# CATEGORIZATION OF NATURAL OBJECTS

♣341

*Carolyn B. Mervis*

Department of Psychology, University of Illinois, Champaign, Illinois 61820

*Eleanor Rosch*

Department of Psychology, University of California, Berkeley, California 94720

## CONTENTS

A category exists whenever two or more distinguishable objects or events are treated equivalently. This equivalent treatment may take any number of forms, such as labeling distinct objects or events with the same name, or performing the same action on different objects. Stimulus situations are unique, but organisms do not treat them uniquely; they respond on the basis of past learning and categorization. In this sense, categorization may be considered one of the most basic functions of living creatures.

The last chapters on concept formation in the *Annual Review of Psychology* (Neimark & Santa 1975, Erickson & Jones 1978) treated concepts (categories) as part of the study of problem solving within the general field of psychological learning theory. Meanwhile, an essentially new field of research and theory concerning concepts and categories has emerged, fed

89

by two major trends: 1. The study of naturalistic categories (for example, "red," "chair") particularly as influenced by input from anthropology, philosophy, and developmental psychology. 2. The modeling of natural concepts in the field called semantic memory, an area greatly influenced by artificial intelligence. This chapter is a selective review of these newer developments.

First a word about the historical context of this work. In the usual way of thinking, people distinguish objects (material things in space and time) from the attributes, properties, or qualities of those objects (such as color, shape, function, or parts). In the history of thought, there have been many ideas about the nature of objects, of qualities, of their relation to one another, and of their relation to the ideas which people have of them. British empiricist philosophy had one such view. In British empiricism (for example, Locke 1690), the ideas that people have of objects (concepts) consist of an intension (meaning) and an extension (the objects in the class). The intension is a specification of those qualities that a thing must have to be a member of the class; the extension consists of things that have those qualities. Thus, qualities (attributes) connect concepts to the world. Concept formation research within learning theory, by the very nature of its research paradigm, presupposes a British empiricist stand on these issues (e.g. see Fodor 1981).

In a classical concept formation experiment, stimuli are typically sets of items varying orthogonally on a limited number of sensory qualities such as color and form. Concepts are complexes composed of and decomposable into the defining qualities and logical relations between those qualities (e.g. red and square) which are their elements. Originally, the passive and gradual learning of common defining elements was emphasized in research (Hull 1920). However, since Bruner (Bruner et al 1956), research has concentrated on subjects' active hypothesis testing in the learning of relevant features and the logical rules combining them (see Bourne et al 1979).

The newer categorization research has raised for debate at least six empirical and theoretical issues, none of which had been considered debatable by the earlier approach. They are listed below, beginning with the somewhat more concrete structural problems.

1. Arbitrariness of categories. Are there any a priori reasons for dividing objects into categories, or is this division initially arbitrary?
2. Equivalence of category members. Are all category members equally representative of the category, as has often been assumed?
3. Determinacy of category membership and representation. Are categories specified by necessary and sufficient conditions for membership? Are boundaries of categories well defined?

4. The nature of abstraction. How much abstraction is required—that is, do we need only memory for individual exemplars to account for categorization? Or, at the other extreme, are higher-order abstractions of general knowledge, beyond the individual categories, necessary?
5. Decomposability of categories into elements. Does a reasonable explanation of objects consist in their decomposition into elementary qualities?
6. The nature of attributes. What are the characteristics of these "attributes" into which categories are to be decomposed?

Below we consider work bearing on each of these issues.

## THE NONARBITRARY NATURE OF CATEGORIES

In the stimulus sets of the classical concept formation paradigm, attributes are combined arbitrarily to form items. This view has been echoed in related disciplines ". . . the physical and social environment of a young child is perceived as a continuum. It does not contain any intrinsically separate 'things' " (Leach 1964, p. 34).

However, the contention that the division of real world objects into categories is originally arbitrary would make sense only if the attributes in the world formed a total set (in Garner's 1974 sense); that is, if all combinations of attribute values were equally likely to occur. For example, consider some of the qualities ordinarily treated as attributes in classifying animals: "coat" (fur, feathers), "oral opening" (mouth, beak), and "primary mode of locomotion" (flying, on foot). If animals were created according to the total set model, then there would be eight different types:

(*a*) those with fur and mouths, which move about primarily on foot;
(*b*) those with fur and mouths, which move about primarily by flying;
(*c*) those with fur and beaks, which move about primarily on foot;
(*d*) those with fur and beaks, which move about primarily by flying;
(*e*) those with feathers and mouths, which move about primarily on foot;
(*f*) those with feathers and mouths, which move about primarily by flying;
(*g*) those with feathers and beaks, which move about primarily on foot;
(*h*) those with feathers and beaks, which move about primarily by flying.

It is not immediately obvious how to assign these (hypothetical) creatures to categories; any of several schemes (e.g. by coat type, by oral opening type) would be equally plausible, and none seems particularly reasonable a priori. Thus, given the total set type of organization, it makes sense that category assignments should be originally arbitrary. However, it hardly requires research to demonstrate that the perceived world of objects is *not* structured in this manner. Just two of the eight theoretically possible combinations of attribute values, types *a* and *h* (mammals and birds, respectively), comprise

the great majority of existent species in the world that are possible based on this total set. This correlated attribute structure of the perceived world has been used as the basis for several programs of research concerning natural category structure.

## Basic Level Categories

Any object may be categorized at each of several different hierarchical levels. When the levels are related to each other by class inclusion, they form a taxonomy. Anthropologists working with botanical and zoological categories (Berlin et al 1973, C. H. Brown et al 1976) have suggested, on the basis of linguistic and cultural evidence, that one of these levels is more fundamental than the others. Psychologists (Rosch et al 1976a) have argued that the most cognitively efficient, and therefore the most basic level of categorization, is that at which the information value of attribute clusters is maximized. This is the level at which categories maximize within-category similarity relative to between-category similarity.

Several studies have investigated hierarchical levels of abstraction. Rosch et al (1976a) performed attribute analyses for three-level hierarchies of common concrete objects (e.g. furniture, chair, easy chair) and found the level corresponding to the level of "chair" to possess the characteristics of basic level categories. Cantor et al (1980) have confirmed that a basic level also exists for psychiatric category hierarchies. Using somewhat different measures, Tversky (1977) and Hunn (1976) have found the same level to be basic.

If this level of categorization is really the most fundamental, one would expect categories at this level to have special properties. In fact, several such properties have been identified. Rosch et al (1976a) have shown that the basic level is the most general level at which (a) a person uses similar motor actions for interacting with category members, (b) category members have similar overall shapes, and (c) a mental image can reflect the entire category. Hunn (1975) has argued that the basic level is the only level at which category membership can be determined by an overall Gestalt perception without an attribute analysis. Rosch et al (1976a) have shown that objects are recognized as members of basic level categories more rapidly than as members of categories at other levels. In language, the basic level is the one at which adults spontaneously name objects, whether for adults (Rosch et al 1976a) or for young children (R. Brown 1958, 1976; Anglin 1977). Cruse (1977) has argued that labels for basic level categories are unmarked linguistically—that is, words at this level are used in normal everyday conversation. In American Sign Language basic level categories are generally denoted by single signs, while superordinate and subordinate categories are almost always denoted by multiple sign sequences (Newport & Bellugi 1978).

One of the most pervasive research findings is that basic level categories are acquired before categories at other hierarchical levels. Rosch et al (1976a) and Daehler et al (1979) found that young children can solve simple sorting problems at the basic level before solving them at the superordinate level. Mervis & Crisafi (1981), using artificial category hierarchies, found that 2½-year-olds were able to sort basic level triads correctly, but could not sort either superordinate or subordinate level triads. With regard to language acquisition, Stross (1973) and Dougherty (1978) have both shown that the first botanical labels that children learn are names for basic level categories. Other studies have yielded similar results for selected nonbotanical taxonomies (Rosch et al 1976a, Anglin 1977). Taking a historical perspective, Berlin (1972) has shown that languages first encode basic level biological categories, and only later (if at all) encode categories superordinate or subordinate to the basic level ones.

All of these studies have concerned naturally occurring hierarchies, and it could be argued that the basic level effects are due to linguistic factors (e.g. shorter names, greater frequency, learned first) rather than to perceptual-cognitive structural factors. Two recent studies, using artificial categories whose hierarchical structure mirrored the naturally occurring structure, have suggested that the perceptual-cognitive explanation is more appropriate.

Murphy & E. E. Smith (1981) taught subjects to label stimuli at each of three levels. Order of learning was counterbalanced, and word frequency and length were controlled. After learning the labels, subjects participated in a verification task. Response times to verify labels for basic level categories were significantly shorter than response times to verify labels for subordinate or superordinate level categories. Mervis & Crisafi (1981) controlled for potential linguistic confounds by never naming the stimuli for their subjects. One group of subjects was asked to sort the stimuli however it made sense to them. A second group of subjects was told that a particular stimulus had been given a certain name, and they should decide which of the other stimuli should also be given that name. For both tasks, virtually all of the responses corresponded to the predicted basic level categories.

The principles underlying the determination of which hierarchical level is basic are expected to be universal. However, for a given domain, the particular level which is found to be basic may not be universal. This level can vary as a function of both the cultural significance of the domain and the level of expertise of the individual (Rosch et al 1976a, Dougherty 1978). These two factors are important because they influence which attributes of an object are noticed (perhaps constructed) by an observer; psychological measures of basicness rely on analyses of perceived attribute structures. Dougherty and Rosch et al both provide examples of the relativity of the basic level.

## Basic Level Categorization as a Basic Process

Flavell & Wellman (1976, Flavell 1977) have proposed that memory phenomena be divided into four types: basic processes, knowledge (semantic memory), strategies, and metamemory. Might basic level categorization be included as a basic process?

Flavell & Wellman have described two important characteristics of basic processes. First, a person is not conscious of the actual working of the process. Second, the process undergoes no significant development (other than that due to maturation) with age; development is complete by the end of the sensorimotor period (age 1½ to 2 years). They provide three examples of basic processes: 1. the processes by which an object is recognized; 2. the processes of representation underlying recall of absent objects or events; 3. the process of cueing or associating. They also point out that the four types of memory phenomena are not mutually exclusive.

Why should basic level categorization be included as a basic process? Without any categorization an organism could not interact profitably with the infinitely distinguishable objects and events it experiences. Therefore, even infants should be able to categorize. Nevertheless, until recently there was little motivation to consider infant categorization abilities, since it was widely believed (see Gelman 1978) that children could not categorize until they reached the stage of concrete operations (when they are 5 to 7 years old). However, once simple categorization abilities were demonstrated in preschool children, research with infants began in earnest. Most of these studies have taken advantage of an infant's predictable preference for novel stimuli over familiar ones (L. B. Cohen & Gelber 1975). The studies use the same general procedure. First, the infant is given several familiarization trials with different category members. Then he is shown either a novel member of the same category, a novel member of a different category, or both at once. If the infant has formed a category, then he should spend significantly more time looking at a stimulus from a novel category than from the familiar one. Using this format, G. Ross (1977) demonstrated that 12-month-old infants were able to form a variety of basic level categories. L. B. Cohen demonstrated that much younger infants (30-week-olds) were able to form the categories "female face" (L. B. Cohen & Strauss 1979) and "stuffed animal" (L. B. Cohen & Caputo 1978). Strauss (1979), using schematic faces, demonstrated that 10-month-olds were able to categorize an average prototype after familiarization with other category members.

Three additional studies have used different techniques. Husaim & L. B. Cohen (1980), using a discrete trial discrimination learning paradigm, found that ten-month-olds could form two noncriterially defined categories (of schematic animals). The infants attended to more than one attribute, and the same models that predict adult categorization behavior were able to

predict infant behavior. Ricciuti (1965) examined the behavior of 12-, 18-, and 24-month-olds who were given two types of toys to play with, and found considerable evidence of categorization abilities in even the 12-month-olds. K. Nelson (1973), using 20-month-olds, has replicated this result for other basic level categories. In summary, then, there is now substantial evidence that basic level categorization should be considered a basic process.

## NONEQUIVALENCE OF CATEGORY MEMBERS

In a classical concept formation experiment, any one stimulus which fits the definition of the concept (possesses the relevant attributes in the correct combination) is as good an example of the concept as any other. More generally, if categories are seen as determinately established by necessary and sufficient criteria for membership (and if, in addition, the role of rationality is to abstract out what is essential to a situation while ignoring what is inessential; see e.g. James 1890a,b), then any member of a category should be cognitively equivalent qua the category to any other member. However, there is now a growing amount of empirical evidence that all members are not equally representative of their category.

The first domain for which nonequivalence was proposed was that of color. Berlin & Kay (1969) showed that many apparent contradictions reported in the anthropological literature on color naming could be clarified by distinguishing focal from nonfocal colors. Focal colors are points in the color space which speakers of diverse languages agree represent the best examples of the 11 basic color categories. While the number of color terms in a language and the boundaries of color categories vary widely across cultures, colors most representative of basic color categories appear to be universal. These results actually provide cross-linguistic confirmation of well-established effects in the physiological literature on color naming functions (see Cornsweet 1970). The best exemplars of the four primary colors correspond to the physiologically determined unique hue points for these colors (De Valois & Jacobs 1968, Kay & McDaniel 1978). Standard psychological variables such as memory accuracy and ease of learning have been shown to co-vary with representativeness of the color in question (Heider 1972, Rosch 1974). Findings similar to those with color categories have also been demonstrated for geometric shape categories (Rosch 1973a,b). For recent reviews of research on color categories see R. Brown (1976) and Witkowski & C. H. Brown (1978).

Gradients of representativeness have been found not only for color and geometric shape categories but also for many common semantic categories (e.g. "dog," "furniture"). The great majority of psychological studies of

representativeness have focused on such categories. Representativeness is here defined operationally by means of subjects' ratings of how good an example an item is of its category (Rosch 1975b). Consistency in such ratings has been obtained. Individual subjects agree that some exemplars of a category are more representative than others, and different subjects consistently choose the same examples as most representative of the category. The overall scale that is obtained is robust under differing conditions of instruction and stimulus presentation (Rips et al 1973; Rosch 1973b, 1975a,b; Rosch & Mervis 1975; E. E. Smith et al 1974; Whitfield & Slatter 1979). Two recent studies have found similar gradients for other types of categories: locatives (Erreich & Valian 1979) and psychiatric classifications (Cantor et al 1980). Gradients of representativeness for various linguistic categories have also been widely reported (see e.g. J. Ross 1972; Fillmore 1975, 1977; Lakoff 1977; Bowerman 1978; Bates & MacWinney 1980; deVilliers 1980; Maratsos & Chalkley 1980; Coleman & Kay 1981).

Representativeness of items within a category has been shown to affect virtually all of the major dependent variables used as measures in psychological research. In this section we consider speed of processing, free production of exemplars, natural language use of category terms, asymmetries in similarity relationships between category exemplars, and learning and development.

*Speed of processing* (reaction time) has been extensively investigated in category verification tasks. Subjects are usually asked to verify statements of the form "An [exemplar] is a [category name]" as rapidly as possible. Response times are shorter for verification of the category membership of representative exemplars than nonrepresentative exemplars; these effects are robust and appear in a variety of experimental paradigms (see reviews in E. E. Smith et al 1974, E. E. Smith 1978, Hampton 1979, Danks & Glucksberg 1980, Kintsch 1980). Rosch et al (1976b) have also demonstrated this effect for three types of artificial categories, where representativeness was defined by family resemblance, by mean values of attributes, or by degree of distortion from the prototype (random dot pattern). These differences in response times are amplified when a prime (prior mention of the category name) is provided. Priming reduces response times to verify the category membership of representative exemplars but increases response times to verify the membership of nonrepresentative exemplars. This result has been obtained for colors (Rosch 1975c), superordinate semantic categories (Rosch 1975b, MacKenzie & Palermo 1981), and for the artificial categories just described (Rosch et al 1976b).

*Order and probability of exemplar production* have been investigated primarily for superordinate semantic categories. Battig & Montague (1969) asked subjects to list exemplars of each of 56 superordinate categories. Frequency of mention of an exemplar was found to be significantly corre-

lated with degree of representativeness (Mervis et al 1976). Posnansky (1973) replicated this result using elementary school children. Both Rosch et al (1976b) and Erreich & Valian (1979) found that when subjects were asked to sketch an exemplar of a particular category, they were most likely to depict the most representative exemplar.

*Natural languages* possess mechanisms for coding gradients of representativeness. For example, languages generally include qualifying terms ("hedges") such as "true" or "technically." Lakoff (1973) has shown that a given hedge is applicable to only a subset of category exemplars; this subset is determined by degree of representativeness. For instance, it is acceptable to say "A sparrow is a true bird," but not "A penguin is a true bird." Correspondingly, the sentence "A penguin is technically a bird" is acceptable, but "A sparrow is technically a bird" is not. Similarly, Rosch (1975a) has shown that when subjects are given sentence frames such as "[x] is virtually [y]," they reliably place the more representative member of a pair in the referent (y) slot. In addition, representativeness ratings for members of superordinate categories predict the extent to which the member term is substitutable for the superordinate word in sentences (Rosch 1977). Finally, Newport & Bellugi (1978) have shown that in American Sign Language, when superordinate terms are denoted by a short list of exemplars only the more representative exemplars may be used.

*Asymmetry in similarity ratings* between members that vary in representativeness is another way in which members of a category fail to be equivalent. Tversky & Gati (1978) and Rosch (1975a) have shown that less representative exemplars are often considered more similar to more representative exemplars than vice versa. For example, subjects felt that Mexico was more similar to the United States than the United States was to Mexico. This phenomenon helps to explain the asymmetries which Whitten et al (1979) found in similarity ratings of pairs of "synonyms." It also helps to explain Keller & Kellas's (1978) finding that release from proactive inhibition is significantly greater if the change is from typical to atypical members of a category than if the change is from atypical to typical members. In addition, asymmetry in similarity ratings has implications for inductive reasoning. Rips (1975) found that new information about a category member was generalized asymmetrically; for example, when told that the robins on an island had a disease, subjects were more likely to decide that ducks would catch it than that robins would catch a disease which the ducks had.

In the *learning and development* of categories, representativeness appears to be a major variable. Representativeness gradients have two basic implications for category acquisition (Mervis & Pani 1980). The first implication is that category membership is established (for the set of exemplars to which a person has been exposed) first for the most representative exemplars and

last for the least representative exemplars. One of the most robust findings from research using statistically generated categories is that correct classification of novel exemplars is strongly negatively correlated with degree of distortion of the exemplar from the prototype pattern. This result has been obtained using both random dot pattern categories (e.g. Posner & Keele 1968, Homa et al 1973, Homa & Vosburgh 1976) and random polygon categories (e.g. Aiken & Williams 1973, Williams et al 1977). Similarly, when subjects are asked to indicate which of a series of categorically related stimuli have been seen previously, percentage of false recognition responses and degree of confidence that the (novel) pattern has been seen previously are both negatively correlated with degree of distortion from the prototype (e.g. Franks & Bransford 1971; Neumann 1974, 1977; Posnansky & Neumann 1976). When subjects are given explicit feedback concerning the correctness of their classifications, categories consisting of low distortions are learned significantly faster than categories consisting of either high distortions or both low and high distortions (e.g. Posner et al 1967, Homa & Vosburgh 1976). For categories including both low and high distortions, the low distortions are learned first (Mirman 1978). Similarly, Rosch (1973a,b) found that focal (representative) colors and forms were learned more rapidly than nonfocal colors and forms by persons whose language did not contain explicit labels for these categories. In a study of 5-year-olds learning artificial categories modeled after natural categories, Mervis & Pani (1980) found that more representative exemplars were learned first; in this study, no feedback was provided during learning.

The developmental research relevant to this issue has concentrated primarily on the acquisition of superordinate semantic categories. K. E. Nelson & K. Nelson (1978) have argued that as children learn about a category, their criteria for assigning an object to that category shift back and forth between generous and conservative, until finally the adult criteria (which themselves vary according to cognitive style; see Kogan 1971) are used. This pendulum theory predicts that category membership of representative exemplars should be firmly established at a young age, while membership of less representative exemplars will vascillate. Although no single study has considered a wide enough age range to test the theory conclusively, it appears, based on the combined results from several sorting studies using children of different ages (Saltz et al 1972, Neimark 1974, Anglin 1977), that the theory may be correct. Two studies of children's production of category exemplars (K. Nelson 1974, Rosner & Hayes 1977) provided additional support. Research with basic color categories (Mervis et al 1975) and with basic object categories (Saltz et al 1977) support the finding of the superordinate sorting studies.

The second major implication of representativeness is that categories are learned more easily and more accurately if initial exposure to the category

is through only representative exemplars. Two studies have shown that initial exposure to only representative exemplars is more effective than initial exposure to only nonrepresentative exemplars; the stimuli were dot patterns (Mirman 1978) and multimodal artificial stimuli with natural category structure (Mervis & Pani 1980).

Results are somewhat more equivocal when initial exposure to both representative and nonrepresentative examples is compared with initial exposure to only representative examples. Two studies (Homa & Vosburgh 1976, Goldman & Homa 1977) found that for categories with certain characteristics initial exposure to the full range of category membership was not worse than exposure to good examples only. However, three other studies found training on good examples superior to training on a range of examples (Mervis & Pani 1980, Hupp & Mervis 1981, Mervis & Mirman 1981).

What might make some objects more representative of their category than others? It may be useful to consider once more the previous section in which we discussed clusters of correlated attributes. These correlations are not perfect—for example, in our hypothetical set of creatures (p. 91), besides the two main correlated clusters (birds and mammals), there are many types of flightless birds, a few flying mammals (bats), and the duck-billed platypus. It has been argued that the logic of attribute structures associated with gradients of representativeness within categories is parallel to the logic (described in the previous section) that predicts which level in a taxonomy will be the basic level (Rosch 1978, Mervis 1980).

Rosch & Mervis (1975) have shown that category members differ in the extent to which they share attributes with other category members. They call this variable family resemblance (after Wittgenstein 1953). Items which have the highest family resemblance scores are those with the most shared attributes. Rosch & Mervis (1975) have also shown that the exemplars with the highest family resemblance scores are those which share few (if any) attributes with members of related categories. In other words, given the nature of real-world attribute clusters, the items that have most attributes in common with other members of their own category also have fewest attributes in common with related contrast categories. Both family resemblance and dissimilarity from contrast categories are highly correlated with ratings of representativeness for superordinate and basic level natural categories and for artificial categories (Rosch & Mervis 1975). The within-category correlations have been confirmed using different measures (Neumann 1977, Tversky 1977, Tversky & Gati 1978). Studies with various artificial categories have shown that when within-category similarity and between-category dissimilarity are dissociated, either factor is sufficient to produce a representativeness gradient (Rosch et al 1976b, E. E. Smith & Balzano 1977). (Note that the family resemblance idea does not indicate that category members must have no attributes common to all members—

in fact, insofar as category members are the same higher level "sort of thing" they will share such higher level, and therefore necessary, attributes as "animate" or "solid object"; see Keil 1979, E. E. Smith & Medin 1981.)

We can now see how a family resemblance structure of categories might make sense of the findings that the most representative members of categories are established first as category members and are the most useful basis for learning categories. Because basic level categories maximize within-category similarity relative to between-category similarity, it is reasonable that they were found to be learned first—before categories subordinate and superordinate to them. Correspondingly, the most representative exemplars of a category have maximal within-category and minimal between-category similarity. Therefore, category membership is most obvious for the highly representative exemplars, and generalization based on similarity to these will be the most accurate.

The above findings on the nonequivalence of natural category members have been mirrored in research on social phenomena. Relying on the correlated attribute cluster as a basis for assigning category membership serves to make the world seem more orderly than it really is (Rosch 1978, Mervis 1980). Lippmann (1922) has argued that social stereotypes serve exactly this purpose. Kahneman & Tversky (1973) have shown that when subjects are asked to predict a person's occupation based on a description of the person, the person is assigned to the occupation for which the best match between personal description and occupational stereotype is obtained. C. E. Cohen (1976) found that occupational and role stereotypes are used as a basis for inferring a person's characteristics. Cantor & Mischel (1979) showed the usefulness of a family resemblance stereotype notion for determining attribution of personality trait categories such as "introvert" and "extrovert." McCauley & Stitt (1978) have presented a Bayesian method for determining which attributes should be included in a stereotype; their method is reminiscent of family resemblances. In fact, McCauley & Stitt have argued that their method is also applicable to concrete object representations, since stereotypes of groups and representations of object categories serve the same function. For reviews of research concerning stereotypes, see Brigham (1971) and McCauley et al (1980).

## INDETERMINACY OF CATEGORY MEMBERSHIP AND REPRESENTATION

That category members vary in degree of representativeness is essentially a set of empirical findings. What does it imply about the nature of categories? There are two separable issues: the relatively empirical question of whether the boundaries of categories are determinate (well defined) or

fuzzy, and the theoretical issue of how well defined one wants to consider the category "representation" itself.

Two experimental approaches have been used to demonstrate that category boundaries are not well defined. The first involves demonstrations that there are between-subject disagreements concerning which categories certain (poor) exemplars belong to. Berlin & Kay (1969) found substantial disagreement among subjects concerning the location of color category boundaries, even when native language was controlled. This result has been replicated by Labov (1973), using schematic drawings of cups, by McCloskey & Glucksberg (1978), using superordinate semantic categories, by Cantor et al (1980), using subordinate psychiatric categories, and by Kempton (1978) using drinking vessels in a cross-cultural setting.

The demonstration of between-subject disagreement is suggestive, but this disagreement could possibly be an artifact stemming from the combining of data from different subjects, each of whose categories had a different well-defined cutoff. Therefore, a demonstration of within-subject disagreement is also important. Berlin & Kay (1969) noted substantial within-subject disagreement across testing sessions concerning color category boundaries. McCloskey & Glucksberg (1978) found the same result for multiple within-subject judgments concerning superordinate category assignments of potential poor exemplars. They also demonstrated that their results could not be explained simply by reference to polysemous superordinate category labels.

Another empirical consideration points to the reasonableness of nondefinite boundaries of categories. Poorer members of categories are likely to contain attributes from the correlated attribute clusters of other categories (see e.g. Rosch & Mervis 1975). Sokal (1974) has provided an elegant demonstration of this point for biological categories (see also Simpson 1961, Sneath & Sokal 1973).

The controversy over the determinacy of categories, however, extends beyond empirical evidence. In present cognitive psychology it has become almost obligatory to explain and model phenomena in terms of cognitive representations and processes which act on them. If one believes that categories consist of determinate necessary and sufficient criteria, one can develop a model which attempts to explain representativeness and indeterminate boundary effects by means of processes operating on a determinate representation. For example, Wanner (1979) reported the finding that mathematical concepts such as "odd number" show the same representativeness effects described in the Nonequivalence section. He argued that since mathematical concepts are the archetype of concepts "true by definition alone," one may interpret these results to imply that the "real meaning" of a concept consists of a criterial definition; representativeness effects would be produced by separate processing heuristics. [It is interesting to

note in this context that a major contemporary school of mathematics (the constructivist school) does not consider mathematical concepts to be either true by definition alone or necessarily criterial; see Calder 1979.] Glass & Holyoak (1975) have developed a model in which concepts are represented by semantic markers (Katz 1972) which contain the essential features of the concept. These markers are nodes in semantic memory connected by pathways; representativeness effects are modeled by means of variation in length and directness of these pathways. Another strategy is used in the fuzzy set (Zadeh 1965) model of Caramazza (1979). In this model noun concepts are represented by determinate specification of defining attributes, but the attributes (which are presumed not to be concepts) are treated as fuzzy. E. E. Smith & Medin (1981) provide a general characterization of such models. They argue that such models cannot account for a variety of empirical findings.

Other models incorporate greater indeterminacy into the representation itself. In the two-stage model of E. E. Smith et al (1974) and the single-stage models of McClosky & Glucksberg (1979) and Hampton (1979), concepts are represented by sets of weighted non-necessary features. Processing decisions about category membership are made on a probabilistic basis. Collins & Loftus's (1975) model also includes a probabilistic decision process, but it is allowed to operate on more varied types of structural information than simply attributes.

The issue of determinacy has been approached in a slightly different fashion in research on context effects. Both Collins & Loftus (1975) and McClosky & Glucksberg (1979) invoke Bayesian inference procedures specifically to deal with context; however, all of the probabilistic models have an unchanging (and, in that sense, determinate) representation of some sort. Context has been employed to criticize just this sort of assumption. In the psychological literature, changes in meaning, comprehension, or memory of particular terms as a function of differing contexts have been used to question the adequacy of semantic memory models (see e.g. Barclay et al 1974, R. C. Anderson & Ortony 1975, R. C. Anderson et al 1976, Potter & Faulconer 1979). These studies tend to be primarily critical rather than to offer formulations of their own. In addition, context has been used as the basis of more far reaching criticisms of determinate views; for authors in the hermeneutic tradition, context becomes the basis of arguments against representations and other noninteractive accounts of meaning (see for example the papers in Rabinow & Sullivan 1979).

## THE NATURE OF ABSTRACTION

In the classic concept formation paradigm, a concept is an abstraction consisting of a set of defining features and the relationship between them.

Contemporary views have argued both that concepts may be conceived as less abstract or must be conceived as more abstract than this formulation. There are, of course, also accounts that posit intermediate levels of abstraction.

On the one hand, it has been asserted that we need only memory for individual exemplars in order to account for categorization. In a sense, from the time of Pavlov, "strength theory" models of stimulus generalization have been of this type (see Riley & Lamb 1979). In human categorization research, Reber (1976) and Brooks (1978) have demonstrated cases where learning of instances can occur without the learning of rules or abstractions; in fact, where telling a subject the rule may retard performance. If only specific exemplars are stored in memory, categorization of novel items could occur by matching the new instance to the most similar item in memory. Formal exemplar ("nearest neighbor") models which incorporate this type of processing have been tested against various abstraction models; in all cases, exemplar models were inferior to the abstraction models (Reed 1972, Hyman & Frost 1975, Hayes-Roth & Hayes-Roth 1977). In addition, in order to account for hierarchical relationships, exemplar models must require that the names of all possible superordinate categories be stored with each exemplar. Meyer (1970) has discussed problems with this approach.

Given the state of present cognitive modeling, exemplar models are also theoretically anomalous for two reasons. First, if beyond learning items cognitive representations of them are required, instances must either be coded by first order isomorphism (the representation of "green square" as green and square; Shepard & Chipman 1970, Palmer 1978) or undergo some kind of abstractive process. Second, nearest neighbor models require an account of similarity judgments; presently such accounts all involve abstractions (Tversky 1977).

Virtually all models of categorization involve abstraction—that is, ways in which the cognitive system acts "creatively" on input during learning of categories and uses the resultant categorical information to classify novel items. The creativity is of two types: determining which elements of a situation are "essential" and which irrelevant; and the creation of new higher order information which was not given in any particular exemplar. In the classical concept formation paradigm, abstraction of essential elements is involved in learning which attributes are relevant, and creation of higher order information is involved in learning the logical relationship between these attributes. Any model that includes representation of features (whether defining or characteristic) posits creativity of the first type. The type of novel higher order information generated varies for different models. The most minimal computation is required by prototype models based on central tendency: e.g. on means (Posner et al 1967, Posner & Keele 1968, Reed 1972, Reed & Friedman 1973), modes (Neumann 1974, 1977; Hayes-

Roth & Hayes-Roth 1977) or ideal values based on perceptual characteristics (Kay & McDaniel 1978, Oden & Massaro 1978). Some models posit that category representations include both summary information and exemplar information (Medin & Schaffer 1978, Smith & Medin 1981). For their summary information, these models require abstraction of "essential" elements to generate features and the creation of new information in the form of weights for the features (computed, in general, on the basis of the usefulness of the feature for determining category membership).

Abstraction models involving simple attributes, rules, or prototypes (such as any of the above) are criticized by those who feel that higher order abstractions and general knowledge more extensive than that of individual categories are required in any account of categorization. For example, Pittenger & Shaw (1975, Pittenger et al 1979) argue that higher order knowledge about transformations serves as the perceptual invariant underlying certain types of categorization. In the tradition of constructive memory research (e.g. Bartlett 1932, Bransford & McCarrell 1974), categories are treated as part of very general schemas. Finally, large scale computer models (Collins & Loftus 1975, Schank & Abelson 1977, Winograd 1972) treat categories and categorization processes as inseparable from world knowledge and the inference processes used in such knowledge.

## DECOMPOSABILITY OF CATEGORIES INTO ELEMENTS

Virtually all accounts of the representation and processing of categories assume that categories are decomposable into more elementary qualities. This is not surprising: as Dreyfus (1979) has pointed out, since the time of Plato one of the major aspects of what has been meant by an explanation has been the decomposition of the thing to be explained into its elements. In psychology, however, arguments against the indiscriminate use of explanation-by-decomposition have been with the field since its inception (see e.g. James 1890a on the unitary nature of a single complex thought). The issue of decomposability was the focus of the debate in the early part of this century between the structuralists, who saw all experience as built out of primitive meaningless sensations, and the Gestaltists, who emphasized irreducible emergent properties of wholes (see Boring 1950).

At present, while decomposition is the unmarked assumption in model building, the possible need for less analytic factors is periodically acknowledged. For example, in the pattern recognition literature, analysis into features and holistic matching to a template are generally presented as the two major types of alternative models (Reed 1973), although for good reasons templates are usually treated as straw men (see Palmer 1978).

Various empirical developments have brought the nature and role of decomposition into current debate. First, categorization has been investigated for types of stimuli that do not have obvious elements at a cognitive level. The most notable of these are color (Rosch 1973b, 1974) and overall configuration (e.g. Attneave 1957, Posner 1969, Lockhead 1972—but see also Barresi et al 1975, Homa & Vosburgh 1976). It is not surprising that such stimuli do not strike us as obviously decomposible, since they are themselves normally treated as attributes, i.e. the qualities into which more complex objects are decomposed. There has also been considerable disagreement as to whether faces should be considered special holistically perceived objects (Hochberg & Galper 1967, Yin 1969, Rock 1973, Bradshaw 1976). A second development which has offered the opportunity to view categories as wholes is the possibility for spatial representation of within- and between-category structures through techniques such as multidimensional scaling. For example, Hutchinson & Lockhead (1977) have argued that categories can best be conceived as unanalyzed points in metric multidimensional space. A third trend has been use of the concept of a prototype and the facts of gradients of representativeness to suggest holistic processing (e.g. Rosch 1973b, Dreyfus 1979).

The great majority of arguments over decomposition concern specifying the level of abstraction at which a particular kind of decomposition can or cannot be said to occur. While most categorization models include decomposition, it is never to the point of infinite regress. Some elements are included as the primitives, although usually by default, rather than by explicit labeling as primitives.

Because some elements are not decomposed, many accounts of categorization include an explicit holistic component. For example, this can be introduced by means of a (relatively) holistic processing stage (E. E. Smith et al 1974). Another possibility is that a given level of abstraction may be a basic and (potentially) holistically perceived level, even if other levels require more analytic mechanisms (Rosch et al 1976a). Perceptual processing of figures (such as a large letter constructed of smaller letters) has been shown to proceed from global to local analysis under some stimulus conditions (Navon 1977) but to proceed from local to global under others (e.g. Kinchla & Wolf 1979). In the perception models of Palmer (1975) and Winston (1975), the decomposition of a visual scene is viewed as a hierarchical network of subscenes, and it is claimed that higher-order properties are processed first, followed by lower-order properties. Depending on the circumstances, however, a given aspect of a scene might be either the higher- or the lower-order property. The controversy over lexical decomposition in linguistics and artificial intelligence (does "kill" really mean "cause to die") can be seen as largely an issue of which linguistic level to consider a whole and which to consider the elements (Fodor 1970; McCawley 1971,

1978; Schank 1973; Fodor et al 1980). The recent suggestion that the capacity to match figures holistically may be a cognitive strategy which shows individual differences (Cooper 1976, Cooper & Podgorny 1976) is intriguing; for contrasting work on individual differences see Day (1976).

Two important points have been made in this discussion of decomposability. First, although the tendency in cognitive models is to decompose almost automatically, the evidence of holistic processing of some stimuli or at some stages suggests that we be more thoughtful about decompositional models. Second, findings concerning decomposition appear to be dependent on the level under consideration. Some general principles of decomposition are needed.

## THE NATURE OF ATTRIBUTES

In the British empiricist account, attributes correspond to elementary sensations. However, in modern cognitive psychology, almost anything has been used as an attribute at one time or another. This produces some anomalies, particularly in the use of parts, relations, and functions as attributes (Rosch 1978). Indeed, as pointed out in the previous section, what is considered a category and what are called its attributes depend on the level one is describing; the same item (e.g. "red" or "circular") can be what is to be explained (category) or what is referred to as part of the explanation (attribute). Appropriately, therefore, there have recently been a number of discussions of the nature of attributes and the manner in which they combine.

The first controversy in the field involves use of features vs use of dimensions in the representation of categories. Features generally designate qualitative properties (e.g. legs, wooden, you sit on it) and so need not be applicable to all objects in the same domain. Large numbers of features may be included in a single representation. There are many different types of feature representations, such as feature lists and structural descriptions; for an extensive discussion see Palmer (1978). Explanations using features are overtly decompositional.

In contrast, dimensions are usually employed to describe quantitative properties (e.g. size); therefore, every object in a given domain is assigned some value on each of the dimensions used to describe the domain. An ideal dimensional representation includes only a small number of dimensions. There are two different types of dimensional representation, metric and nonmetric; for a discussion of their use in categorization models see E. E. Smith & Medin (1981). Dimensional descriptions often use a spatial metaphor (encouraged by the availability of multidimensional scaling techniques) and thus may appear to be relatively holistic representations of categories.

However, as Palmer (1978) and E. E. Smith & Medin (1981) have pointed out, the difference between features and dimensions may apply more to the surface form of the representation than to the underlying information that is represented. It can be shown that features may be extended to handle quantitative properties, and dimensions may be extended to handle most (but perhaps not all; see Beals et al 1968) qualitative properties. (But note that missing values communicate different information for features vs for dimensions; see Garner 1978a,b.) Features, transformations, and nonmetric dimensions can be integrated reasonably into the same representation.

One of the first psychologists to question the nature of attributes (whether features or dimensions) was Garner (1970, 1974). Garner was concerned not with the form by which attributes should be represented in cognitive models, but rather with a proposed difference in kind among perceptual attributes. This difference is concerned with how types of attributes combine with each other. Garner distinguished two types of attribute combinations: those that are separable (e.g. form and size) and those that are integral (e.g. brightness and saturation). Attribute combinations are considered separable if they are perceived in terms of their separate attributes; similarity is therefore judged by comparing the relevant stimuli with regard to their values on each of the component attributes. Attribute combinations are considered integral if the two attributes are not treated separately, that is, if a change in one attribute appears to produce a stimulus which is different as a whole rather than different for that one attribute. For integral attributes, similarity is judged holistically, according to how much the relevant stimuli are alike.

This distinction between types of attributes appeared temporarily to have major developmental implications. For adults, certain combinations of attributes are separable, while others are integral; however, young children appeared to treat virtually all attribute combinations as though they were integral (see e.g. Shepp & Swartz 1976, Shepp 1978). Clarification of the developmental data results from a further consideration of the nature of integral combinations. It has been suggested (e.g. Lockhead 1972, Garner 1974) that there are actually two types of integral combinations: those which seem to be mandatorily perceived holistically, and those which people prefer to process holistically, but which can also be processed dimensionally if such processing is advantageous. Recently, there have been several demonstrations (e.g. L. B. Smith & Kemler 1977, 1978; Kemler & L. B. Smith 1978) that young children treat those attribute combinations which are separable for adults as though they corresponded to the second type of integral combination. Thus, children are in fact able to perceive each of the attributes and to treat them as though they were separable; young children simply prefer to attend to holistic relationships. Young children are especially likely to consider separable dimensions separately if the re-

quired task is conceptual rather than perceptual (Kemler & L. B. Smith 1979).

The question arises as to what makes some attributes combine in an integral fashion and others in a separable fashion. Aside from some initial speculation (Garner 1974), this question has not been pursued. It may be pointed out, however, that integral and separable attributes appear to be at different levels of abstraction. When stimulus dimensions are considered at the level at which one normally calls something an attribute (e.g. at the level of colors and forms), the attributes are separable. Integral attributes are further decompositions of that level (e.g. hue and brightness are further decompositions of color). Thus separability and integrality of attributes, like other issues in decomposition, appear to depend on the level of abstraction considered.

Integrality and separability of attributes may be considered part of the general issue of information integration. Even given separable attributes, there remains the question of how to model the way in which they combine. The main choice in formal models has been between additive and multiplicative. Additive models treat attributes as though they were independent. These models appear to work best when relevant information is presented sequentially and correlations between attributes are absent or not apparent. Multiplicative models treat attributes as though they were nonindependent, and therefore work best when relevant information is presented simultaneously and correlations between attributes are apparent. (For a review of information integration see N. H. Anderson 1974.) In categorization research, additive and multiplicative models may make very similar predictions for real-world categories, since the attributes which are correlated are generally also most frequent.

Let us return to the original role of attributes in categorization theory. In empiricist philosophy, attributes were used to connect concepts to the real world; that is, to connect the meaning (intension) of a concept with the objects (extension) which fit that meaning. In the psychology of categorization, attributes are often used for this purpose. These attributes are generally of four types: parts, physical characteristics such as color and shape, relational concepts such as taller, and functional concepts. However, these types of attributes as represented in categorization models are all categories themselves; therefore, they can themselves be examined as a categorization problem (see Rosch 1979).

Note that one major psychological theory takes a different approach to the origin of attributes. A constructivist approach to logical classification (Piaget 1970, 1972) takes as its unit of analysis the *interaction* of persons and objects. Attributes are developed out of this interaction. Perhaps the closest analogy to such an approach in non-Piagetian cognitive psychology is the current interest in modeling categories by means of procedures. At

present, this work is largely confined to formal systems (Miller & Johnson-Laird 1976) and to artificial intelligence (see Winograd 1975).

## SUMMARY

New trends in categorization research have brought into investigation and debate some of the major issues in conception and learning whose solution had been unquestioned in earlier approaches. Empirical findings have established that: (*a*) categories are internally structured by gradients of representativeness; (*b*) category boundaries are not necessarily definite; (*c*) there is a close relation between attribute clusters and the structure and formation of categories. This appears to be a particularly promising approach for future research.

These findings challenge determinate definitions of categories and provide constraints on alternative views. Other issues that research and theory in the modeling of categorization have brought into focus are the nature of the abstractive process, the question of decomposition of categories into elements, and the nature of the attributes into which categories are often decomposed. In short, current research on categories could be said to represent a kind of experimental epistemology.

*Literature Cited*

Aiken, L. S., Williams, T. M. 1973. A developmental study of schematic concept formation. *Dev. Psychol.* 8:162-67

Anderson, N. H. 1974. Algebraic models in perception. In *Handbook of Perception*, ed. E. C. Carterette, M. P. Friedman, 2:215-99. New York: Academic. 556 pp.

Anderson, R. C., Ortony, A. 1975. On putting apples into bottles—A problem of polysemy. *Cognit. Psychol.* 7:167-80

Anderson, R. C., Pichert, J. W., Goetz, E. T., Schallert, D. L., Stevens, K. V., Trollip, S. R. 1976. Instantiation of general

terms. *J. Verb. Learn. Verb. Behav.* 15:667-79

Anglin, J. M. 1977. *Word, Object and Conceptual Development.* New York: Norton. 302 pp.

Attneave, F. 1957. Transfer of experience with a class-schema to identification-learning of patterns and shapes. *J. Exp. Psychol.* 54:81-88

Barclay, J. R., Bransford, J. D., Franks, J. J., McCarrell, N. S., Nitsch, K. 1974. Comprehension and semantic flexibility. *J. Verb. Learn. Verb. Behav.* 13:471-81

Barresi, J., Robbins, D., Shain, K. 1975. Role of distinctive features in the abstraction of related concepts. *J. Exp. Psychol.–Hum. Learn. Mem.* 104:360–68

Bartlett, F. C. 1932. *Remembering: A Study in Experimental and Social Psychology.* Cambridge: Cambridge Univ. Press. 317 pp.

Bates, E., MacWinney, B. 1980. Functionalist approaches to grammar. In *Language Acquisition: The State of the Art,* ed. L. Gleitman, E. Wanner. Cambridge: Cambridge Univ. Press. In press

Battig, W. F., Montague, W. E. 1969. Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *J. Exp. Psychol. Monogr.* 80:1–46

Beals, R., Krantz, D., Tversky, A. 1968. Foundations of multidimensional scaling. *Psychol. Rev.* 75:127–42

Berlin, B. 1972. Speculations on the growth of ethnobotanical nomenclature. *Lang. Soc.* 1:51–86

Berlin, B., Breedlove, D. E., Raven, P. H. 1973. General principles of classification and nomenclature in folk biology. *Am. Anthropol.* 75:214–42

Berlin, B., Kay, P. 1969. *Basic Color Terms: Their Universality and Evolution.* Berkeley: Univ. Calif. Press. 178 pp.

Boring, E. G. 1950. *A History of Experimental Psychology.* New York: Appleton-Century-Crofts. 777 pp. 2nd ed.

Bourne, L. E. Jr., Dominowski, R. L., Loftus, E. F. 1979. *Cognitive Processes.* Englewood Cliffs, NJ: Prentice-Hall. 408 pp.

Bowerman, M. 1978. The acquisition of word meaning: An investigation into some current conflicts. In *Development of Communication: Social and Pragmatic Factors in Language Acquisition,* ed. N. Waterson, C. Snow, pp. 263–87. New York: Wiley. 498 pp.

Bradshaw, M. 1976. An investigation of stimulus integrality in the perception of schematic faces. *Tech. Rep. 82, Dep. Psychol., Johns Hopkins Univ.*

Bransford, J. D., McCarrell, N. S. 1974. A sketch of a cognitive approach to comprehension: Some thoughts about understanding what it means to comprehend. In *Cognition and the Symbolic Processes,* ed. W. B. Weimer, D. S. Palermo, pp. 189–229. New York: Wiley. 450 pp.

Brigham, J. C. 1971. Ethnic stereotypes. *Psychol. Bull.* 76:15–38

Brooks, L. 1978. Nonanalytic concept formation and memory for instances. In *Cognition and Categorization,* ed. E. Rosch,

B. B. Lloyd, pp. 169–215. Hillsdale, NJ: Erlbaum. 328 pp.

Brown, C. H., Kolar, J., Torrey, B. J., Truong-Quang, T., Volkman, P. 1976. Some general principles of biological and non-biological folk classification. *Am. Ethnol.* 3:73–85

Brown, R. 1958. How shall a thing be called? *Psychol. Rev.* 65:14–21

Brown, R. 1976. Reference: In memorial tribute to Eric Lenneberg. *Cognition* 4:125–53

Bruner, J. S., Goodnow, J. J., Austin, J. G. 1956. *A Study of Thinking.* New York: Wiley. 330 pp.

Calder, A. 1979. Constructive mathematics. *Sci. Am.* 241:146–69

Cantor, N., Mischel, W. 1979. Prototypes in person perception. In *Adv. Exp. Soc. Psychol.* 12:3–52

Cantor, N., Smith, E. E., French, R. D., Mezzich, J. 1980. Psychiatric diagnosis as prototype categorization. *J. Abnorm. Psychol.* 89:181–93

Caramazza, A. 1979. *Are concepts ill-defined or vague?* Presented at Conf. Word & Concept, Stanford, Calif.

Cohen, C. E. 1976. *Cognitive basis of stereotyping: An information-processing approach to social perception.* PhD dissertation. Univ. Calif., San Diego

Cohen, L. B., Caputo, N. F. 1978. *Instructing infants to respond to perceptual categories.* Presented at Midwestern Psychol. Assoc. Conv., Chicago

Cohen, L. B., Gelber, E. R. 1975. Infant visual memory. In *Infant Perception: From Sensation to Cognition: Basic Visual Processes,* ed. L. B. Cohen, P. Salapatek, 1:347–403. New York: Academic. 426 pp.

Cohen, L. B., Strauss, M. S. 1979. Concept acquisition in the human infant. *Child Dev.* 50:419–24

Coleman, L., Kay, P. 1981. Prototype semantics: The English word *lie. Language,* Vol. 57. In press

Collins, A. M., Loftus, E. F. 1975. A spreading activation theory of semantic processing. *Psychol. Rev.* 82:407–28

Cooper, L. A. 1976. Individual differences in visual comparison processes. *Percept. Psychophys.* 19:433–44

Cooper, L. A., Podgorny, P. 1976. Mental transformations and visual comparison processes: Effects of complexity and similarity. *J. Exp. Psychol.–Hum. Percept. Perform.* 2:503–14

Cornsweet, T. N. 1970. *Visual Perception.* New York: Academic. 475 pp.

Cruse, D. A. 1977. The pragmatics of lexical specificity. *J. Ling.* 13:153–64

Daehler, M. W., Lonardo, R., Bukatko, D. 1979. Matching and equivalence judgments in very young children. *Child Dev.* 50:170–79

Danks, J. H., Glucksberg, S. 1980. Experimental psycholinguistics. *Ann. Rev. Psychol.* 31:391–417

Day, R. 1976. *Language-bound and language-optional processing.* Presented at Psychon. Soc., St. Louis

DeValois, R. L., Jacobs, F. H. 1968. Primate color vision. *Science* 162:533–40

deVilliers, J. 1980. The process of rule learning in child speech: A new look. In *Children's Language,* ed. K. E. Nelson, Vol. 2. New York: Gardner. In press

Dougherty, J. W. D. 1978. Salience and relativity in classification. *Am. Ethnol.* 5:66–80

Dreyfus, H. L. 1979. *What Computers Can't Do: A Critique of Artificial Reason.* New York: Harper & Row. 354 pp. 2nd ed.

Erickson, J. R., Jones, M. R. 1978. Thinking. *Ann. Rev. Psychol.* 29:61–90

Erreich, A., Valian, V. 1979. Children's internal organization of locative categories. *Child Dev.* 50:1071–77

Fillmore, C. D. 1975. An alternative to checklist theories of meaning. *Proc. 1st Ann. Meet. Berkeley Ling. Soc.* 1:123–31

Fillmore, C. D. 1977. Topics in lexical semantics. In *Current Issues in Linguistic Theory,* ed. R. W. Cole, pp. 76–138. Wilmington, Ind: Indiana Univ. Press. 303 pp.

Flavell, J. H. 1977. *Cognitive Development.* Englewood Cliffs, NJ: Prentice Hall. 286 pp.

Flavell, J. H., Wellman, H. M. 1976. Metamemory. In *Perspectives on the Development of Memory and Cognition,* ed. R. V. Kail Jr., J. W. Hagen, pp. 3–33. Hillsdale, NJ: Erlbaum. 498 pp.

Fodor, J. 1970. Three reasons for not deriving 'kill' from 'cause to die'. *Ling. Inq.* 1:429–38

Fodor, J. 1981. The current status of the innateness controversy. In *Representations,* ed. J. Fodor. Vermont: Bradford Books. In press

Fodor, J., Garrett, M., Walker, E., Parkes, R. 1980. Against definitions. *Cognition* Vol. 8. In press

Franks, J. J., Bransford, J. D. 1971. Abstraction of visual patterns. *J. Exp. Psychol.* 90:65–74

Garner, W. R. 1970. The stimulus in information processing. *Am. Psychol.* 25:350–58

Garner, W. R. 1974. *The Processing of Information and Structure.* New York: Wiley. 203 pp.

Garner, W. R. 1978a. Aspects of a stimulus: Features, dimensions, and configurations. See Brooks 1978, pp. 99–133

Garner, W. R. 1978b. Selective attention to attributes and to stimuli. *J. Exp. Psychol.–General* 107:287–308

Gelman, R. 1978. Cognitive development. *Ann. Rev. Psychol.* 29:297–332

Glass, A. L., Holyoak, K. J. 1975. Alternative conceptions of semantic memory. *Cognition* 3:313–39

Goldman, D., Homa, D. 1977. Integrative and metric properties of abstracted information as a function of category discriminability, instance variability, and experience. *J. Exp. Psychol.–Hum. Learn. Mem.* 3:375–85

Hampton, J. A. 1979. Polymorphous concepts in semantic memory. *J. Verb. Learn. Verb. Behav.* 18:441–61

Hayes-Roth, B., Hayes-Roth, F. 1977. Concept learning and the recognition and classification of exemplars. *J. Verb. Learn. Verb. Behav.* 16:321–38

Heider, E. R. 1972. Universals in color naming and memory. *J. Exp. Psychol.* 93:10–20

Hochberg, J., Galper, R. E. 1967. Recognition of faces I: An exploratory study. *Bull. Psychon. Soc.* 9:619–20

Homa, D., Cross, J., Cornell, D., Goldman, D., Shwartz, S. 1973. Prototype abstraction and classification of new instances as a function of number of instances defining the prototype. *J. Exp. Psychol.* 101:116–22

Homa, D., Vosburgh, R. 1976. Category breadth and the abstraction of prototypical information. *J. Exp. Psychol.–Hum. Learn. Mem.* 2:322–30

Hull, C. L. 1920. Quantitative aspects of the evolution of concepts. *Psychol. Monogr.* Vol. 28 (whole No. 123). 86 pp.

Hunn, E. 1975. Cognitive processes in folk ornithology: The identification of gulls. *Work. pap. No. 42. Lang. Behav. Res. Lab.,* Univ. Calif., Berkeley

Hunn, E. 1976. Toward a perceptual model of folk biological classification. *Am. Ethnol.* 3:508–24

Hupp, S. C., Mervis, C. B. 1981. *Acquisition of Basic Object Categories by Severely Handicapped Children.* Submitted for publication.

Husaim, J. S., Cohen, L. B. 1980. *Infant learning of ill-defined categories.* Presented at Int. Conf. Infant Stud. New Haven

Hutchinson, J. W., Lockhead, G. R. 1977. Similarity as distance: A structural

principle for semantic memory. *J. Exp. Psychol.–Hum. Learn. Mem.* 3:660-78

Hyman, R., Frost, N. H. 1975. Gradients and schema in pattern recognition. In *Attention and Performance,* ed. P. M. A. Rabbit, S. Dornig, 5:630-54. New York: Academic. 732 pp.

James, W. 1890a. *The Principles of Psychology,* Vol. 1. New York: Dover. 689 pp.

James, W. 1890b. *The Principles of Psychology,* Vol. 2. New York: Dover. 688 pp.

Kahneman, D., Tversky, A. 1973. On the psychology of prediction. *Psychol. Rev.* 80:237-51

Katz, J. J. 1972. *Semantic Theory.* New York: Harper & Row. 464 pp.

Kay, P., McDaniel, C. K. 1978. The linguistic significance of the meanings of basic color terms. *Language* 54:610-46

Keil, F. C. 1979. *Semantic and Conceptual Development: An Ontological Perspective.* Cambridge, Mass: Harvard Univ. Press. 214 pp.

Keller, D., Kellas, G. 1978. Typicality as a dimension of encoding. *J. Exp. Psychol.–Hum. Learn. Mem.* 4:78-85

Kemler, D. G., Smith, L. B. 1978. Is there a developmental trend from integrality to separability in perception? *J. Exp. Child Psychol.* 26:498-507

Kemler, D. G., Smith, L. B. 1979. Accessing similarity and dimensional relations: Effects of integrality and separability on the discovery of complex concepts. *J. Exp. Psychol.–General* 108:133-50

Kempton, W. 1978. Category grading and taxonomic relations: A mug is a sort of a cup. *Am. Ethnol.* 5:44-65

Kinchla, R. A., Wolf, J. M. 1979. The order of visual processing: "Top-down," "bottom-up," or "middle-out." *Percept. Psychophys.* 25:225-31

Kintsch, W. 1980. Semantic memory: A tutorial. In *Attention and Performance VIII,* ed. R. S. Nickerson. Hillsdale, NJ: Erlbaum. In press

Kogan, N. 1971. Educational implication of cognitive styles. In *Psychology and Educational Practice,* ed. G. Lesser, pp. 242-92. Glenview, Ill: Scott, Foresman. 580 pp.

Labov, W. 1973. The boundaries of words and their meanings. In *New Ways of Analyzing Variation in English,* ed. C. J. Bailey, R. Shuy, pp. 340-73. Washington: Georgetown Univ. Press. 373 pp.

Lakoff, G. 1973. Hedges: A study in meaning criteria and the logic of fuzzy concepts. *J. Philos. Logic* 2:458-508

Lakoff, G. 1977. On linguistic gestalts. *Chicago Ling. Soc. Pap.* 13:236-87

Leach, E. 1964. Anthropological aspects of language: Animal categories and verbal abuse. In *New Directions in the Study of Language,* ed. E. H. Lenneberg, pp. 23-63. Cambridge, Mass: MIT Press. 194 pp.

Lippmann, W. 1922. *Public Opinion.* New York: Harcourt, Brace. 427 pp.

Locke, J. 1690. *An Essay Concerning Human Understanding.* Annotated by A. C. Fraser, 1959. New York: Dover. 495 pp.

Lockhead, G. R. 1972. Processing dimensional stimuli: A note. *Psychol. Rev.* 79:410-19

MacKenzie, D. L., Palermo, D. S. 1981. *The Effect of Context on Semantic Categorization.* Submitted for publication

Maratsos, M. P., Chalkley, M. A. 1980. The internal language of children's syntax: The ontogenesis and representation of syntactic categories. See deVilliers 1980. In press

McCauley, C., Stitt, C. L. 1978. An individual and quantitative measure of stereotypes. *J. Pers. Soc. Psychol.* 36:929-40

McCauley, C., Stitt, C. L., Segal, M. 1980. Stereotyping: From prejudice to prediction. *Psychol. Bull.* 87:195-208

McCawley, J. 1971. Prelexical syntax. *Georgetown Univ. Monogr. Ser. Lang. Ling.* 23:19-33

McCawley, J. 1978. Conversational implicature and the lexicon. In *Syntax and Semantics,* ed. P. Cole, 9:245-59. New York: Academic. 340 pp.

McCloskey, M. E., Glucksberg, S. 1978. Natural categories: Well defined or fuzzy sets? *Mem. Cognit.* 6:462-72

McCloskey, M. E., Glucksberg, S. 1979. Decision processes in verifying category membership statements: Implications for models of semantic memory. *Cognit. Psychol.* 11:1-37

Medin, D. L., Schaffer, M. M. 1978. Context theory of classification learning. *Psychol. Rev.* 85:207-38

Mervis, C. B. 1980. Category structure and the development of categorization. In *Theoretical Issues in Reading Comprehension,* ed. R. Spiro, B. C. Bruce, W. F. Brewer. Hillsdale, NJ: Erlbaum. In press

Mervis, C. B., Catlin, J., Rosch, E. 1975. Development of the structure of color categories. *Dev. Psychol.* 11:54-60

Mervis, C. B., Catlin, J., Rosch, E. 1976. Relationships among goodness-of-example, category norms, and word frequency. *Bull Psychon. Soc.* 7:283-84

Mervis, C. B., Crisafi, M. A. 1981. *The Perceptual-Cognitive Primacy of Basic Level Categories.* In preparation

Mervis, C. B., Mirman, M. C. 1981. *The Effects of Category Size and Distortion Level on Concept Abstraction.* In preparation

Mervis, C. B., Pani, J. R. 1980. Acquisition of basic object categories. *Cognit. Psychol.* Vol. 12. In press

Meyer, D. E. 1970. On the representation and retrieval of stored semantic information. *Cognit. Psychol.* 1:242–300

Miller, G. A., Johnson-Laird, P. N. 1976. *Language and Perception.* Cambridge, Mass: Harvard Univ. Press. 760 pp.

Mirman, M. C. 1978. *The Effects of Number and Distortion Level of Category Exemplars on Concept Abstraction.* Honors BS thesis. Univ. Illinois, Urbana-Champaign

Murphy, G., Smith, E. E. 1981. *Levels of Categorization and Object Identification.* In preparation

Navon, D. 1977. Forest before trees: The precedence of global features in visual perception. *Cognit. Psychol.* 9:353–83

Neimark, E. D. 1974. Natural language concepts: Additional evidence. *Child Dev.* 45:508–11

Neimark, E. D., Santa, J. L. 1975. Thinking and concept attainment. *Ann. Rev. Psychol.* 26:173–205

Nelson, K. 1973. Some evidence for the cognitive primacy of categorization and its functional basis. *Merrill-Palmer Q.* 19: 21–39

Nelson, K. 1974. Variations in children's concepts by age and category. *Child Dev.* 45:577–84

Nelson, K. E., Nelson, K. 1978. Cognitive pendulums and their linguistic realization. In *Children's Language,* ed. K. E. Nelson, 1:223–85. New York: Gardner. 567 pp.

Neumann, P. G. 1974. An attribute frequency model for the abstraction of prototypes. *Mem. Cognit.* 2:241–48

Neumann, P. G. 1977. Visual prototype formation with discontinuous representation of dimensions of variability. *Mem. Cognit.* 5:187–97

Newport, E. L., Bellugi, U. 1978. Linguistic expression of category levels in a visual-gestural language: A flower is a flower is a flower. See Brooks 1978, pp. 49–71

Oden, G. C., Massaro, D. W. 1978. Integration of featural information in speech perception. *Psychol. Rev.* 85:172–91

Palmer, S. E. 1975. Visual perception and world knowledge: Notes on a model of sensory-cognitive interaction. In *Explo-ration in Cognition,* ed. D. A. Norman, D. E. Rumelhart, LNR Research Group, pp. 279–307. San Francisco: Freeman. 430 pp.

Palmer, S. E. 1978. Fundamental aspects of cognitive representation. See Brooks 1978, pp. 259–303

Piaget, J. 1970. Piaget's theory. In *Carmichael's Manual of Child Psychology,* ed. P. H. Mussen, 1:703–32. New York: Wiley. 1519 pp. Piaget, J. 1972. *The Principles of Genetic Epistemology.* New York: Basic Books. 98 pp.

Pittenger, J. B., Shaw, R. E. 1975. Aging faces as visual-elastic events: Implications for a theory of nonrigid shape perception. *J. Exp. Psychol.-Hum. Percept. Perform.* 1:374–82

Pittenger, J. B., Shaw, R. E., Mark, L. S. 1979. Perceptual information for the age level of faces as a higher order invariant of growth. *J. Exp. Psychol.-Hum. Percept. Perform.* 5:478–93

Posnansky, C. J. 1973. *Category norms for verbal items in 25 categories for children in grades 2-6.* Prog. Cognit. Factors Hum. Learn. Mem., Rep. 7, Univ. Colo., Boulder

Posnansky, C. J., Neumann, P. G. 1976. The abstraction of visual prototypes by children. *J. Exp. Child Psychol.* 21:367–79

Posner, M. I. 1969. Abstraction and the process of recognition. In *The Psychology of Learning and Motivation,* ed. G. H. Bower, J. T. Spence, 3:44–96. New York: Academic. 398 pp.

Posner, M. I., Goldsmith, R., Welton, K. E., Jr. 1967. Perceived distance and the classification of distorted patterns. *J. Exp. Psychol.* 73:28–38

Posner, M. I., Keele, S. W. 1968. On the genesis of abstract ideas. *J. Exp. Psychol.* 77:353–63

Potter, M. C., Faulconer, B. A. 1979. Understanding noun phrases. *J. Verb. Learn. Verb. Behav.* 18:509–21

Rabinow, P., Sullivan, W. M., eds. 1979. *Interpretive Social Science: A Reader.* Berkeley: Univ. Calif. Press. 367 pp.

Reber, A. S. 1976. Implicit learning of synthetic languages: The role of instructional set. *J. Exp. Psychol.-Hum. Learn. Mem.* 2:88–94

Reed, S. K. 1972. Pattern recognition and categorization. *Cognit. Psychol.* 3:382–407

Reed, S. K. 1973. *Psychological Processes in Pattern Recognition.* New York: Academic. 244 pp.

Reed, S. K., Friedman, M. P. 1973. Perceptual vs. conceptual categorization. *Mem. Cognit.* 1:157–63

Ricciuti, H. N. 1965. Object grouping and selective ordering behavior in infants 12 to 24 months old. *Merrill-Palmer Q.* 11:129–48

Riley, D. A., Lamb, M. R. 1979. Stimulus generalization. In *Perception and Its Development: A Tribute to Eleanor J. Gibson,* ed. A. D. Pick, pp. 7–37. Hillsdale, NJ: Erlbaum. 258 pp.

Rips, L. J. 1975. Inductive judgments about natural categories. *J. Verb. Learn. Verb. Behav.* 14:665–81

Rips, L. J., Shoben, E. J., Smith, E. E. 1973. Semantic distance and the verification of semantic relations. *J. Verb. Learn. Verb. Behav.* 12:1–20

Rock, I. 1973. *Orientation and Form.* New York: Academic Press. 165 pp.

Rosch, E. H. 1973a. Natural categories. *Cognit. Psychol.* 4:328–50

Rosch, E. 1973b. On the internal structure of perceptual and semantic categories. In *Cognitive Development and the Acquisition of Language,* ed. T. E. Moore, pp. 111–44. New York: Academic. 308 pp.

Rosch, E. 1974. Linguistic relativity. In *Human Communication: Theoretical Explorations,* ed. A. Silverstein, pp. 95–121. Hillsdale, NJ: Erlbaum. 264 pp.

Rosch, E. 1975a. Cognitive reference points. *Cognit. Psychol.* 7:532–47

Rosch, E. 1975b. Cognitive representations of semantic categories. *J. Exp. Psychol.– General* 104:192–233

Rosch, E. 1975c. The nature of mental codes for color categories. *J. Exp. Psychol.– Hum. Percept. Perform.* 1:303–22

Rosch, E. 1977. Human categorization. In *Studies in Cross-Cultural Psychology,* ed. N. Warren, 1:3–49. London: Academic. 212 pp.

Rosch, E. 1978. Principles of categorization. See Brooks 1978, pp. 27–48

Rosch, E. 1979. *Attributes.* Presented at Conf. Word & Object, Stanford, Calif.

Rosch, E., Mervis, C. B. 1975. Family resemblances: Studies in the internal structure of categories. *Cognit. Psychol.* 7:573–605

Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M., Boyes-Braem, P. 1976a. Basic objects in natural categories. *Cognit. Psychol.* 8:382–439

Rosch, E., Simpson, C., Miller, R. S. 1976b. Structural bases of typicality effects. *J. Exp. Psychol.–Hum. Percept. Perform.* 2:491–502

Rosner, S. R., Hayes, D. S. 1977. A developmental study of category item production. *Child Dev.* 48:1062–65

Ross, G. 1977. Concept categorization in 1 to 2 year olds. Presented at Bien Meet. Soc. Res. Child Dev., New Orleans

Ross, J. 1972. The category squish: Endstation Hauptwort. *Chicago Ling. Soc. Pap.* 8:316–29

Saltz, E., Dixon, D., Klein, S., Becker, G. 1977. Studies of natural language concepts: III. Concept overdiscrimination in comprehension between two and four years of age. *Child Dev.* 48:1682–85

Saltz, E., Soller, E., Sigel, I. E. 1972. The development of natural language concepts. *Child Dev.* 43:1191–1202

Schank, R. C. 1973. Identification of conceptualizations underlying natural language. In *Computer Models of Thought and Language,* ed. R. C. Schank, K. M. Colby, pp. 187–247. San Francisco: Freeman. 454 pp.

Schank, R. C., Abelson, R. P. 1977. *Scripts, Plans, Goals and Understanding: An Inquiry into Human Knowledge Structures.* Hillsdale, NJ:Erlbaum. 248 pp.

Shepard, R. N., Chipman, S. 1970. Second-order isomorphism of internal representations: Shapes of states. *Cognit. Psychol.* 1:1–17

Shepp, B. E. 1978. From perceived similarity to dimensional structure: A new hypothesis about perceptual development. See Brooks 1978, pp. 135–67

Shepp, B. E., Swartz, K. B. 1976. Selective attention and the processing of integral and nonintegral dimensions: A developmental study. *J. Exp. Child Psychol.* 22:73–85

Simpson, G. G. 1961. *Principles of Animal Taxonomy.* New York: Columbia Univ. Press. 247 pp.

Smith, E. E. 1978. Theories of semantic memory. In *Handbook of Learning and Cognitive Processes,* ed. W. K. Estes, 6:1–56. Hillsdale, NJ: Erlbaum. 311 pp.

Smith, E. E., Balzano, G. 1977. *Concepts and prototypes.* Colloquium, Harvard Univ.

Smith, E. E., Medin, D. L. 1981. *The Psychology of Conceptual Processes.* Cambridge, Mass: Harvard Univ. Press. In press

Smith, E. E., Rips, L. J., Shoben, E. J. 1974. Semantic memory and psychological semantics. In *The Psychology of Learning and Motivation,* ed. G. H. Bower, 8:1–45. New York: Academic. 305 pp.

Smith, L. B., Kemler, D. G. 1977. Developmental trends in free classification: Evidence for a new conceptualization of perceptual development. *J. Exp. Child Psychol.* 24:279–98

Smith, L. B., Kemler, D. G. 1978. Levels of experienced dimensionality in children and adults. *Cognit. Psychol.* 10:502–32

Sneath, P. H. A., Sokal, R. R. 1973. *Numerical Taxonomy*. San Francisco: Freeman. 573 pp.

Sokal, R. R. 1974. Classification: Purposes, principles, progress, prospects. *Science* 185:1115–23

Strauss, M. S. 1979. Abstraction of prototypical information by adults and 10-month-old infants. *J. Exp. Psychol.–Hum. Learn. Mem.* 5:618–32

Stross, B. 1973. Acquisition of botanical terminology by Tzeltal children. In *Meaning in Mayan Languages,* ed. M. Edmonson, pp. 107–42. The Hague: Mouton. 256 pp.

Tversky, A. 1977. Features of similarity. *Psychol. Rev.* 84:327–52

Tversky, A., Gati, I. 1978. Studies of similarity. See Brooks 1978, pp. 79–98

Wanner, E. 1979. *Discussion of prototypes.* Presented at Meet. Soc. Philos. Psychol., New York

Whitfield, T. W. A., Slatter, P. E. 1979. The effects of categorization and prototypicality on aesthetic choice in a furniture selection task. *Br. J. Psychol.* 70:65–75

Whitten, W. B. II, Suter, W. N., Frank, M. L. 1979. Bidirectional synonym ratings of 464 noun pairs. *J. Verb. Learn. Verb.*

*Behav.* 18:109–27

Williams, T. M., Fryer, M. L., Aiken, L. S. 1977. Development of visual pattern classification in preschool children: Prototypes and distinctive features. *Dev. Psychol.* 13:577–84

Winograd, T. 1972. Understanding natural language. *Cognit. Psychol.* 3:1–191

Winograd. T. 1975. Frame representations and the declarative-procedural controversy. In *Representation and Understanding: Studies in Cognitive Science,* ed. D. G. Bobrow, A. Collins, pp. 185–210. New York: Academic. 427 pp.

Winston, P. H. 1975. Learning structural description from examples. In *The Psychology of Computer Vision,* ed. P. H. Winston, pp. 157–210. New York: McGraw-Hill. 282 pp.

Witkowski, S. R., Brown, C. H. 1978. Lexical universals. *Ann. Rev. Anthropol.* 7:427–51

Wittgenstein, L. 1953. *Philosophical Investigations.* New York: Macmillan. 232 pp.

Yin, R. K. 1969. Looking at upside-down faces. *J. Exp. Psychol.* 81:141–45

Zadeh, L. A. 1965. Fuzzy sets. *Inf. Control* 8:338–53