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Functional and Conditional Equivalence: Conceptual Contributions from Behavior Analysis

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Abstract

Behavior analysis has recently developed a new paradigm for the study of categorization and language based on the mathematical notion of equivalence. Inspired by this paradigm, this paper presents a definitional framework that could be relevant for several of the phenomena under study in Cognitive Science. First, categories are viewed as classes of functional equivalence. By doing so, results from behavior analysis and cognitive psychology seem to converge towards an experience-based interpretation of category basicness. Second, conditional equivalence is proposed as the basis for symbol-meaning and symbol-symbol relationships. Transfer of function through conditional links is suggested as the mechanism of connection between language and other aspects of cognition. The adoption and extension of these functionalist formalisms provides us with significant methodological, conceptual and even empirical advantages.

Introduction: Equivalence Relations

Behavior analysis is not one of the constituent partners of Cognitive Science because of unfortunate historical circumstances. This paper will try to show how recent conceptual and methodological innovations developed within the behavior analytic discipline can be extremely relevant for cognitive science. The new paradigm, based on the mathematical notion of equivalence relation, provides a coherent conceptual framework in which results and theories of categorization and language can be interpreted.

Equivalence is, mathematically speaking, a relation between two objects of certain space that is reflexive, symmetric and transitive. Let A, B, C, etc. be arbitrary objects of a given space, and $\sim$, a relation defined among those elements. *Reflexivity* requires that any object in the space be related to itself ($A \sim A$). *Symmetry* requires that, if an object A is related to another object B ($A \sim B$), then B must be related to A ($B \sim A$). *Transitivity* requires that, if $A \sim B$ and $B \sim C$, then it must be the case that $A \sim C$. If the relation $\sim$ is an equivalence relation and $A \sim B$, then A and B are said to be *equivalent* with respect to $\sim$. Each equivalence relation induces a partition of the space into non overlapping classes of equivalence. Given any particular object A, the set of all objects that are equivalent to it constitute the equivalence class of A. An equivalence class is completely specified by any of its members.

The notion of *relation* has a long history in experimental psychology. From the stimulus-stimulus and stimulus-response links proposed by early theories of classical and operant conditioning, up to some of the most recent models of semantic memory (Anderson, 1991) and category acquisition (Gluck, 1991), the concept of relation among a set of objects --be they stimuli, responses or cognitive structures-- seems to be unavoidable. However, it has not been until recently that behavior analysts have raised the question of whether any of the relations formed by animals and humans are equivalence relations.

Functional Equivalence and Categories

The behavior analytic tradition studies behavior as a *function* of stimuli that varies with the history of the individual organism. Let us define *psychological function* as a context dependent relation between a stimulus and an action, where *context* refers not only to situational aspects but also to an agent's goal[1]. Like algebraic functions, every psychological function can be said to have a *domain*, which is defined as the set of all stimuli with some effect on its outcome. For example, "mushroom-gathering" can be thought of as a psychological function whose domain consists of all visual perceptions of mushrooms, and whose outcome can be specified as a positive or negative selection (the mushroom is picked or not). Psychological functions can be innate or acquired. Through learning, an agent can form new functions or adapt existing ones in order to increase the likelihood of achieving its goals. For example, mountain people that have developed an appropriate mushroom-gathering function are more likely to satisfy their hunger (feeding goal) and avoid poisonous reactions (sickness prevention goal).

Each psychological function f induces an equivalence relation $\sim f \sim$ among the elements of its domain, A, B, etc., such that $A \sim f \sim B$ if and only if $f(A) = f(B)$. In other words, two stimuli are equivalent with respect to a given psychological function if they can be substituted for each other without affecting the outcome of the function. The

[1] Since the concepts discussed in this paper apply to both natural and artificial agents, the terms "organism" and "agent" will be used interchangeably.

equivalence relation so defined, creates a partition of the function's domain into equivalence classes or *functional classes*. The elements of a given functional class have the common property of producing the same outcome under a certain psychological function. For example, a person's mushroom-gathering function may partition all possible perceptions of mushrooms into two functional classes: poisonous and non-poisonous mushrooms. On the contrary, elements of a function's domain that produce different outcomes will be referred to as functionally *distinct*. Any two elements of a function's domain must be either equivalent or distinct with respect to the function.

Functional classes are the behaviorist counterpart to *categories* in cognitive science. Under the functional approach, category acquisition is viewed as the induction of a partition for a new psychological function. In other words, the problem of learning a new category consists of figuring out what elements in the domain of a new function require the same action and what elements require different actions. To the extent that functional classes relate some aspect of the environment with a possibility of action, functional classes may also be viewed, from the ecological perspective, as Gibsonian *affordances* (Greeno, 1994).

The domains of different psychological functions are not necessarily disjoint. In fact, many psychological functions associated with different contexts may have the exact same domain. This does not mean that functions with the same domain must induce the same partition. Finding wood for construction and for making a fire are two functions on the same domain (wood), that do not induce the same partition: some sorts of wood may be good for fire and construction, while others may be good for fire only. However, it could be the case that two different functions not only share their domain, but also induce the same partition on the domain. In this case, the members of a functional class would be equivalent with respect to both functions, although the specific outcome they would produce under each of the two functions might actually be quite different.

Let us define *functional load* or *strength* of a functional class (or category) as a measure of: (a) the number of psychological functions for which its elements are equivalent, (b) the frequency of occurrence of those functions in the organism's life, and (c) the relevance of the functions for the organism's existence. That is to say, strong or highly loaded categories are those whose elements are equivalent with respect to a large class of frequently occurring relevant psychological functions. Functional load has a direct effect on the speed and accuracy with which an organism categorizes a stimulus: the more frequently an organism needs to make a discrimination, and the more relevant the discrimination is, the more efficiently the discrimination is performed. As we will see, functional load may also have an important effect in the learning of new categories.

The elements of a category (e.g. DOGS) can be further partitioned by a new function into smaller categories (German-Shepherd, Golden-Retriever, etc.) These embedded functional classes are normally referred to as *subcategories* of the initial category (see Figure 1). Analogously, elements of two distinct categories (e.g. dogs, cats, horses) may be equivalent with respect to a new function. In this case, the new function is said to induce a *supercategory* (mammals) of the previously acquired categories. In principle, it is also possible that a new function induces a partition that cuts across the boundaries of previously acquired categories (see Figure 2). For example, the partition PET / WILD-ANIMAL cuts across the boundaries of the partition MAMMAL / BIRD / REPTILE.

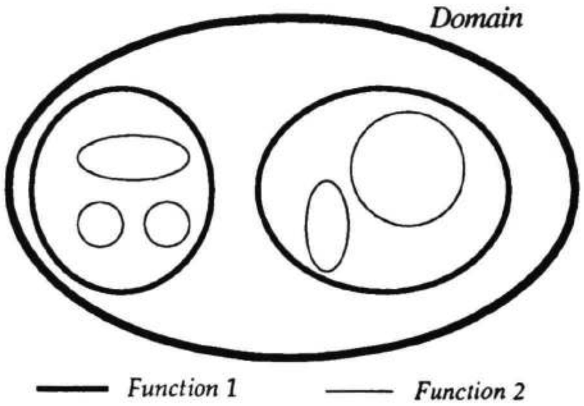

Figure 1: Example of embedded partition or subcategory.

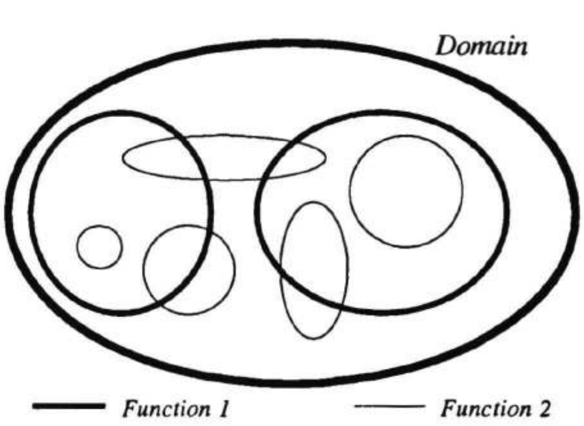

Figure 2: Example of crossed partitions.

One of the main advantages of this definitional framework is that it allows us to express hypotheses about category acquisition in an unambiguous way. It provides a common ground on which apparently unrelated or even opposing theories can be compared. Moreover, it lets us address the effect of prior categories in the formation of new categories. Consider for instance the following two hypotheses:

Hypothesis 1

When acquiring new categories, human learners are biased toward considering partitions that do not cut across the boundaries of previously acquired categories. The higher the functional load of the previous categories, the stronger the bias toward preserving their boundaries.

Hypothesis 2

When acquiring new categories, human learners are biased toward choosing partitions that have shown high functional load in the past.

An immediate implication of Hypothesis 1 is that human categories tend to be hierarchically organized. Whereas this phenomenon is not big news for cognitive science (Keil, 1983), the functional framework allows us to describe it in terms of learning biases or constraints that may result in such an organization. Once a given partition of a domain has been formed, learners are biased against producing new crossed partitions like in Figure 2. Category formation is not only based on specific learning contingencies, but also on the categories the learner has previously acquired. The functional framework also allows us to be more explicit in claims regarding category basicness. Let us define the *basic level of categories* in a given domain as the level in the hierarchy of partitions with the highest functional load. By doing so, we give the otherwise "magic" basic level an experience-based character. Another implication from the first hypothesis is the claim that the closer we get to the basic level, the more difficult it becomes to form crossed categories. To my knowledge, this claim has still not been directly tested experimentally.

Hypothesis 2 on the other hand, underlines the effect of functional load in guiding new learning. When the learner faces the task of finding the partition induced by a new function, partitions that have been successful in the past are preferred over novel partitions. If it is the case that the members of a preexisting category are also equivalent with respect to the new function, this bias facilitates the learning considerably by reducing the number of instances needed to find the new partition of the domain. Evidence from a large variety of experiments seems to support this claim. For example, when children learn a new property of a certain object, they tend to generalize the property to the members of the basic category the object belongs to, as opposed to the less functionally loaded subordinate and superordinate levels (Gelman & O'Reilley, 1988). When acquiring language, children tend to generalize novel labels to taxonomically related objects as opposed to thematically related ones (Markman, 1990). If we view "labeling" as a psychological function, and learning a new word as figuring out the category the label refers to, the taxonomic bias becomes a particular case of Hypothesis 2: children tend to generalize new labels to classes of objects that have shown functinal equivalence in the past.

Hypothesis 2 also accounts for results of animal learning. Vaughan (1988) trained pigeons to produce discriminative responses in the presence of two classes of visual stimuli. Then, he reversed the pattern of responding several times by manipulating reinforcing contingencies, but always preserving the same partition of the domain into the two original classes. After several of those reversals took place, pigeons were able to generalize new response patterns to all the members of each of the two classes in just a couple of trials. Consistent with our second hypothesis, the reversals had contributed to increasing the functional load of the two classes, which facilitated the generalization of a new function within each of the two categories (see also Bonardi, Rey, Richmond & Hall, 1993).

Hypotheses 1 and 2 combined provide an explanation of the human preference for the basic level in generalization tasks. An explanation based not just on the structure of the environment, but on the history of interactions between the learner and its environment.

Conditional Equivalence and Symbol Grounding

Human and non human organisms can be taught conditional discrimination relations between arbitrary classes of stimuli. In a typical matching to sample task, subjects learn to select a certain target from a set of *comparison* stimuli following the presentation of a discriminative or *sample* stimulus. For instance, given discriminative stimuli *A1* (a red light) and *A2* (a green light), the subject is taught to select stimulus *B1* (a square) following the presentation of *A1* and *B2* (a circle) following the presentation of *A2*, by positive reinforcement of the appropriate choices. The conditional relation being learned in a task of this sort is nothing but the selection production "if stimulus *A1* is observed, then select stimulus *B1*". Production rules need not be, in general, equivalence relations. For example, the fact that an organism has learned to select a square in the presence of a red light does not necessarily imply that the organism will choose a red key whenever a square is observed, unless this relation is explicitly trained. The question of which organisms are able to generate conditional equivalence relations without explicit training was initially raised by Sidman and Tailby in 1982.

To test the conditional equivalence capacity of an organism, the experimenter first trains the subject to perform certain conditional discriminations and then tests whether those specific relations that prove mathematical equivalence emerge without explicit training. Spontaneous emergence of conditional equivalence was first reported by Sidman and Tailby (1982). Several retarded youths were trained to select one of 20 pictures (*B* stimuli) conditionally upon hearing any of 20 novel picture names (*A* stimuli). Then they were taught to select novel printed names (*C* stimuli) conditionally upon hearing one of the picture names (*A*). Finally, tests of emergent conditional relations showed that subjects were able to select the pictures corresponding to each printed name and vice versa. So, after having learned 20 productions "if A then B" and 20 "if A then C", subjects demonstrated to have formed 20 new productions "if B then C" and 20 "if C then B".

An extensive body of research shows that humans (children and adults) are capable of forming complex conditional equivalence classes with stimuli of different kinds: visual (Lazar, Davis-Lang & Sánchez, 1984; Sidman & Tailby, 1982; Sidman, Kirk and Willson-Morris, 1985), auditory (Dube, Green & Serna, 1993), interoceptive --i.e. drugs-- (DeGrandpre, Bickel & Higgins, 1992), reinforcing items (Dube, McIlvane, Mackay and Stoddard, 1987), etc.

There is also some preliminary evidence relating conditional equivalence formation with functional equivalence. Sidman, et al. (1989) found that normal adults spontaneously induce conditional equivalence among the members of a functional class. Moreover, they found that new stimuli could be added to an existing functional class by establishing a conditional relation between some of the members of the functional class and the new stimuli. Curiously enough, these findings seem to further support Hypothesis 2. Conditional discriminations are, according to our definition, instances of psychological function whose domain is the set of comparison stimuli and whose outcome consists of selecting one of the sample stimuli. In the learning of a new discrimination rule, it is likely that prior strong functional classes be used as function generalization vehicles.

It is a common belief among conditional equivalence researchers that forming conditional equivalence links may be tightly related to the ability of associating verbal labels with categories (Hayes & Hayes, 1992). If a child is taught to pick up some object after a particular noun is uttered, the child may later utter some approximate version of the same word when shown that same object, without specific instruction to do so. When that happens, we can argue that the child has learned a conditional equivalence relation between the word and the class of objects it refers to (Sidman & Tailby, 1982). The strong version of this hypothesis can be stated as:

Hypothesis 3

The relationship between a verbal label and the category it refers to is a conditional equivalence relation.

An indirect way of supporting this hypothesis consists of showing that non verbal organisms do not form conditional equivalence links very easily or at all. Based on the experimental evidence collected in the last years, this seems to be the case. Devany, Hayes and Nelson (1986) compared performance in a conditional equivalence task among normal and retarded children with different degrees of linguistic ability. The results of their matching to sample task showed that only children with no verbal competence were unable to form conditional equivalence relations. Sidman et al. (1982) compared conditional discrimination performance of monkeys, baboons and children, and only found evidence for symmetry in the children. D'Amato et al. (1985) found transitivity in monkeys but not in pigeons. Neither monkeys nor pigeons were able to form symmetric relations. Whereas a large number of animals can learn conditional discrimination rules, no valid proof of conditional equivalence in animals is yet available.

If hypothesis 3 is true, i.e. if the link between a label and the class of objects the label refers to actually can be characterized as a conditional equivalence relation, the question of whether and how function is transferred through a conditional equivalence link acquires tremendous relevance. It does so because the answer to that question would help explain the relationship between language and other aspects of cognition and action. A general tentative answer is given below:

Hypothesis 4

Conditional discrimination links between functional classes and the symbols of a language can induce some degree of functional transfer from the classes to the symbols and vice versa.

This notion of function transfer could provide a learning account of the coupling between semantic and syntactic structure in adults (Fisher, Gleitman & Gleitman, 1991), the effects of language structure in category formation (Cabrera & Billman, 1993) and other relevant phenomena..

Some preliminary support for this hypothesis has been presented by Barnes and Keenan (1993). Several undergraduate students were taught the conditional equivalence relations $A1 \rightarrow B1$, $A2 \rightarrow B2$, $A1 \rightarrow C1$ and $A2 \rightarrow C2$ (all labels represent categories of visual stimuli). Then, two different patterns of actions were trained under control by $C1$ and $C2$: subjects were taught to produce fast responses in the presence of $C1$ and slow responses in the presence of $C2$. They found that the patterns of responding learned for $C1$ and $C2$ transferred without explicit instruction to the classes $B1$ and $B2$. Although these are interesting results, the issue of what exact sorts of functions are transferred through conditional rules is still to be experimentally solved (Hayes, 1989; Hayes & Hayes, 1992).

In summary, conditional links may provide channels through which some functions can be transferred. Figuring out the nature of that transfer remains an open experimental challenge.

Discussion

One of Cognitive Science's present obstacles is the scarcity of coherent and unambiguous definitional formalisms of its subject matter. Despite the extensive research that has been devoted to trying to understand the human ability to form categories, no consensus has yet been reached as to what categories really are. Whether they are internally represented as a system of prototypes, exemplars, connection weights or correlations among features, nobody seems to dare to specify what it is that we are studying when we study categories. An analogously disappointing statement can be made about many other problems, such as the relationship between language and other aspects of cognition. In this paper I have tried to take a step toward developing a definitional framework for categorization research by borrowing a few conceptual notions from the behavior analytic field.

Functional equivalence has been suggested as a definitional basis for categories. By doing so, results from different areas in psychology seem to converge toward the idea that learners may be biased toward preserving highly functionally loaded partitions when acquiring new categories (Hypotheses 1 and 2), and toward preferring nested (hierarchical) over crossed partitions (Hypothesis 1). This view may challenge current notions of category basicness (Corter & Gluck, 1992; Anderson, 1991) according to which, the correlational structure of the environment is responsible for a given level of categories (the basic level) being more accessible than its subordinate or superordinate levels. Instead, basicness may be due to the repeated successful occurrence of a given partition throughout the life of an organism. So, the fact that DOG is a basic category may not be due to the perceptual properties of dogs per se, but to the fact that, in our lives, the partition DOG / CAT / COW / HORSE tends to be more functionally loaded than the partition MAMMALS / BIRDS / FISH / REPTILE.

The notion of functional equivalence is not novel to linguists. In some sense, psychological function and functional equivalence are analogous to the concepts of *syntagmatic* and *paradigmatic* relationships. When two linguistic units are combined to build an expression, they are said to be in syntagmatic relationship. Two linguistic objects are said to be in paradigmatic relationship when they can hold the same syntagmatic relationship with some linguistic unit, i.e. when they can play similar roles in building a more complex unit. For example, "my cousin", "the person next to me" and "he" are paradigmatically related because of their syntagmatic subjecthood relationship with "is eating", "feels bad" or "won't come". Notice that syntagmatic relationships can be viewed as *linguistic functions*, and paradigmatic relationship as the equivalence relations induced by those functions. Paradigmatic relations can be thought of as partitioning the space of linguistic units into *linguistic categories*. The question of whether linguistic functions and linguistic categories share any properties at all with other modalities of psychological functions and functional classes is an open empirical problem.

This paper has also suggested that conditional equivalence could offer an interesting interpretation of symbol-meaning and symbol-symbol relationships (Hypothesis 3). Speech understanding can be thought of as conditional matching of auditory to visual stimuli, internal states or actions. Reading aloud could be thought of as conditional matching of visual stimuli to oral responses. Learning a second language can be thought of as a combination of expanding the existing symbolic equivalence classes by adding new members to each class, and the acquisition of new classes not existing in the first language. This interpretation of language may provide new insight into the way language interacts with human behavior. Conditional links may act as function transfer channels between perceptual categories and the units of the language refering to those categories (Hypothesis 4).

It has recently been suggested that conditional equivalence links may just be a particular case of function transfer relation or *relational frame* (Hayes and Hayes, 1992). A relational frame is a relation with specific function transfer characteristics that is established in a particular context. Relational frames can be learned. Learning a relational frame consists of abstracting, from experience, the sort of functional transfer required by relations established in a certain context. The first time that a category is associated with a label in a new context, no transfer of function may take place. However, if, through direct experience with the category and the label, the agent discovers some common functions in both category and label, a relational frame associated with that context can be abstracted so that automatic function transfer can take place the next time a category is given a label in the same context. This ability has the beneficial consequence of allowing the agent to be instructed from other agents about how to behave in novel situations without necessarily having to experience those situations personally.

The functionalist framework presented in this paper fits particularly well with the research agenda of situated and ecological approaches to cognition (Greeno, 1994). On the contrary, it may awaken some discomfort among advocates of traditional "symbolic" cognitive science for its apparent disregard for internal mechanisms[2]. The question, some would claim, is not whether functional load of categories affects future learning, but what mechanisms may be responsible for that effect. However, D. Marr, A. Newell and J. Anderson (see. Anderson, 1991) have agreed on the importance of analyzing cognition not just at the level of possible internal mechanisms (algorithm or symbol level), but also at the level of overall computational goals (computational, knowledge or rational level). The functional formalism discussed in this paper belongs to the latter. The study and design of models that can account for or reproduce that behavior is a related but independent problem.

My conjecture with regard to this issue is that connectionist architectures may be particularly well suited for modeling functional load learning biases for several reasons (Clark, 1993): (a) connectionist models are good partitioning devices, (b) connectionist models reproduce in an elegant way phenomena related to category boundary fuzziness, and (c) the adaptation of hidden layer nodes in order to detect complex features of the input could be interpreted as a bias toward considering category boundaries resulting from previous learning experiences. It is not obvious, however, whether purely connectionist models could be able to deal with conditional equivalence and transfer of function. It would be interesting to see which of the current models of artificial adaptive agents have that capacity. A preliminary test could be as follows:

1. Train the agent to produce action A under stimulus category A and action B under stimulus category B.
2. Train the agent to chose label A under stimulus category A and label B under stimulus category B.
3. Train the agent to produce action A under label A.
4. Test: Is the agent able to produce action B under label B without being explicitly trained to do so?

Conclusion

Behavior analysis has been unfairly stereotyped and disregarded by cognitive science in general. It is probably true that behavior analysis' low tolerance for ambiguity has kept its disciples from facing problems about complex

[2]This issue was, in fact, raised by one of the anonymous reviewers of the earlier version of this paper.

human skills. However, this Skinnerian obsession for scientific rigor has had the side effect of producing a highly coherent body of conceptual formalisms that should not be underestimated. In this paper I have tried to show how cognitive science can take advantage of some of these formalisms in trying to build its own. Bridging the doctrinal schism between the cognitivist and the behaviorist traditions may be fruitful in several ways: methodologically, conceptually and empirically. It may even prevent us from reinventing the wheel.

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