

# DOCUMENT DELIVERY ARTICLE

**Journal Title:** Animal cognition :  
proceedings of the Harry Frank  
Guggenheim Conference, June 2-4,  
1982

**Trans. #:** 405319



**Article Author:** Bever, T.G.

**Call #:** QL785 .H355 1982 c.2

**Article Title:** The road from  
behaviorism to rationalism.

**Location:** Science-Engineering Library

**Volume:**

**Item #:**

**Issue:**

**Month/Year:** 1984

**Pages:** 61-73

**Imprint:**

## CUSTOMER INFORMATION:

**HOLLIS J WEIDENBACHER**  
hjweiden@email.arizona.edu

**STATUS:** Staff  
**DEPT:** Psychology

**University of Arizona Library**  
**Document Delivery**  
1510 E. University Blvd.  
Tucson, AZ 85721  
(520) 621-6438  
(520) 621-4619 (fax)  
AskILL@u.library.arizona.edu

**Paged by** KSJ (Initials)

**Reason Not Filled (check one):**

- NOS  NFAC (GIVE REASON)  
 LACK VOL/ISSUE  OVER 100 PAGES  
 PAGES MISSING FROM VOLUME

**Rec'd:** 9/29/2007 09:30:03 AM

University of Arizona Document Delivery

- Wasserman, E. A. Further remarks on the role of cognition in the comparative analysis of behavior. *Journal of the Experimental Analysis of Behavior*, 1982, 38, 211-216.
- Wasserman, E. A. Is cognitive psychology behavioral? *The Psychological Record*, 1983, 33, 6-11.
- Yerkes, R. M. Animal psychology and criteria of the psychic. *Journal of Philosophy, Psychology, and Scientific Methods*, 1905, 2, 141-149.

#### 4 THE ROAD FROM BEHAVIORISM TO RATIONALISM

Thomas G. Bever  
Columbia University

##### I. ON THE ROAD

Most of the articles in this book reflect some dissatisfaction with the behaviorist approach to animal activity. During the last 70 years behaviorism has appeared in many guises - for the present discussion I will assume that a behaviorist framework follows two principles:

Physicalism:  
every term in a description must be based on a physically definable entity.

Associationism:  
distinct descriptive terms can be related to each other only by undifferentiated association.

Many scholars now doubt that certain aspects of animal behavior can be described by a model which strictly obeys such postulates. This doubt underlies what can be taken as the current "cognitive revolution" in the study of animal behavior. In this essay, I contrast two directions that this revolution can now take; one that continues the emphasis on learning particular behaviors for which the behaviorist framework still appears to be adequate, and a new direction towards rationalism - the unashamed description of animal minds.

The inadequacy of behaviorism as a complete account of behavior has in fact been known for a long time. The demonstration of perceptual gestalten simultaneously invalidated the physicalist and associationist principles, by proving the existence of internal plans of perception (Wertheimer, 1923); rapidly-executed and species-specific behaviors indicated the presence of internal plans of action (Tinbergen, 1951); maze learning in rats was shown to be like acquiring a "map" of the maze rather than a series of responses (Tolman, 1948); the conceptual unity of reasoning processes in higher primates inexplicable by any compilation of behaviorist principles (Kohler, 1925). Thus, a definitive crisis in animal psychology should have occurred many years ago. It is instructive to consider why it did not.

How should psychologists have responded to crucial demonstrations of behaviorism's inadequacies? There were two choices: one could reject

behaviorism entirely, or one could retain it for those phenomena for which it was not yet invalidated. The latter choice required two related assumptions, one about descriptive efficiency, the other about organismic efficiency. I will call these assumptions Descriptive and Representational Reductionism.

#### Descriptive Reductionism:

Science best proceeds by applying only the weakest descriptive device until forced to apply a stronger one.

#### Representational Reductionism:

An animal organizes each newly acquired behavior with the most concrete mechanisms available.

The appeal of these assumptions explains why gestalt and ethological demonstrations of abstract perceptual and conceptual units had little impact on the behaviorist program. The first assumption allowed behaviorism to continue as the theory of non-gestalt phenomena; the second assumption rationalized the application of behaviorist descriptions to behaviors of higher animals whenever possible. This scientific posture was aided further by the fact that the simple gestalt and ethological phenomena were taken to be innate and not a problem for learning theory; the learned skills that were also complex were limited to a few higher organisms, such as apes and humans.

Descriptive reductionism is a doctrine from the philosophy of science, whose acceptance depends on its overall efficacy – yet, there are notorious counterexamples to the view that science best proceeds from the simple to the complex. Often a crucial scientific revolution is characterized by the replacement of an unwieldy and complex model with a much simpler one that makes different assumptions. I do not wish to belabor this point, since the general topic is more appropriate for a philosophical context. The primary moral for our considerations here is that descriptive reductionism is not always the correct move; therefore, it was not necessary to maintain behaviorism as true of some phenomena, once it was proven to be inadequate for other phenomena.

Descriptive reductionism has another argument that can be made in its favor – if representational reductionism is true, then descriptive reductionism will be most likely to lead us to correct theories of how new skills are learned. This raises a question that is potentially empirical – is representational reductionism true?

#### A. REPRESENTATIONAL REDUCTIONISM IS NOT TRUE OF AT LEAST ONE ANIMAL

To examine the validity of representational reductionism we must first define a concrete/abstract continuum for representations; such a continuum is required to give content to the claim that one kind of representation is more concrete than another. The definition of such a continuum is surely a central theoretical problem for psychological science, one which I will

not solve here. Rather, I will rest my argument on some intuitive notions of this continuum and attempt to use only clear relative cases along it, cases that will hold up even when a precise scientific specification of the continuum has been developed. The concrete/abstract dimension I have in mind may be interpreted as one of functional specificity – concrete representations are relatively close to specific sensori-motor phenomena, while abstract representations draw more on internal codes, and can be applied to a wider variety of sensori-motor phenomena (see also Gallistel, 1980).

How do humans first represent a new problem to themselves? In particular, do we follow the representational reductionist principle, always representing a new problem at the most concrete level, and resorting to a more abstract level only when we must? I will review three kinds of evidence that support a negative answer to this question – anecdotal, as in learning a new physical skill; observational, as in mastering a game; and experimental, as in retaining a list of stimuli. In each case, there is a contrast between the initial approach to the task and its ultimate organization. Characteristically, humans develop a concrete, automatic representation only after they have started out with a relatively abstract and conscious representation of a new problem.

1. *Learning to ski.* Skiing well is a physical skill that relies on developed "instincts," i.e., rapid movements that are appropriate to the slope's surface and the directional intent of the skier. The main problem is learning to turn (and thereby to stop) with a minimum of effort and a maximum of grace. Clearly the component acts of this skill, once developed, are largely unconscious – a good skier has internalized a set of general movements and slope-appropriate parameters that he or she can adjust without direct conscious thought about them. Once learned, it would indeed seem that whenever possible this behavior is organized at a concrete level of representation.

In this essay I am concerned with the problem of learning itself as well as the end product of learning, so the pertinent question is, how does the apprentice skier represent the problem during the early stages of acquisition? The anecdotal evidence is that all too often, novice skiers think explicitly about their individual body movements, and even the physical theory underlying how turns are made. The result of such conscious activity is usually snow-encrusted chaos. This fact exemplifies two points at once: first, we often do not start out conceptualizing a problem at its most concrete level; second, we initially depend on an abstract level of representation that may be dysfunctional.

2. *Learning to play chess.* The behavior of chess-players has received considerable attention within the contemporary framework for the study of cognition (De Groot, 1965). One reason is that there is wide variation in the skill level among players: this highlights a distinction between formal knowledge and perceptual heuristics, rather like the knowledge/behavior-program distinction in skiing. Here, too, we see a course of learning that moves from the abstract to the concrete – novice chess players concentrate on stringing legal moves together in order to increase the chance of checkmating an opponent's king. Skilled chess players have developed perceptual schemata that signal situation-

appropriate strategies. The latter skill depends in part on acquiring set sequences of moves, and in part on nonlateral perceptual organizations of the situation. These relatively concrete perceptual processes lead to improved performance not only in the game, but in such arbitrary tasks as remembering the positions of all the pieces at a particular point in a game. Conversely, skilled chess players recall the location of fewer pieces than unskilled players, when the pieces are randomly arranged on the board (Chase & Simon, 1972). That is, skilled players have started from an abstract representation of the board and legal moves, and developed a set of perceptual schemata that categorize important aspects of the configuration.

3. *Learning lists of things.* The study of cognitive psychology in humans has often been taken to be tantamount to the study of memory. Ebbinghaus (1885) was not only the first to develop the study of memory via the learning of arbitrary sequences; he noticed early in his research on his own memorization of lists of real words, that he could not avoid utilizing the meanings of the words as part of his memorization process. This interfered with his scientific goal, to study pure memory - specifically, how sets are memorized "by rote," without the aid of any internal relations among the components, and without any prior associations. To this end, he invented the "nonsense syllable" as a meaningless stimulus that can be used to probe the learning and recall processes themselves. He used this kind of stimulus to explore basic parameters of learning and forgetting, for example the effects of repeated presentations of different kinds.

The succeeding century of research has gradually instructed us that subjects generally attempt to avoid rote learning: they use abstract codes as the basis for their memorization of lists, even lists of nonsense syllables. Despite the psychologist's attempt to force subjects to learn the stimuli as unorganized and association-free entities, subjects impose abstract analyses on the stimuli whenever possible (Anderson & Bower, 1973). Such reanalyses make certain kinds of syllables selectively easier to recall than others. For example, pronounceable syllables are more easily learned than unpronounceable ones; syllables that have a high "meaning" associate (either via synthetic content or by being phonetically close to a real word) are easier to recall; syllables or words that are easily imaged are easier to recall; finally, lists of words that can be interrelated propositionally are easiest of all to recall (see Glass, Holyoak, & Santa, 1979, for a review).

Relative ease of recall has become a tool in cognitive psychology to demonstrate the existence of a particular kind of representational code. In fact, much current research on memory is specifically addressed to the interactions among different kinds of representations and methods of presentation (see, e.g., Norman & Rumelhart, 1975). In this way, cognitive science has made a virtue out of necessity. The original goal was to study memory with association-free stimuli so that differential representational mechanisms would not obscure the properties of a "pure" memory process. Human subjects resist that goal whenever they can.

## B. REPRESENTATIONAL ABSTRACTION IN HUMANS - CONCLUSION

The above examples support several principles. First, humans do not always practice representational reductionism when presented with new tasks; rather, they would seem initially to represent a new task at the most abstract level possible. Second, fully mastered skills may depend on more concrete representations than they first receive; these representations themselves are relatively specialized, "automatic" and inflexible.

If humans are typical in this regard, then the principle that is true for the initial representation of new problems is:

Representational Abstraction:

an animal represents a newly acquired behavior at the most abstract level of which it is capable.

A moment's thought shows that such a principle is neither gratuitous nor dysfunctional, despite its inconvenience for behaviorism. The first stage of solving a new task is to figure out what kind of task it is, or is best represented as. The more abstract the level of representation, the less prematurely committed the organism is to a particular mode of representation. Thus, even on evolutionary and functional grounds, the principle of representational abstraction makes good sense. This point is similar to that concerning the functional value of consciousness in animals (Griffin, 1978). A conscious representation of the world may be the very best way to negotiate through variations in it. In this sense, consciousness is the ultimate expression of the principle of representational abstraction. We know this principle to characterize at least part of human behavior; a conservative assumption is that other animals follow the principle as well.

## II. SERIAL LEARNING IN PIGEONS

The mastery of a rapid sequence of behaviors precludes simple explanation in terms of isolated stimulus-response associations (Lashley, 1950).

Accordingly, we have studied the acquisition and maintenance of both production and discrimination of sequences. The fact that pigeons, for example, can learn to peck a particular sequence of colors and correctly discriminate a presented sequence would seem to force us to accept the view that the pigeons can "represent" a sequence - in that sense it would seem that we are forced to study avian "cognition." I shall show that the issue does not concern whether there is a representation, but what the nature of the representation is, and most important, how the representation is performed.

### A. SEQUENCE PRODUCTION

Consider first the production of a sequence. In a typical paradigm, birds are required to peck four simultaneously-presented colored buttons in a particular order of colors (the colors are presented in randomly distinct physical locations) - the task is of interest particularly because correctly ordered pecks within the sequence are not individually reinforced once the skill is acquired. The animal is positively reinforced only after an entire correct order is produced. (In these experiments, however, negative reinforcement - in the form of trial termination - immediately follows an incorrectly ordered peck. (Terrace, Straub, Bever, & Seidenberg, 1977; Straub, Seidenberg, Bever, & Terrace, 1979; Straub, 1979; Straub & Terrace, 1981; Bever, Straub, Terrace, & Townsend, 1980). How do we assess the competence that an animal has when it has attained this skill? From the perspective of the most obvious behaviorist model, the question is whether the animal has learned an unordered group of adjacent pair-wise associates, which can be performed in only one order, or whether the animal has learned a particular ordinal position for each response. The latter representational form would appear to be difficult to represent within the usual behaviorist framework.

1. *Generalization to subsequences.* One way to determine this is to present deformed versions of the problem to see if the animal is sensitive to relative order. Suppose buttons are arbitrarily labelled in the order, ABCD. To see if the animal learned the sequence with each item in a particular ordinal position, one could observe its behavior when only a subset of the 4 buttons is available to peck, e.g., AB, AC, BD, etc. My colleagues have shown that such transfer can occur from a full sequence to subsequences of it (Straub & Terrace, 1981; Terrace, 1983). This proves that the animal indeed mastered the sequence, but the mechanisms of its representation remain undetermined. If the animal pecks the correct relative order that the subsets have in the complete sequence, we know only one thing: the animal can apply its complete serial skill to deformations of the original serial problem. This could be because the original skill is itself composed out of a complex of both adjacent and remote ordering relations, or because the animal can transform the sequence it has learned into a new sequence; it could also be because the animal treats the generalization subset as a full stimulus in which some of the buttons are missing (e.g., it "air-pecks" the missing colors). One thing is certain from such results, however: the animals are capable of relatively abstract operations on the skill they have mastered, operations that are inconsistent with physicalism. Transforming the sequence into subsequences is surely such an abstraction, as would be "air-pecking" responses to physically absent colors.

The generalization technique exemplifies negative reasoning: a particular example of the behaviorist framework is invalidated by a particular experiment; other versions of behaviorist models will have to be systematically disqualified as they appear. To further narrow down alternative models and emphasize the claim that the animal must have a non-behaviorist "representation" of the learned sequence, Terrace (1983; Chapter 1, this volume) has reported several other studies in which learning

to produce a sequence transfers to other sequences. To show that pigeons learn the ordinal position of each item in a sequence, he trained subjects on ABC and tested their generalization to XBY (in which X and Y are new colors). The subjects learned that new sequence more quickly than BXY or XYB, presumably because XBY maintains the ordinal position of B. Like the earlier generalization studies, there are many alternate interpretations of what this means about the original learning. A similar point applies to Terrace's demonstration (see Chapter 1, this volume) that learning to discriminate a sequence is facilitated by having already learned to produce the same sequence. None of the generalization studies rules out the possibility that the subjects learn and represent the sequence according to adjacent pair-wise associations, and map what they learn onto new situations by some other, more abstract, processes. Indeed, following the principle of scientific reductionism, this is the required interpretation.

This emphasizes the futility of trying to disqualify behaviorism by proving that an animal has learned a non-behaviorist "representation" of a skill. Every internalized skill presumes a representation of some kind. The problem is that we must also have a theory of how the representation is performed before we can test its validity. (See Roitblat, 1982, and Anderson, 1978.)

### B. MODELS OF THE ANIMAL'S MIND

A positive technique to explore the nature of the mastery of a sequence is to construct a model that describes as many observed parameters as possible. One can then take the features of the model to be hypotheses about the animal's processes - the model is of the behavior *animal*, not the behavior. Such practice in the study of human cognition has flourished under the rubric of "information-processing" automata (Newell & Simon (1972), recently revised into a system of "productions": conditional statements on internal operations). I constructed such a model for the 4-color sequence production experiment by Straub (1979), which is shown in Figure 4.1. This model has two temporal parameters, the time to move along the sequence for each new peck position and the time to rehearse each item in the sequence up to the new peck position. It is striking that the two parameters predict more than 99% of the (mean) variance observed in the latencies to the 16 independent kinds of responses. The model also allows for the description of the two main types of out-of-order pecks that occur: repeat pecks to a just-pecked key occur when a false negative occurs in response to condition 1 ("are there positions to the right"); keys are skipped when the same conditional is answered with a false positive. (There are 4 correct responses, A, B, C, D; 3 "repeat pecks" on keys A, B, or C; 6 forward errors that skip over a key; and 3 backwards responses, e.g., pecking A, B, C, A; see Bever *et al.*, 1980, for a more complete description of how the model operates.)

The model in Figure 4.1 describes the results for a study by Straub in which pigeons were pre-trained on the full 4-color sequence only in a left-right, "forwards" manner. That is, after pre-training on individual colors presented alone, they were presented with overlapping subsequences building from left to right: first, AB, then ABC and finally

1. Attach a peck response to the end of what has just been rehearsed.
2. After each peck, go to a constant reference point and rehearse the sequence up to the next color where a peck can be attached.

There are many ways to instantiate each of those principles. (1) tells us that our subjects pecked the colors in order by running through the sequence before each peck. (2) reflects the fact that in order to produce ordered behavior, the animal must have some way of running through it to keep track of where it is in the sequence. The variation in the reference-point according to the early pre-training demonstrates the way in which critical early exposure to a problem can set a parameter that dominates its subsequent organization.

At first blush, the empirical success of these models is impressive. But the models have several limitations as well. First, they are models of the acquired skill, far transcending any direct theory of how they are acquired. Second, no matter how successful, they must be taken as initial metaphors in relation to actual physiological processes. The main potential virtue of behaviorist descriptions is that they are simultaneously models of learning and directly interpretable as hypotheses about physiological mechanisms. An information processing model of a skill does not dictate how it is learned nor how it is physically instantiated. It is a model of what is learned and instantiated. Finally, the information-processing systems that they exemplify are arbitrarily powerful, setting no constraints on possible conditions and operations. Before we can argue that they have explanatory power, we must show that they deploy formally constrained mechanisms. We remain afflicted by a basic scientific dilemma. We are between the Scylla of behaviorist descriptive limits, and the Charybdis of information processing models' unconstrained descriptive power.

### C. SEQUENCE DISCRIMINATION

When theory is inconclusive or too rich, one instinctively tries to enrich the data and restrict the theory. To achieve this, we have explored the mastery of the perceptual discrimination of sequences. The sequence discrimination paradigm has its own properties and exigencies that have lead us in some new directions as well as supplementing what we have learned from the study of sequence production (Roitblat, Dopkins, Scopatz, & Bever, 1983; Dopkins, Scopatz, Roitblat, & Bever, 1983; Bever, Scopatz, Dopkins, & Roitblat, 1983). I will argue that the best way to understand the data is to assume that the pigeons divide the problem of sequence discrimination into terms of the same two mechanisms isolated in the study of sequence production, rehearsal and pecking.

The first step is to show that the birds can learn a sequential discrimination at all. We extended a paradigm of Weisman and his colleagues (Weisman, Wasserman, Dodd, & Larew, 1980) to the discrimination of a sequence of three colors. (A, B, C) presented on the

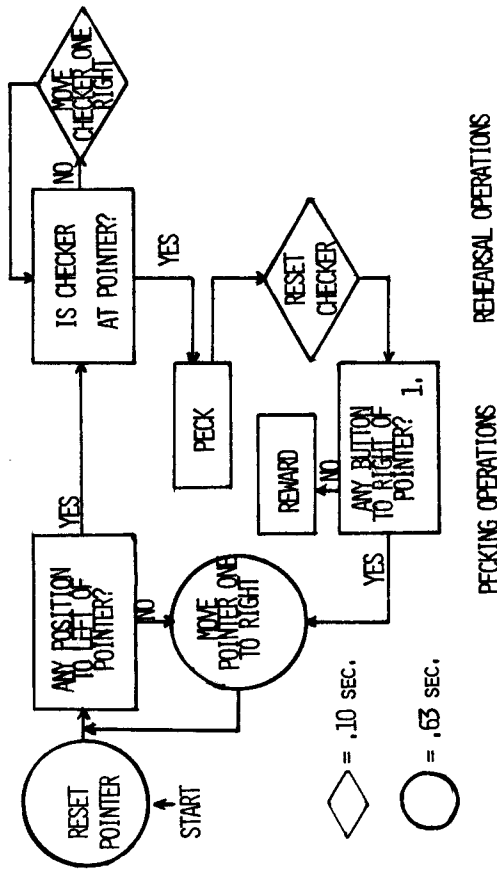


FIG. 4.1. Information-processing model of serial pecking in pigeons with initial forward training. (Adapted from Bever et al., 1980.)

ABCD. In the model this property corresponds to the fact that after each independent peck, the checking operation resets to the beginning of the sequence, and the sequence is "rehearsed" from the beginning until the new peck position.

In another experiment (Straub et al., 1979), the subjects were initially focused on the final color of the sequence before forwards training was initiated (so-called "backwards" training). The animals were exposed repeatedly to the last color alone, D, then the last two, CD, and so on. (This pretraining was ultimately halted in favor of forwards training, because the subjects almost always ignored the early colors and pecked the last one.) The best-fit model of the type in Figure 4.1 for this experiment has *exactly* the same temporal parameters as the forwards model, and one change in the model's operation - the checking operation resets to the *end* of the sequence after each peck; the sequence is, in effect, rehearsed from the end to the beginning.

Each model accounts for more than 99% of the variance in the observed latencies in the experiment it describes. (One model's predictions account for only 58% of the variance in the other model's predictions, demonstrating that the models are distinct from each other.) Thus, the two experiments confirm both the types of operations of the models and their temporal parameters. Such models are also consistent with successful transfer to sequence subsets, at least because of the indeterminant meaning of such transfer that I noted above. The models isolate two principles governing the serial skills of our subjects.

same key (see Roitblat *et al.*, 1983, for a more complete description; also see Chapter 12, this volume, by Weisman & von Konigslow). Birds are reinforced contingent on at least one peck following presentation of a correct color sequence ("ABC"); there are no consequences of a peck following a negative sequence; the measure of discrimination is the ratio of response rate following a positive sequence to the rate following both kinds of sequences; most sequences were presented at about 1 stimulus/sec, which corresponds to the rate of correctly ordered pecks in the production experiments. In the first study, the negative sequences were all possible orders of the same three colors (except one order, CCC, which was used as a (successful) post-training generalization test). After initial pretraining to establish an orienting and responding sequence of behaviors to a white key, sequences of 3 stimuli were presented without any pretraining on shorter sequences. With about 60 sessions, the birds mastered the discrimination to a reasonable criterion level.

1. *The uniqueness of the sequence-final color.* Our procedure naturally prompted us to consider the stages of acquisition imposed by the subjects during their acquisition of the skill. One question is, what does the animal learn first? — to which kinds of negative sequences does the subject first stop responding? Our initial analysis suggests that responses to incorrect sequences ending in something other than the last correct color, C, drop out first. That is, the subjects appear spontaneously to learn the perceptual task by first discriminating the final position. The next-acquired position tends to be the initial one, A, rather than the medial one, B.

We have examined the special importance of the final color in two other ways, first by selectively withholding certain negative sequences. In particular, one group of subjects received no trials with a negative sequence that ended in C, while another group received no negative sequence beginning in A. Informationally, the two paradigms are exactly equivalent. Yet, the group with no negative sequences ending in C discriminated the positive sequence much more quickly. Apparently, an unambiguously correct C in the final position is much more conducive to learning to discriminate the correct sequence than is an unambiguously correct A in initial position.

In a third set of paradigms, the subjects were presented within the same session with correct sequences of length 3, 2, and 1 color. The sequences of length 2 and 1 were either successive overlapping subsets from the beginning or end of the complete 3-color sequence. (The forwards overlapping set was ABC, AB, A; the backwards overlapping set was ABC, BC, C). In each case, the corresponding negatives of each length were also presented. The results are dramatic: subjects exposed to the backwards overlapping set learned the 3-color discrimination sequence quickly, while subjects exposed to the forwards overlapping set barely learned the 3-color sequence at all. In brief, the experimental set that provided multiple instances of C as the final color was much easier to learn than the set that provided multiple instances of A as the initial color. This too, highlights the importance of isolating the final color.

The emphasis on discrimination of the final color might seem consistent with the principle of "backward spread of reinforcement." On

this view, later items are discriminated first by virtue of their relative proximity to reinforcement. This view is inconsistent with our findings in a number of ways. The second color to be discriminated was not clearly the next-to-last (B) but tended to be the first (A). The gradient hypothesis does not explain why the sequence set with missing negative initial A sequences is so difficult to learn; it would be expected on a reinforcement theory of any kind that systematic reduction of the alternative negatives should facilitate learning to some extent. Finally, the backwards set with overlapping positive sequences might be easier to learn, if distance from the reinforcement inhibits discrimination — the birds were presented with pure examples of the most distant color from reinforcement, A, which might be expected to facilitate its isolation and discrimination.

#### D. A MODEL OF SEQUENCE DISCRIMINATION

There appears to be something categorically unique about discriminating the last color in a sequence. We can explain this by constructing a model of the discrimination process for the normal conditions, with all negative sequences included. The subjects do learn to discriminate the sequence under such conditions. This means that they must have some mechanism for tracking the correct sequence; they must also have the means to attach the contingently necessary response to the end of a correct sequence. In brief, a consistent model of the serial discrimination task must include two processes, rehearsing the sequence internally to an external match, and discriminative pecking at the end of the sequence. (We have not yet constructed a detailed model like that for sequence production because we are still analyzing the data.) It is natural (though not formally necessary) to think of these two sub-mechanisms as the same as in the production model. (The sequence discrimination model may also require a color-matching procedure — unnecessary in the case of sequence production, since all colors were simultaneously present.)

According to the model, the animal divides the discrimination problem into two sub-problems, as in our model for sequence production — rehearsing the sequence internally (and matching each stage in the sequence to the input) and attaching a peck to the end of what is rehearsed. The key to the special status of the final color in sequence discrimination may be that the contingently important peck is always after the 3-color sequence is complete. Accordingly, the animal is not guided by intermediate training (as it is in the production studies) to attach pecks to the intermediate points in the 3-color sequence. We postulate that C is uniquely linked to a response because of its final position as the animal "rehearses" the 3-color sequence as part of tracking the input color sequence.

This interpretation of the special status of the final color in the original experiment with most negative sequences present as due to dividing the task into internal tracking and pecking, can explain the results from the other studies. In the missing negatives set with initial A correct, attention may be called to the initial A, but the animal cannot link a discriminative peck response because (on the model) it has not yet internally rehearsed

sense is irrelevant, since it does not involve what the animal may know. As in complex human behavior, the models describe distinct systems interrelated in aid of solving particular problems.

This is an important result of our rationalist attempt to describe the "whole bird" with one set of mechanisms, rather than constructing a different set for each behavior. In modelling the animal rather than the behavior alone, we may make discoveries about the internal mechanisms it has at its disposal. The different behaviors result from assembling the same mechanisms in different configurations (see Gallistel, 1980, for a general discussion of this approach).

The broadest question germane to this book is whether there is such a thing as animal cognition. The study of cognition in humans has involved a pun, which is tolerable when it is among us humans, but intolerable when applied to other species, who cannot talk back when a theory is obviously silly. There are two areas of study which currently go under the name "human cognition"; the nature of knowledge, and the mechanisms whereby we represent and act on it. In studying the latter in humans we often fudge the true nature of the former by common agreement that it is unnecessary initially to decide whether we "know" what we think we do, or only believe it. It is harder to justify this heuristic when dealing with organisms with whom we cannot communicate easily. It seems reasonable, however, to assume that whether animals know that they know what they know about such matters, that like humans, they have mechanisms for representation and behavior. (See also Chapter 13, this volume, by Shimp.)

There is every reason to believe further that the scientific study of these mechanisms in the human species is typical of what we will achieve in the study of other species.

#### ACKNOWLEDGMENTS

The main theme of this paper was stimulated by preparing the concluding presentation of the conference on which this book is based. I am grateful to my co-conferes for many discussions about these issues, both during the conference and afterwards. Preparation of this paper was in part supported by a grant from NIMH to Columbia University, "Acquisition and representation of stimulus sequences," Number RO1-MH-37070.

#### REFERENCES

- Anderson, J. R. Arguments concerning representations for mental imagery. *Psychological Review*, 1978, 85, 249-277.  
 Anderson, J. R., & Bower, G. H. *Human Associative Memory*. Washington, D. C.: V. H. Winston & Sons, 1973.  
 Bever, T. G., Scopatz, R. A., Dopkins, S. C., & Roitblat, H. L. The beginning and end of sequence discrimination. Paper presented at a meeting of the Psychonomic Society, November, 1983.

the sequence when it has perceived A. The same model can explain the difficulty of learning the forwards overlapping-positives set: A and B are sometimes the final color requiring attachment of the single contingent response to three different colors; in the alternative backwards set, C is always the final color available to attach to a peck.

#### III. BEHAVIORISM AND RATIONALISM - BACK AGAIN

What can we conclude about the pigeon's mind from these sequence production and discrimination studies? The production and perception experiments support the same conclusion via quite distinct theoretical and empirical routes. The fact that the sequence tasks are successfully learned demonstrates that the animal has a mechanism that keeps track of the ongoing sequence. The animal also has a distinct mechanism that links the final element in a just-rehearsed sequence to a peck. That is, a parsimonious explanation of the animal's behavior via information processing models differentiates two processes - internal rehearsal while tracking the sequence and pecking when the sequence is successfully rehearsed internally. The proposal that the animal keeps track of the sequence with one mechanism and pecks with another is not astounding. But it is important in light of the incompatibility of our models with several of the behaviorist principles outlined above.

Suppose the models are correct. First, they falsify the principle of representational reductionism. There is no *a priori* basis on which the sequence production problem is most simply represented in terms of rehearsal and pecking at the end of each sub-rehearsal; indeed, given the possibility of adjacent pair-wise associates (since the mean response rates are so slow) the animal should use them if representational reductionism were true. Similarly, the discrimination problems would be most simply represented as isolated positive and negative sequences. In fact, the comprehensive bipartite analysis that the animals apply (according to the model) is positively *dysfunctional* in certain cases. (e.g. the forward overlapping positive set).

Second, the internal workings of the models are not associationistic. No doubt, there are information processing models which can be intentionally constrained to have only associative relations among their components; but there hardly seems any reason to exert this constraint without the physicalist constraint as well - it is the latter that makes important the proposal that there is only one kind of mentally internal relation - association.

This leads to a further point - any controversy between physicalist and cognitive processes turns out to be totally irrelevant to our descriptions and discoveries. The argument here does not turn on the existence of a so-called "cognitive representation"; the representation itself of the model could in fact be motoric, sensory, or an abstract structure (see also Roitblat, 1982, for a full discussion of this issue). Rather, the argument for internal, non-associationistic and non-reductionistic structure depends on the internal properties of the models that describe how the behaviors are organized and executed. The question of "cognition" in its everyday



- Bever, T. G., Straub, R. O., Terrace, H. S., & Townsend, D. J. Study of serial behavior in humans and non-humans. In P. Jucysk & D. Klein (Eds.), *The nature of thought: Essays in honor of D. O. Hebb*. Hillsdale, N.J.: Erlbaum, 1980.
- Chase, W. G. & Simon, H. A. The mind's eye in chess. In W. G. Chase (Ed.), *Visual information processing*. New York: Academic Press, 1972.
- De Groot, A. D. *Thought and choice in chess*. The Hague: Mouton, 1965.
- Dopkins, S. C., Scopatz, R. A., Roitblat, H. L., & Bever, T. G. *Encoding and decision processes in the discrimination of 3-item sequences*. Proceedings of the 54th annual meeting of the Eastern Psychological Association, Philadelphia, April, 1983.
- Ebbinghaus, H. *Memory*. New York: Teachers College, 1885. Translated by H. A. Ruger & C. E. Bussenius, 1913.
- Gallistel, C. R. *The organization of action: A new synthesis*. Hillsdale, N.J.: Erlbaum, 1980.
- Glass, A. L., Holyoak, K. J., & Santa, J. L. *Cognition*. Reading, Mass.: Addison-Wesley, 1979.
- Griffin, D. R. Prospects for a cognitive ethology. *The Behavioral and Brain Sciences*, 1978, 1, 527-538.
- Kohler, W. *The mentality of apes*. New York: Kegan Paul, Trench, Trubner, 1925.
- Lashley, K. S. In search of the engram. *Symposia of the Society for Experimental Biology*, 1950, 4, 454-482.
- Newell, A. Physical symbol systems. In D. A. Norman (Ed.), *Perspectives on cognitive science*. Norwood, N.J.: Ablex, 1981.
- Newell, A., & Simon, H. *Human problem solving*. Englewood Cliffs, N.J.: Prentice-Hall, 1972.
- Norman, D. A., Rumelhart, D. E., & The LNR Research Group. *Explorations in cognition*. San Francisco: Freeman, 1975.
- Roitblat, H. L. The meaning of representation in animal memory. *The Behavioral and Brain Sciences*, 1982, 5, 353-406.
- Roitblat, H. L., Dopkins, S. C., Scopatz, R. A., & Bever, T. G. Discrimination of 3-item sequences. Paper presented at a meeting of the Psychonomic Society, November, 1983.
- Straub, R. O. *Serial learning and representation of a sequence in the pigeon*. PhD Thesis, Columbia University, 1979.
- Straub, R. O., & Terrace, H. S. Generalization of serial learning in the pigeon. *Animal Learning and Behavior*, 1981, 9, 454-468.
- Straub, R. O., Seidenberg, M. S., Bever, T. G., & Terrace, H. S. Serial learning in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1979, 32, 137-148.
- Terrace, H. S. Simultaneous chaining: The problem it poses for traditional chaining theory. In M. L. Commons, R. J. Herrnstein, & A. R. Wagner (Eds.), *Quantitative analyses of behavior: Vol. III, Acquisition*. Cambridge, Mass.: Ballinger, 1983. In press.
- Terrace, H. S., Straub, R. O., Bever, T. G., & Seidenberg, M. S. Representation of a sequence by a pigeon. *Bulletin of the Psychonomic Society*, 1977, 10, 269.
- Tinbergen, N. *The study of instinct*. London: Oxford University Press, 1951.
- Tolman, E. C. Cognitive maps in rats and men. *Psychological Review*, 1948, 55, 189-208.
- Weisman, R. G., Wasserman, E. A., Dodd, P. W. D., & Larew, M. B. Representation and retention of two-event sequences in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 1980, 6, 312-325.
- Wertheimer, M. Untersuchungen zur Lehre von der Gestalt. II. *Psychologische Forschung*, 1923, 4, 301-350. Abridged translation by M. Wertheimer, 1958. Principles of perceptual organization. In D. C. Beardslee & M. Wertheimer (Eds.), *Readings in perception*. Princeton: Van Nostrand.