more general implications for the applicability of fuzzy set theory to human categorization. It suggests that the fuzzy set definition of containment will generally not provide an accurate description of the relationship between the membership functions of a super-category and its sub-categories. In fuzzy set theory, set A is contained in set B if every item with a positive membership value in A has at least as high a membership value in B. We have argued that, in the color domain as well as in other semantic domains, the best example of a sub-category will (almost always) have a higher membership value in its own category than in a super-category. The studies we have reported provide empirical evidence supporting this conclusion within the color domain. Violations of containment have been observed in other domains as well. Kempton has reported that the membership functions for the categories 'mug' and 'cup' do not accord with the fuzzy set definition of containment. We have found similar violations of containment for a number of other semantic categories. Thus some of the basic definitions of fuzzy set theory do not appear to be applicable to human categorization.

In conclusion, we find that K&M's formulation in particular—and, more generally, formulations based on fuzzy set logic—cannot differentiate basic from non-basic color categories. In discovering this, we have uncovered an important fact about categories in general: that, by the nature of their formation and representation, every category contains at least one member—the best example—that is a better example (or, in the limiting case, as good an example) of its own category than of any other category.

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