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EDITORIAL

THE DYNAMICS OF BEHAVIOR

Operants are defined by behavior change. Skinner (1938) defined the operant as a behavioral unit whose rate changed as a function of consequent stimulus relations now termed reinforcement and punishment. But operant behavior involves more than just a change in the rate of preexisting behavioral units. It involves processes by which behavior's structure in time and space is modified, differentiated, shaped to something entirely novel. I have noted previously (1988), as have many before me, that the malleable nature of behavior served as one impetus to Skinner's break with traditional learning theory in the conceptual development of the operant. Formally distinguishing operants and respondents for the first time provided a mechanism by which behavior could freely change from one spatio-temporal set of characteristics to any other, through a seemingly endless number of pathways. Behavior change *was* the operant.

The *Journal of the Experimental Analysis of Behavior* likewise began its career with an emphasis on behavior change, the seminal article being Keller's (1958) search for the phantom plateau in Morse code acquisition. Keller outlined the traditional view that such learning involved multiple discrete stages of acquisition corresponding to the verbal units that could be processed at each (first letters, then words, then phrases, etc.). He then went on to present data suggesting that no such plateaus exist and that behavior changes continuously throughout acquisition of the skill. The journal's early emphasis on behavior change is further evident throughout the first volume. Of the 38 research articles published in Volume 1, 11 were explicitly concerned with acquisition or extinction of responding under a variety of conditions involving different schedules of positive or negative reinforcement, of conditioned reinforcers and response chains, and of the effects of amphetamine on avoidance acquisition.

The publication of Sidman's *Tactics of Scientific Research* (1960) is often cited as inadvertently damping future work involving transition states. Although Sidman addressed the experimental analysis of acquisition and extinction, the emphasis was on steady-state research design. Measures of behavior achieved a special status if they reflected stable asymptotic responding. Dynamic transition states were overlooked, and acquisition curves were increasingly replaced by functional relations between overall asymptotic response rate and some parameter of reinforcement or punishment. Overall response rate itself was, in many cases, usurped by relative response rate in an explosion of research on concurrent operants and the matching law. The quantification of the law of effect had begun in earnest.

The lack of emphasis on behavior change promoted an increasing utilization of variable-interval (VI) schedules as behavioral barometers of the effects of a host of independent variables. Responding under these procedures was conceptually preferred because the lack of gross temporal variation in VI responding simplified the translation of response rate into relative rate and from there into response strength. It is not too surprising that correlated with the increasing popularity of VI schedules was a negatively accelerated frequency of cumulative records published in the journal. As Skinner (1976) noted,

> There is no point in publishing a block of sloping straight lines if the only important fact is the slope; better a point on a graph. But what has happened to the curves that were *curves*? What has happened to experiments where rate changed from moment to moment in interesting ways, where a cumulative record told more at a glance than could be described in a page? (p. 218)

As an editor of this journal, I am no less

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guilty of excising my share of the (very) occasional cumulative records, proffered as experimental results, than the editors who asked the same of me. However, in most cases (including my own submissions) these were not experiments designed to demonstrate local dynamics of behavior, so curves seemed inappropriate. The bias, as Skinner noted, was not so much against the records as against research methods that generated interesting ones.

Whether a subject matter is best characterized in terms of local or global structure is a question fundamental to the definition of most scientific disciplines, and behavior analysis has proved to be no exception. The analysis has struggled to accommodate behavior in the best possible terms. For some, this translates to measuring behavior in terms of large aggregates of temporally nonextensive responses and relating them to correlated changes in aggregate reinforcement parameters programmed to minimize any local organization of either aggregate. For others, behavior is best characterized by a series of extended sequences of behavior modulated by locally dynamic parameters of reinforcement. This distinction forms the basis of the molar–molecular dichotomy that has provided one of the most enduring research questions in our field. The late 1960s and early 1970s saw the emergence of a sometimes vitriolic debate between molar theorists describing behavior in terms of Herrnstein's (1970) matching law or one of its offspring (see Davison & McCarthy, 1988, for a review) and those intrigued by the notion first systematically analyzed by Anger (1956) that schedule-controlled responding could best be construed in terms of changes in the differential reinforcement of interresponse times (IRTs) provided by different reinforcement schedules. Molar analyses have always outnumbered molecular ones, but until recently this bias resulted as much from methodological as from conceptual constraint. That is, VI tape programmers were a lot cheaper and more accessible than the computers needed to conduct molecular analyses, program the synthetic schedules used to parcel the relative contribution of molar versus molecular variables, and dynamically model the outcome.

Although molar analyses and theories still carry the day, there has recently been a resurgent interest in molecular dynamics, even within some of the more molar analyses. Momentary maximizing (e.g., Shimp, 1966; Silberberg, Hamilton, Ziriax, & Casey, 1978), hill climbing (e.g., Hinson & Staddon, 1983), and melioration (e.g., Vaughan, 1985) all attempt analysis of aggregate as well as local responding in terms of local parameters of reinforcement. New procedures designed to illuminate the local dynamics of behavior have also become more commonplace. Linear-IRT schedules (Galbicka & Platt, 1984; Platt, 1979; Weiss, 1970), cyclic-interval schedules (Innis & Staddon, 1971; McDowell & Sulzen, 1981; Staddon, 1964), percentile schedules (Arbuckle & Lattal, in press; Galbicka, Fowler, & Ritch, 1991; Galbicka & Platt, 1986, 1989; Machado, 1989), and concurrent schedules for response sequences (e.g., Fetterman & Stubbs, 1982), among others, all provide reinforcement dynamically as a function either of ongoing behavior or of time, to control *the rate of change* of overall reinforcement frequency. In some cases (e.g., percentile, linear IRT), the rate of change is zero, holding the aggregate reinforcement rate constant throughout the session while varying reinforcement for particular extended sequences of behavior. In others (e.g., cyclic interval), the rate of change varies in a controlled fashion, and behavior may track these local changes. Such procedures allow more detailed control over local and global reinforcement parameters, thereby providing more precise assessment of the effects of each on responding. Not too surprisingly, given the extensive history of the debate, independent control of each factor has indicated independent contributions of each in determining behavior (e.g., Fetterman & Stubbs, 1982; Galbicka & Platt, 1986). Although a denouement has not been reached, data from studies such as these have softened the rhetoric between the molar and molecular camps to the level of at least benign coexistence, it not downright acceptance.

Like most behavior, generating the present issue had multiple sources of control. Edmund Fantino and I discussed the possibility of a special issue on response acquisition and differentiation in 1989. At the same time, M. Jackson Marr approached the journal with the suggestion that it publish the proceedings of a conference on behavioral dynamics held at Jacksonville State University in that same year. This Special Issue on Behavior Dynamics, including papers presented at the conference as well as others submitted following an open invitation, resulted as a compromise. Each paper included here has independently met the journal's normal editorial criteria via peer review.

The selected papers all deal with some aspect of the forces that drive behavior change. Some are relatively traditional treatments, such as Baum's extension of variable-interval feedback functions to extremely low response rates. Others, such as Hoyert's analysis of fixed-interval responding in terms of nonlinear dynamics, or chaos theory, represent relatively novel ways of analyzing behavioral data. Some are almost entirely empirical. Palya's extensive analysis of the structure of schedule-controlled responding, I believe, sets a new record for the volume of data presented in a single article in *JEAB*. Others are almost wholly conceptual, such as McDowell, Bass, and Kessel's attempt to predict the dynamics of transition states from linear systems theory applied to the time domain. Gibbon and Church use variation and covariation in the trial-by-trial response patterns under a peak procedure to distinguish scalar expectancy theory (Gibbon, 1977) from Killeen and Fetterman's (1988) behavioral theory of timing. Nevin's contribution reviews results from studies of behavioral momentum and provides an integrative model of such effects, whereas Harper and McLean attempt to extend such analyses to steady-state procedures but find incomplete concordance with previous results. Rachlin and Shimp each attempt a reanalysis of an established finding from very different perspectives. Rachlin's subject is the law of diminishing marginal value (which details the decrement in reinforcing efficacy of a commodity as additional units are delivered), with an analysis based on local delay discounting. Shimp's is a mechanistic model designed to produce the global as well as local choices observed by Nevin (1969) in his now-classic study of discrete-trial concurrent schedules.

The remaining three contributions, by Marr, Zeiler, and Killeen, are difficult to characterize because each touches a number of topics and raises an abundance of questions. Introducing behavior dynamics, Marr notes parallels between the development of physics as a science and the development of behavior analysis. He provides an interesting metaphor for the molar/molecular quandary that has driven a large part of the analysis of behavior and also introduces concepts and methods from nonlinear dynamics taken up in further detail by Hoyert. Finally, he presents two illustrative examples of how dynamic models can be used to program reinforcement and analyze response patterning to increase our understanding of how reinforcement contingencies influence behavior.

On the other side of the issue is Zeiler's contribution, presented as a counterpoint to many of the preceding articles. His is a cautionary note that behavior analysis is primarily a biological science, and as such a mechanics of action cannot wholly subsume function in the analysis of behavior. If behavioral adaptation to a changing environment (learning) results from natural selection, searching for cause–effect relations with generality similar to those in the nonbiological sciences is likely to fail as long as the evolutionary history and function of the organism and behavior are ignored.

Finally, Killeen provides a remarkable integration of the physical and the biological in his contribution detailing a system of mechanics for the animate. Killeen's goal is nothing short of a complete remaking of the study of learning into a comprehensive system that defines behavior in terms of motion within behaviorally redefined dimensions of stimuli, responses, and time. Through appropriate scaling, Killeen attempts to demonstrate that in the behaviorally appropriate frame of reference, general laws can be derived that simultaneously accommodate the organism and/or behavior as an evolutionary entity. In this analysis, reinforcers warp the dimensions of behavior-space into potential wells, moving responding along a trajectory that decreases the distance to reinforcement, measured in terms of intervening stimuli, time, or responses. The pervasive reanalysis of behavior provided by Killeen touches on practically every aspect of behavior analysis as an experimental domain, prompting an extraordinary number of questions and extensions. It is as fundamental a reinterpretation of behavior as was *The Behavior of Organisms* (Skinner, 1938), and as deserving of critical appraisal.

The articles contained in this issue all emphasize behavior change. To continue Skinner's (1976) lament,

> Straight lines and steady states are no doubt important, but something is lost when one must reach a steady state before an experiment begins. There was a special kind of orderliness in a smooth curve lasting a few minutes or at most an hour. It suggested a really extraordinary degree of control over an individual organism as it lived its life from moment to moment. (p. 218)

We have come a long way in the analysis of behavior, in quantifying the relations between parameters of reinforcement and measures of behavior, in developing quantitative formulations of the law of effect, signal detection, and self-control, to name but a few. We have not, however, exhausted the richness of behavioral diversity to which our analytical tools may be turned. In generating our static laws, we have not done justice to the moment-to-moment changes Skinner noted. The dynamics underlying behavior as we observe it, even in the steady state, are still largely undelineated, and response acquisition remains a relatively fallow field of inquiry. Hence, although we may rightfully take pride in the path we have forged to date, there remains much uncharted territory. Paths mark an achievement in controlling nature, but they may also occasion oversight by speeding transit between two points, allowing only a cursory examination of roadside events. We should not marvel at our ingenuity in clearing such a road, if in doing so it only hurries us past the behavioral thicket of everyday experience.

This issue attempts a few new inroads by turning more or less off the beaten track of behavior analysis. By opening up some new avenues of inquiry and broadening some old ones, it lays the groundwork for a potential network of paths, a fractal system in which the order seen at one level of analysis is observable at all levels. The figure opposite shows such order. It results from a very simple game, if you have lots of time, or from a simple computer algorithm, if you don't (Timothy Elsmore provided the BASIC code for this particular program). After establishing the coordinates of an equilateral triangle and choosing a point at random inside the triangle, the game begins by randomly selecting one vertex (roll a die and assign 1 and 4 to one vertex, 2 and 5 to the second, and 3 and 6 to the last). Move halfway along the line connecting the current location and the selected vertex and place a dot. Then roll the die and repeat. After several thousand turns, the figure below emerges. A similar figure has hung outside my laboratory door for a few years now, as a reminder that the most delicate order can arise from seemingly random processes, and that units are a matter of perspective. Whether this figure is a triangle or a trio of triangles is a question that can be asked of every triangle in the figure. The only limits on this recursive order are the resolution limits of our measuring devices. Operant behavior is much the same. Asking whether key pecks, interresponse times, or multiresponse sequences are "fundamental" units of behavior obscures the search for order at all levels of analysis. The order created by reinforcement contingencies applied at each of these levels may not be as perfectly recursive as that in the figure, but the perspective that such order exists at all levels is necessary for the development of the grand unified theory of behavior that remains at present only a possibility. The articles herein will promote that theory's realization, if only by increasing the scope and resolution of the analysis to include whole new triangles in the overall picture.

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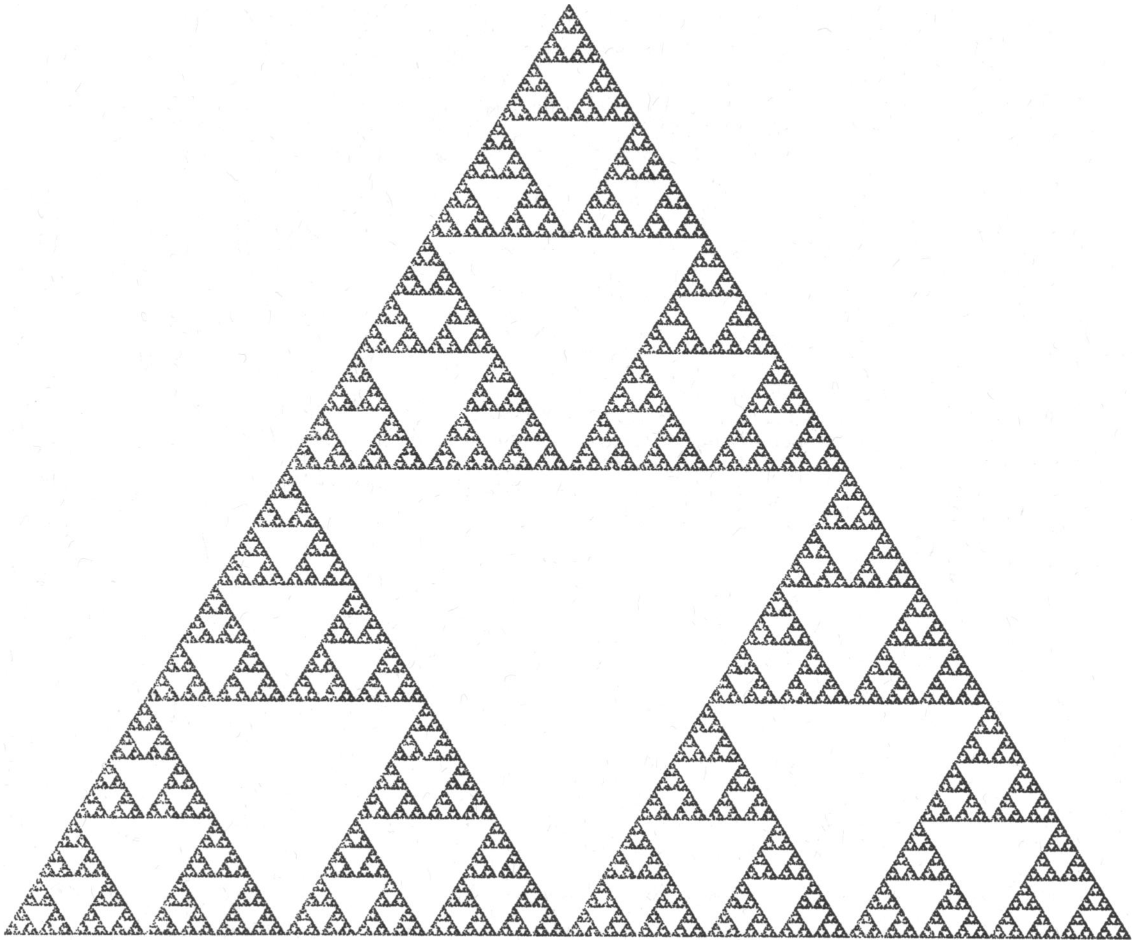

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