Toward the Unification of Molecular and Molar Analyses

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Three categories of behavior analysis may be called *molecular*, *molar*, and *unified*. Molecular analyses focus on how manual shaping segments moment-to-moment behaving into new, unified, hierarchically organized patterns. Manual shaping is largely atheoretical, qualitative, and practical. Molar analyses aggregate behaviors and then compute a numerical average for the aggregate. Typical molar analyses involve average rate of, or average time allocated to, the aggregated behaviors. Some molar analyses have no known relation to any behavior stream. Molar analyses are usually quantitative and often theoretical. Unified analyses combine automated shaping of moment-to-moment behaving and molar aggregates of the shaped patterns. Unified controlling relations suggest that molar controlling relations like matching confound shaping and strengthening effects of reinforcement. If a molecular analysis is about how reinforcement organizes individual behavior moment by moment, and a molar analysis is about how reinforcement encourages more or less of an activity aggregated over time, then a unified analysis handles both kinds of analyses. Only theories engendered by computer simulation appear to be able to unify all three categories of behavior analysis.

Key words: computer theory, molar analysis, molecular analysis, shaping, unification

There is no disputing that a science of behavior should provide powerful methods to control behavior precisely. The issue becomes less clear, however, as to what kinds of behavior should be controlled. Skinner suggested two kinds: moment-to-moment behaving of individual organisms and numerical averages of aggregated behaviors. He found that different methods were especially useful to control each kind, shaping to create and control new moment-to-moment behavioral patterns, and free-operant methods to quantify aggregated behaviors. These two categories of analysis have unfortunately hardened into distinctly different molecular and molar analyses. I propose a third category to show how to begin to unify them.

MOLECULAR, MOLAR, AND UNIFIED CATEGORIES OF BEHAVIOR ANALYSIS

I caution the reader that I compare different kinds of analyses, and advocates of each may feel like John Kennedy during his presidential debate with Nixon, when he said he did not recognize the positions Nixon attributed to him. Here, instead of Kennedy and Nixon, we have advocates of molecular and molar analyses. With that in mind, let me begin by saying the terms *molecular* and *molar* are highly misleading: In behavior analysis, molecular is not small, molar is not big, the two terms do not always refer to different levels of analysis, and there is no scale of measurement common to both terms that would justify a *multiscale* analysis. A molecular analysis describes how reinforcement shapes and organizes continuous, moment-to-moment behaving into new higher order patterns, and a molar analysis describes how reinforcement affects averages of aggregates of different instances of the same behaviors that occurred at

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different times. Quite often, a molar analysis describes how reinforcement affects an aggregate's average viewed as an estimate of the strength of the aggregated responses; a molar analysis is about how much of some activity there is over a period of time over which the activity is aggregated. The terms *molecular* and *molar* have had several different meanings attributed to them, and my meanings are not identical to all of them; however, mine are similar to most of them. I propose to clarify where these different analyses come from, to describe their current strengths and limitations, to show how they can be partially combined, and to speculate on how current technology might advance their unification.

CATEGORY 1: A MOLECULAR ANALYSIS

The most familiar example of what I mean by a molecular analysis is the method of manual shaping, in which an experimenter defines a target behavioral pattern, observes an organism, and delivers reinforcers contingent on the organism's producing those temporal patterns judged from moment to moment to be successively more similar to the target pattern. Shaping reorganizes *behavior streams*, which is a useful metaphor to remind us of the temporal continuity of behavior. Shaping creates new, unified, and hierarchically organized temporal patterns of behavior. But, what does it mean to say a shaped response is unified and hierarchically organized?

Unified Shaped Responses

Consider what *unified* means here. A shaped pattern is unified virtually by definition because a reinforcer is contingent on the pattern as a whole, not specifically on any independent component of the pattern. The experimenter delivers reinforcers as nearly contiguously in time with the ends of patterns as he or she can;

otherwise, shaping is less effective. However, one would not say response and reinforcer are contiguous, because delivery of a reinforcer depends on the pattern as a whole and the pattern has temporal duration. It is rather as though a music teacher says, "fine, nice phrasing, nice dynamics, a clear build up to the climax at letter H" to a piano student after a complicated passage, where the compliment applies to the whole passage, not just to the last note. A useful historical video available on the Web shows two pigeons playing the game of pigeon ping pong (see <http://www.youtube.com/watch?v=vGazyH6fQQ4>). Two pigeons stand across from each other with a table between them. One pigeon swipes the ball with its beak and sends the ball rolling back toward the other pigeon. (The ball does not fly through the air; it rolls back and forth on the table.) The receiving pigeon quickly moves toward the ball, then swipes it and sends it back toward the other pigeon. This goes on and on until one pigeon fails to swipe it back and the ball goes off the table. Whichever pigeon sends the ball off the table on the other pigeon's side wins a point (actually, food).

Skinner shaped the performances that define the unified game of pigeon ping pong, not an infinite number of independent component behaviors that, when somehow aggregated, produced pigeon ping pong. Although it makes sense to say that shaping creates a new unified pattern called *a game of pigeon ping pong*, it is important not to claim there is a single stereotyped pattern that is shaped; the pigeons engaged in many different specific patterns depending on what each other and the ball did on a moment-to-moment basis. All these specific component patterns define the higher order game of pigeon ping pong. Skinner's (1960) World War II program to develop a smart bomb guided by three pigeons in the nose cone of an air-to-ground missile involved behavior that was

similarly controlled on a moment-to-moment basis.

Hierarchical Shaped Responses

Now consider what it means to say a shaped response is a higher order response, that is, that it is hierarchically organized. I have just called the game of pigeon ping pong a higher order unified pattern, or response. By *higher order*, I mean hierarchically organized. A hierarchically organized pattern is a unitized pattern, the whole of which controls its component parts. Consider pigeon ping pong once again. It is a dynamic system with all the different movements under the control of larger movements. Everything follows a quickly evolving moment-to-moment pattern. We know from research on motor control, feedback systems, the design of artificial limbs, and robotics in general that systems like this do not work unless each momentary behavior is under the control of a larger moment-to-moment pattern, sometimes called a *plan*. The smaller and larger continuously interact. All the momentary dynamics are under the control of the larger shaped pattern, playing the game of pigeon ping pong. We would not even know how to define pigeon ping pong in terms of a finite list of independent momentary behaviors. In short, shaping creates patterns of behavior extended in time, not instantaneous behaviors.

To summarize, we may speak of the game of pigeon ping pong as being shaped and as being both unified and hierarchically organized. At first glance, this game may seem like a trivial exercise in shaping, but I will describe how it challenges both molecular and molar analyses in a way they cannot currently overcome using only their conventional kits of behavioral processes.

Shaping, however, is not very precise conceptually, methodologically, or quantitatively. In plain English,

we would say shaping depends on an experimenter's momentary judgment of the overall similarity between an observed pattern and a target pattern. The resulting process is therefore highly variable. For example, a teacher with a target of shaping student attending in a classroom might change tactics during the shaping process and might use different tactics for different students; hand shaping involves an experimenter's moment-to-moment judgments about when to deliver a reinforcer. Nevertheless, Skinner (1976) thought hand shaping was the most powerful and practical aspect of a science of behavior because it is so generally applicable. Shaping creates new temporal patterns like melodies and rhythms that emerge from sequences of individual notes, sentences from sequences of individual words, or words from phonemes. Component behaviors can overlap and an organism might at different moments do more than one thing, as when a distracted driver learns to steer, brake, look for other cars and pedestrians and traffic signals, and of course, to text, all at once.

If I were starting out in behavior analysis today, I think I might choose to capitalize on new technologies to extend shaping to dynamic games, including social games, like pigeon ping pong. I will discuss the role of automated shaping in Category 3 below. Suffice it here to note that there are visual simulators and computer software that in combination would let somebody like Skinner, or any young readers of this paper, show how behavior analysis can be applied to many everyday behaviors that are now being assimilated by other disciplines. I think behavior analysts might do a better job than anybody else at shaping moment-to-moment behaving, such as training sustained attending by air traffic controllers, better pitching and batting by baseball players, wiser shopping in grocery stores, walking in rehabilitation clinics, phrasing a melody musically

instead of mechanically, and so on and on. Behavior analysis has extended shaping in countless ways, and the technology I refer to is expensive, but given what society spends money on, the cost would not be great compared to the payoff. Technology now available would facilitate engineering society to make it work much better if only people would think more often about how to shape desired behaviors. I will return to this theme near the end of this paper.

No one claims that shaping is a universally applicable method that can teach anybody anything. There are many well-known constraints. For present purposes, it is important that shaping reorganizes a behavior stream and creates new responses so that it does not necessarily involve stable responding that preserves the identity of any behavior over time. Shaping is therefore not necessarily the method of choice if one is interested in quantitative analyses or the steady-state performances often required for quantification. More generally, the reader could probably think up patterns that could not be shaped by any known means as fast as I could think up patterns that could be shaped. From the perspective of a rigorous science of behavior, shaping behavior by hand seems to have the limitations of being non-technical, unscientific, and qualitative in nature. From the perspective of parents and teachers, however, these scientific limitations may be practical virtues; most people can learn to use it, and it is so powerful that it has been at the heart of complaints about Skinner's views about science and freedom. I am simplifying shaping by calling it a process because it is itself a higher order interactive pattern between experimenter and organism, and it no doubt involves many component processes in ways we do not yet understand. Notwithstanding these and other limitations of shaping by hand, it remains the most powerful method we have for creating new

unified temporal patterns in everyday life.

Shaping has not always been recognized outside behavior analysis for what it is. Chomsky overlooked the hierarchical nature of shaping when he mistakenly attributed contiguity and linear chaining to behavior analysis. He correctly saw that linear chaining could not adequately address hierarchical structure in the form of grammar of natural language, but he incorrectly attributed the overall methodology of associative learning theory to behavior analysis. In fact, shaping a pattern and teaching the correct grammatical structure of a sentence may both be examples of the same general problem, creating the molecular and hierarchically organized sequential structure of unitized behaving. MacCorquodale's (1970) reply to Chomsky's (1959) review of Skinner's *Verbal Behavior*, pointed out a further misunderstanding of Skinner's work:

Chomsky seems not to grasp the difference between the overall probability of occurrence of an item in a speaker's verbal repertoire, which is the frequency with which it occurs in his speech over time without regard to his momentary circumstances, and the momentary probability of a given response in some specified set of circumstances. ... Of the two, overall probability is a typically linguistic concern, while momentary probability shifts are, in a sense, the very heart of the psychologists' problem, since they reflect the relation between speech and its controlling variables. (p. 88)

MacCorquodale was saying that the momentary probability shifts intrinsic to shaping are the very heart of an analysis of verbal behavior and grammar. He also was saying that the overall amount of an activity without regard to momentary circumstances was less central to behavior analysis.

In summary, shaping by hand is a predominantly practical, atheoretical, qualitative, empirical method for the creation of new unified behavioral patterns that have hierarchical

organization. It is a moment-to-moment molecular method (Morse, 1966; Peterson, 2004; Zeiler, 2006). Sometimes qualitative methods are criticized for being unscientific, but in this case, if we only assume that observation, experimentation, and powerful control are important parts of science, shaping is actually more scientific than other methods that provide less control, which leads us to the next issue: free-operant methodology.

Free-Operant Methodology

Something may have slowed the development of shaping methodology and of our general conceptual understanding of it. What was it? I speculate free-operant methodology is the answer. It drove behavior analysis toward quantification of things easily quantified. It gave behavior analysis something to count. Shaping is not easy to quantify. A common assumption for several centuries has been that a defining feature of science is quantification. More recently, however, powerful arguments have been made for rigorous qualitative methods in psychology, and the idea that science must be quantitative now does not go unchallenged (see Agnew & Pyke, 2007, for a careful and balanced introduction to qualitative methods). From the received 1930s perspective of what science is, however, it would have been natural for Skinner to feel a need to generate numbers and quantitative empirical functions relating those numbers to reinforcement. In any case, he found a way to assign numbers to behaviors by inventing the free operant. He assumed (Skinner, 1950) that the average rate of a free operant estimated response probability, which is a number. The textbook definition of reinforcement as a process that strengthens a response became expressed in terms of response probability: A reinforcer delivered after a response increases the probability of that response. This

definition gave quantitative conceptual meaning to Aristotle's association theory and Thorndike's law of effect. From the perspective of this historical analysis, the free operant was defined in terms of a number and moved behavior analysis away from the shaping effect of reinforcement toward a focus on the quantitative strengthening effect of reinforcement. As will become clear below, this theoretical quantification of behavior remained largely dormant until the 1960s; for a number of years, it provided mainly an abstract conceptual justification for free-operant behavior and led to very few quantitative empirical analyses. The idea of the average rate of a free operant logically required the idea of an aggregated molar output, the total number of responses obtained from an organism over a temporal duration. Most unfortunately from my perspective, the use of average response rate as a dependent variable carried with it a number of theoretical assumptions that were not immediately evaluated or even recognized. Some of them remain empirically unverified to this day. These assumptions began to constrain and restrict the scope of behavior analysis. Consider three constraints that follow just from Skinner's assumption that average response rate can estimate response probability. One was that a free operant must have a stable identity over time, because otherwise computing its average rate would not estimate an assumed stable response probability. A second, related constraint was encouragement of the study of steady-state behavior to avoid having an average that combined different rates. A third constraint was that Skinner's assumption encouraged leaving reinforced local patterns free and uncontrolled compared to the way shaping imposes hierarchical organization, because free-operant methods allow greater freedom and variability in reinforced moment-to-moment behavior than

shaping does. All these constraints derived from having to aggregate behavior over time on behalf of the assumption that free-operant behavior facilitated the quantification of behavior in the form of response probability.

Skinner's assumptions and beliefs about free-operant methods encouraged the development in the 1960s and 1970s of a kind of behavior analysis Skinner himself seems not to have fully anticipated. Perhaps no one else did, either. Free-operant methods were the right methods in the right place at the right time to generate a quantitative behavior analysis, and tables of numbers began to appear routinely, with a single number (average rate) replacing much moment-to-moment behaving (Jozefowicz, McDowell, & Staddon, 2010). But on behalf of generating a quantitative science, behavior analysis had to focus more on steady-state free-operant behavior and less on shaping unified higher order patterns of behavior. Skinner (1976) lamented the loss of moment-to-moment analyses like shaping when he wrote his paean to cumulative records, "Farewell, My LOVELY!" This leads us to Category 2, molar behaviorism.

CATEGORY 2: A MOLAR ANALYSIS

Molar analyses aggregate behavior; they collect different occasions of ostensibly the same behavior into a single category. That is, all of the aggregated responses are interpreted as different instances of the same generic behavior. A molar aggregate involves behaviors that necessarily occurred at different times and possibly at different places. There are lots of ways to aggregate different behaviors. Perhaps the simplest way to gather together different behavior streams, or continuous segments of behavior streams, would be to preserve all their individual identities within the aggregate. A book full of

cumulative records of individual performances is a kind of pictorial version of this kind of aggregate (Ferster & Skinner, 1957).

The question then becomes how to condense an aggregate and how to discover general principles that unite the specific records. Molar analyses do not involve aggregates of individual continuous, molecular, behavior streams, neither pictured as cumulative records nor as digital computer files of individual behavior streams. That is, molar aggregates are not collections of behavior streams. Ferster and Skinner (1957) is an aggregate of many pictures of behavior streams extended in time, but it is not a molar analysis. Molar analyses involve a different kind of aggregate, a kind that is not bigger than molecular continuous behavior streams. Molar behavior is not just more of molecular behavior, or a longer sample of molecular behavior, or a kind of magnified version of continuous behavior. A molar analysis first transforms a behavior stream into component behaviors, then aggregates the components, and then usually summarizes the aggregate in terms of its average. A molar analysis is a quantitative description of an aggregate, in a manner Ferster and Skinner, even though it was an aggregate of behaviors extended in time, was not. A common example is, of course, collapsing a behavior stream into a collection of a pigeon's key pecks and then taking their average rate of occurrence, or average time allocated to pecking rather than to doing something else. Aggregating behavior assumes the component behavior that is aggregated has a stable identity within the behavior stream. I will call the resulting kind of analysis a *dependent molar analysis*, because the analysis depends on there being a known behavior stream in the first place. There is a second way to aggregate behavior, and it involves a different relation between a molar aggregate and a behavior stream, specifically, no relation at all. I will

call that analysis an *independent molar analysis*.

The dependent case, in which behaving is aggregated in a manner that permits the average of the aggregate to be understood in terms of the original behavior stream, led in the 1960s and 1970s to an early and important form of molar analyses in which rate of responding was plotted against such variables as relative or absolute rates of reinforcement. These molar controlling functions became common, along with the tables of numbers on which they were based. Good examples of dependent molar empirical functions are shown in Catania and Reynolds (1968) and Herrnstein (1961). These functions satisfied the scientific standards Sidman (1960) had advocated in his influential book, *Tactics of Scientific Research*: The curves looked reasonably smooth and orderly, especially if one aggregated a sufficiently large number of component behaviors. In these examples of dependent molar analyses, it would have been possible to run a cumulative recorder during the experimental sessions. This possibility suggests that these molar analyses and molecular analyses based on moment-to-moment behaving, shown in a cumulative record, were still conceptually and methodologically linked. Molar behaviorism had not yet become radically different from Skinner's descriptions of the methods suitable for radical behaviorism, but it did become radically different soon after.

An important development during this period was the invention of an average of performance based on a new kind of aggregate that involved time allocation. Baum and Rachlin's (1969) seminal paper described a task in which an organism in a chamber moved back and forth from one side to the other, and while it was on one side, one variable-interval (VI) contingency delivered reinforcers, and while on the other side, a different VI contingency delivered reinforcers.

(It is important for discussion below that the length of a changeover delay [COD] has a profound effect on choice maintained by concurrent schedules and that a 4-s COD was implemented.) Behaving was aggregated by collecting together all the different times spent on each of the two sides, adding the times on each side, and plotting an aggregate time spent on a side against relative rate of reward on that side. The molar controlling function that emerged roughly approximated the matching function. Baum and Rachlin advocated time allocation as superior to response rate with its dependence on discrete responses. Time allocated to the activity, such as standing on a side, came to be advocated in some molar literature as superior to the vagaries of moment-to-moment details of a behavior stream (Baum & Rachlin) in a manner similar to how other molar literature advocates for aggregates of free-operant behaviors emitted over time as being superior to moment-to-moment responses (Jensen, Miller, & Neuringer, 2012). In any case, controlling molar functions are now commonly plotted, with average time allocations being assumed to be directly under the control of reinforcement.

Time allocated to an activity while an animal was on one side of the chamber in Baum and Rachlin's (1969) experiment may have been independent of many of the details of the behavior stream on that side, but it was not independent of the average rate of a discrete free operant. There were two discrete free operants that segmented the overall behavior stream into two parts; the switching response (moving from one side to the other) could occur at any moment, and was a discrete free operant. Aggregated times allocated to each side, in association with the numbers of discrete switching responses, could be used to compute the average rates of the two free-operant switching responses. Time

allocated to an activity of standing on a side was in this sense equivalent to the average rate of a momentary discrete switching response. This way of aggregating time allocated to an activity defines a molar behavior, but it can be derived from how a momentary switching response segments a behavior stream, so I repeat that this kind of aggregating behavior exemplifies a dependent molar analysis. Herrnstein's (1970) theoretical paper on the law of effect and the matching law was of this type but illustrates how molar theory was becoming less explicitly linked to moment-to-moment behaving. Components of a behavior stream were becoming overshadowed by their collective average rates or times (Rachlin & Laibson, 1997).

This link between a behavior stream and its aggregated components was completely severed by the second kind of molar analysis, the independent case. Here, a molar aggregate is not computed from any individual behavior stream or streams that could ever in practice be known. For example, in Wilson and Herrnstein's (1985) book, *Crime and Human Nature*, the authors cited laboratory results of the dependent type I just described (specifically, molar controlling functions obtained in experiments in which there were individual, knowable, behavior streams) but then used the general shapes of those empirical functions to describe and explain empirical results that have no known relation to any continuous behavior streams. To do this, they moved from referring to behavior related in a knowable way to a behavior stream to a function they plotted showing a behavior they labeled *crime* as a function of the "time interval between each behavior and its reward" (p. 51). These behaviors, time intervals, and rewards were not aggregates obtained from any known individual behavior stream or streams. Furthermore, neither the response stability required for a molar controlling

function to be meaningful nor the reinforcement contingencies were specified. The authors subsequently used speculative functions of this type to interpret empirical functions that have appeared in literatures in sociology, economics, and other disciplines. It would have been impossible to run cumulative recorders during data acquisition for the referenced experiments. For behaviorists who like to summarize what behavior is by saying it is what organisms do, this kind of molar analysis is a problem, because it is not clear what any organism ever actually did. Sometimes molar behaviorists refer to there being different "levels of analysis" between molecular and molar analyses. I suggest that this is true not for the difference between molecular and molar analyses but for the difference between both molecular analyses and dependent molar analyses on the one hand and independent molar analyses on the other hand. The odd man out is independent molar analyses, in which there is no relation between an aggregate and any behavior stream or streams. As a result, it cannot be determined whether such an aggregate forms a meaningful generic operant class. According to MacCorquodale's quote provided above, such an aggregate would more fittingly be described as criminology, not behavior analysis.

Molar Behaviorism and the Control of Behavior

Molar behaviorism has led to a distinctly different treatment of the shaping effect of reinforcement. Independent molar behaviorism severs any relation to shaping; but dependent molar behaviorism also assigns a diminished role to shaping along with other moment-to-moment methods. With its emphasis on aggregates, or collections of different episodes of moment-to-moment behaving, local patterns of behavior play a smaller

role in a molar analysis. Baum (2010) wrote,

In applied behavior analysis, in particular, regularities on the smallest time scale may be of little use or interest ... when one is dealing with problem behavior in a classroom, for example, delivering a teacher's attention or praise at precise moments may be impractical and, in any case, a relation at a longer time scale may suffice. (p. 174)

Such situations no doubt exist, but one must wonder how successful Skinner's shaping pigeon ping pong would have been had he routinely followed such advice. Baum's view of the value of precise control of moment-to-moment behavior would surprise pianists, singers, baseball pitchers, automobile drivers in high-speed heavy traffic, air traffic controllers, and so on and on, all of whom have to engage in split-second, accurate responding. And, split-second decision making in nature is a life-and-death matter, as when a hawk's shadow passes over a rabbit's head or a pedestrian crosses a busy street. As Baum's example correctly reminds us, multitasking in the real world is not always easy, and that is why Skinner suggested in *Beyond Freedom and Dignity* (1971) and in *Walden Two* (1948) that part of the solution to improving people's lives through a science of behavior was not just to reengineer particularistic contingencies on individuals but to change the social reinforcement contexts within which individuals live. We change the contingencies for air traffic controllers so they are distracted as little as possible; I think Skinner would have advocated for a similar change in Baum's hypothetical classroom. His hypothetical teacher should have previously shaped better moment-to-moment control in the classroom to ensure the class was more attentive in the first place. Another example of how molar analyses handle patterns of behavior is provided in the article by Baum and Rachlin (1969), which I discussed above in terms of time allocation and momentary

discrete responses. Recall that a COD was used to generate the desired molar levels of preference, but they wrote, "we excluded time spent during the COD from our calculations, on the ground that it was signaled timeout from the experiment" (Baum, 2002, p. 103). The COD was essential to controlling local behavior to produce the desired molar behavior, but at the same time it was considered to be a timeout from the experiment. If the COD was crucial to obtaining the desired outcome, it is not easy to see, from the perspective of the shaping effect of reinforcement, why it was considered to be a timeout from the experiment. Molar analyses treat moment-to-moment behaving, including "behaviors extended in time," in ways that can sometimes seem logically incoherent. I suggest that molar analyses have generated for themselves an unnecessary problem when it comes to controlling moment-to-moment behaving and when it comes to shaping in general; they appear to do so on behalf of maintaining the idea of the primacy of directly controlling aggregates instead of controlling individual behavior streams. In fact, molar analyses largely abandon the goal of obtaining controlling functions for many behaviors extended in time, including various kinds of temporal patterns I describe below. Molar maximizing became a prominent part of molar analyses in the 1970s and later, and is an excellent illustration of the molar approach (see Tanno & Silberberg, 2012, for a detailed discussion of many problems with this approach).

Molar Behaviorism and Conceptual Ambiguity

Aggregated behavior is indisputably important, as anyone knows who is interested in what political polls say about likely winners of an election, in what monthly jobs reports say about the health of the economy, and in whether national

crime rates are going up or down. Let us accept the necessity of aggregates and briefly note a few conceptual issues that arise in analyses of them. The first issue is the phrase *behavior extended in time*. This phrase is used frequently in molar analyses, but several authors (e.g., Marr, 2011) have noted that the criteria by which we recognize such behavior need clarification. And, how does behavior extended in time get created? (Molar analyses seem to exclude shaping and moment-to-moment behaving, but I will suggest below how a more powerful, unified analysis seems possible when attributes of molecular and molar analyses are combined.) Because behavior extended in time must have a duration that can be measured when we cumulate times allocated to a particular activity, any given instance of that behavior must have a start time and an end time. What are the criteria by which we determine what these times are? How do we determine time allocated to an activity when, for example, we study distracted driving and want to know how much time a person allocates to driving in a day? Suppose we observe a driver simultaneously allocating time to looking at the road ahead, watching for pedestrians and other cars, steering, braking, listening to the radio, and texting. How do we tell when all these separate component activities start and stop, and how do we tell when they overlap and by how much? At the end of our recording, we find all the times the driver allocated to these activities add up to 3 hr, but the driver was in the car for only 1 hr. How can we construct a molar pie chart that shows aggregated times allocated to various activities if the various times do not add up to the actual total time? A problem also arises when we consider the hierarchical organization of molar behavior. How is hierarchical organization created? This question is comparatively simple in the case of shaping that produces patterns similar

to target patterns, as it does in Categories 1 (above) and 3 (below). Molar methods, however, provide no such practical criterion for determining the answer to this question. Is it possible to determine how allocation of time to a hierarchical pattern depends on its quantitative properties? (This will become especially important in Category 3, below.) Lastly, molar behaviorism does not seem to distinguish between dependent and independent molar analyses even though these analyses relate to moment-to-moment behaving in very different ways. Why does that not matter? I will be most interested to see how molar behaviorism overcomes these challenging questions.

Molar Behaviorism, Contiguity, and Linear Chaining

One way molar behaviorism has clarified its position has been to contrast it with molecular theory. Molar theory has allied molecular theory with *contiguity theory*. From the perspective of history and philosophy of behaviorism, three features of this argument stand out. First, the contiguity theory that molar behaviorism critiques is a very old creation and should not be associated with molecular analyses of the last 50 years or so. Advocates of modern molecular analyses have argued against contiguity theory and linear chaining for many years (e.g., Shimp, 1976). There is no more contiguity or linear chaining in shaping than there is in talking or singing or walking. Without hierarchical control, not even machines (e.g., robots that successively weld different parts of automobiles together) could function effectively. I argued (Shimp, 1976) that the work of Anderson and Bower (1973) and others (Tulving & Donaldson, 1972) sufficed to show the limits of linear contiguity theory. I would be happy to learn why molar theorists believe that these earlier arguments do not suffice.

Second, molar literature uses Kuhn's (1996) philosophy of science to describe the difference between molar analyses and molecular analyses. The claim is that a Kuhnian paradigm shift is taking place from molecular to molar analyses (Baum, 2002). At the core of such a claim is that there is what Kuhn called an *incommensurable difference* between the two analyses; that is, that they are utterly incompatible and have nothing important in common between them. Thus, there is nothing on which to build progress when moving from molecular to molar analyses. Molar behaviorism must start anew. This kind of claim reflects an extreme divisiveness between molecular and molar analyses that may be softening: At the Santa Fe conference, after I presented the talk on which this paper is based, I was pleased to hear Baum (2013) say that his position is very similar to mine (also see below). My unified Category 3 described below has developed largely parallel to the development of molar behaviorism, so perhaps molar behaviorists will no longer need to contrast their positions with molecular positions.

Third, molar behaviorism actually shares an important feature of the contiguity theory it argues against. As I noted above, dependent molar behaviorism implicitly relies on discrete momentary free operants in the form of switching responses to segment behavior streams, even when it explicitly deals with time allocated to activities extended in time (Baum & Rachlin, 1969).

I hope it is clear that if we compare the difference between the shaping of pigeon ping pong of the 1940s on the one hand and the matching law of the 1970s and later molar behaviorism on the other hand, behavior analysis has split into two sharply different categories, molecular and molar. I next describe a path I have favored for quite some time that shows that molecular and molar analyses actually have much in common and can be mutually supportive.

CATEGORY 3: A UNIFIED ANALYSIS

From the perspective of Category 3, it is useful to see molecular and molar analyses as mutually informative. My third category of behavior analysis has the goal of at least partially unifying them by combining their respective strengths. I am apparently not alone in this view: I repeat that I was very pleased during the public discussion at the conference in Santa Fe to hear Baum say that the position I described was similar to his own. A unified account may resolve his previous concern that a molar analysis and molar behaviorism define a Kuhnian paradigm shift according to which molecular and molar analyses have nothing basic in common. I am not being facetious when I say I look forward to seeing how molecular and molar analyses can be unified yet have nothing in common.

I believe molar behaviorism faces exactly that challenge. That is, I see molar behaviorism facing a challenge to unite molecular shaping of continuous patterns on the one hand and molar analyses involving aggregate performances in terms of quantitative strengthening or other notions on the other hand. In any case, the molecular shaping component of the unified category I describe here is a quantitative and automated version of the familiar hand-shaping method of Category 1. Automated shaping creates new unified temporal patterns just as does hand shaping in Category 1; but in Category 3 these patterns have precise, quantitative features that a computer controls. Automated shaping can specify (a) the starting behavior of a reinforced pattern and when the pattern should start, (b) the ending behavior and when the pattern should end, and (c) the behavior in between (e.g., Shimp, Sabulsky, & Childers, 1989). Skinner's contingencies that shaped the spacing between successive key pecks or lever presses,

like differential reinforcement of low-rate (DRL) schedules, were very early examples of the shaping method of Category 3. Later methods have shaped more complex multiple patterns, like multiple interresponse times (IRTs; Anger, 1956; Galbicka, 1994; Platt, 1973; Shimp, 1971, 1973), IRTs and interchangeover times (ICTs) from several additional contingencies, and hierarchical patterns of increasing or decreasing rates of component responses that look like a fixed-interval scallop (Hawkes & Shimp, 1975, 1998). These varieties of shaped quantitative patterns presumably only scratch the surface of possible quantitative behaviors extended in time created through shaping.

So far, however, the computer software that supports these molecular analyses cannot control target patterns that shift unpredictably, continuously, and multidimensionally, as in pigeon ping pong. Although the automated shaping component of Category 3 has been more quantitatively precise than hand shaping, it is at the expense of dynamic complexity and realism. I will return to this problem below and will suggest a possible solution.

How can this automated shaping component be combined with a molar component? I suggest two ways. First, I suggest that the unified Category 3 shares the molar feature of involving behavior extended in time, in the form of the unitized target patterns that shaping creates. That is, the moment-to-moment behaving that approximates target patterns is behavior and is extended in time. Second, there is no reason why emitted patterns that approximate shaped target patterns cannot be aggregated. One can aggregate and then count shaped patterns and thereby create an aggregate of patterns rather than discrete momentary responses like free-operant key pecks. One can even proceed further and plot the number of shaped target patterns as a function of reinforcement parameters and contingencies.

One of the first analyses of this type was presented by Anger (1956). Many other contingencies that involved automated shaping led to such functions that have properties of both molecular and molar analyses. They are controlling functions because they plot counts of aggregated behaviors as a function of reinforcement, they are molecular because they involve responses that are unified moment-to-moment patterns that have been shaped, and they are molar because they involve counting aggregated behaviors extended in time (Shimp, 1968, 1969, 1970, 1971, 1973, 1974; Staddon, 1968).

By now, I hope the reader will see there is nothing paradigmatically different between this kind of aggregation and that of conventional molar analyses. The difference here is that the aggregation is of responses that are behaviors extended in time having specified quantitative properties, especially temporal properties. In short, the second component method of Category 3 is the conventional molar aggregation method. The molar component of the unified category therefore has the advantages and disadvantages I described for Category 2. For example, an aggregated IRT distribution assumes that the component IRTs are sufficiently similar so that it is permissible to aggregate them together. As with Category 1 and the dependent molar case, a second limitation of the unified category is that it cannot handle the kinds of aggregates involved in the independent molar case, in which there is no known behavior stream from which a meaningful aggregate can be defined. What do controlling relations that involve shaped behaviors extended in time look like? They show perfectly smooth, orderly, controlling functions. They may be said to show the overall strengths of unitized moment-to-moment patterns, that is, rates of, or times allocated to, aggregated moment-to-moment patterns with specified quantitative features.

What is perhaps the single most important conceptual implication of these functions? They show that pattern strength depends on quantitative parameters of all the shaped patterns. The strength of a pattern depends on that pattern's structure as well as on all the other patterns, for a given fixed molar-reinforcement contingency. It is impossible to study the molar strength of a shaped behavior extended in time without knowing the temporal properties of the other behaviors extended in time (Shimp, 1969; Shimp, Fremouw, Ingebritsen, & Long, 1994; Shimp, Sabulsky, & Childers, 1990).

More particularly, these functions show that time-allocation matching, a time-allocation version of the matching law, is a rare special case, and casts doubt on claims such as that by Williams (1988), who wrote, "the matching relation is a general law of choice" (p. 178; see also Williams, 1990). From the perspective of the unified category of behavior analysis, it seems like a general law only if one does not shape, control, or otherwise know what the various reinforced behaviors extended in time are.

Heroic efforts have been made to determine the relation between the strength of a free operant, in the form of its average rate, and its local components, viewed as latencies, IRTs, or clusters or bouts of component responses, and so on. For instance, Killeen and colleagues (Killeen & Hall, 2010; Killeen, Hall, Reilly, & Kettle, 2002) examined performance under classic free-operant methods and examined how response rate is a combination of what they called molecular components. However, they did not examine performance under any contingency that involved an explicit, experimentally controlled shaping component that creates and unifies temporal patterns. From the perspective of the unified category, in which it is assumed that reinforcement generally has both shaping and strengthening

effects, they examined a special case in which it was assumed that there were no shaping effects. They did not, however, empirically demonstrate that there were no shaping effects. It therefore remains open whether they solved, or even addressed, the general question of the relation between molecular and molar analyses, or the relation between shaped moment-to-moment behaving on the one hand and aggregated behavior on the other hand.

The unified category may resolve a common response to demonstrations of shaping of behaviors extended in time. Such demonstrations of explicit shaping contingencies have been interpreted as having little or no relevance to occasions when the shaping effect of reinforcement is only implicit. This molar perspective is that the effectiveness of explicit shaping does not necessarily imply that shaping is involved when shaping is not explicit. This argument may be designed to preserve free-operant methodology as a context in which response strength can be estimated without having to evaluate the possibility of there being any shaping effects. If so, this argument seems to me to have limited value if the point of a science of behavior is to control behavior, including behavior extended in time. If we view the argument the other way around, one could point out that, if one uses a method in which it is impossible to determine whether there is or is not implicit shaping, there is no evidence that shaping is *not* taking place. It is not clear to me why ambiguous methods that confound shaping and strengthening are particularly desirable. Tanno and Sakagami (2008) and Tanno and Silberberg (2012) have clarified how moment-to-moment analyses can disambiguate a wide variety of empirical phenomena that otherwise might be viewed as support for a molar analysis.

A closely related molar interpretation of demonstrations of shaping is the claim that local patterns of free-operant

behavior are random, just as one might expect if there is no shaping effect of reinforcement and if mean rate estimates overall response probability (Jensen et al., 2012). Some evidence for this position (e.g., Nevin, 1979) can be interpreted by the kind of theory I describe next (see also Shimp, 1994).

TOWARD A MORE GENERAL AND POWERFUL THEORETICAL SCIENCE OF BEHAVIOR: COMPUTER SIMULATION METHODS

This paper so far has summarized molecular, molar, and unified categories of analysis. These analyses have successfully led to both molar and unified empirical controlling functions that relate behavior to reinforcement, but these functions are not the ultimate goal of a science of behavior; they are only part of its development. The next step requires rethinking two of Skinner's assumptions about science. First, Skinner advised against wasting time on several kinds of speculative causal explanations, including, ironically, those on a different level from behavior, such as mathematical explanations. Perhaps Skinner therefore might have balked at the general idea that a statistic descriptive of an average of an aggregate is on the same level as moment-to-moment behavior. That is, however, exactly what mean rate of a free operant is, and Skinner was right that an observer does not see behavior when he or she observes a statistic that describes an aggregate of behavior in the same way that he or she observes moment-to-moment behavior while shaping some new behavior extended in time. Be that as it may, his advice was itself speculative. His speculation is understandable in the context of his time, but times have changed, as I will describe momentarily. There are now quantitative methods to generate moment-to-moment behavior.

Second, he also advocated relying heavily on direct observation of phenomena, inspiring many discussions among behavior analysts about what his advice meant, such as my example of whether mean response rate is observed behavior. Discussions about the difference between overt and covert behavior also follow from his advice. Whatever precisely his advice means, it too is speculative. Here is why both of Skinner's assumptions need updating. When Skinner speculated about theory and observation, the tools available to nearly all psychologists for building and evaluating theory consisted of just plain English and elementary mathematics. The former was highly ambiguous, and the latter imposed severe constraints on the kinds of data that could be analyzed and theories that could be evaluated. Now, however, theories can be as complex as it is judged necessary for them to be, in the sense that they can now involve component processes that interact in real time in ways that are likely, at least in my judgment, to be beyond mathematics to describe. The component processes can be well defined, but the mathematics of how they all interact in time may exceed what mathematics can tell us. In the past, it would not have been possible to evaluate this kind of collection of assumptions; the collection as a whole would have remained mathematically untested, mysterious, and without any tangible value. Now, however, all we have to do is write a program that incorporates the assumptions, start up the program, and see what moment-to-moment behavior streams it generates. We can then compare the simulated streams and real streams in as rigorous a manner as any corresponding comparison in the hard sciences.

Given the availability of theories of this potential explanatory power, what use are all the empirical molar and unified controlling functions that so many researchers have allocated

so much of their personal resources to discovering? They serve as test beds for theory development. The empirical functions are not the be all and end all, and are not “basic” in any important sense, but they serve admirably as constraints on theory development. In an iterative process, we first guess how a theory we define might behave, we simulate the theory and find out how well it does or does not work, revise the theory to make it correspond more closely to data, and so on. There are already several excellent theories of this type, and I recommend the reader to look at molecular computer simulation theories by Catania (2005), Tanno and Silberberg (2012), and McDowell (2013). The former is a wonderful instructional tool for learning about moment-to-moment behaving, including cumulative records, and the latter two are incredible in the breadth and detail of their treatments of classic problems in deriving molar results from molecular theories. There are other viable computational theories as well (Shimp, 1981, 1984a, 1984b, 1992, 1994; Shimp, Childers, & Hightower, 1990). It must be acknowledged that some behavior analysts may not be as sanguine as I am when they think about the daunting challenges that theories of behavior face (e.g., Marr, 2004), although recent and continuing progress may change their minds.

For readers who think they might want to work on developing computer simulation models, let me describe an even bigger challenge. Why stop at using computer simulation to describe and explain molecular and molar empirical functions and cumulative records? Operant methods have been used to study spatial attention (Shimp & Friedrich, 1993), visual search (Blough, 2012), categorization (Herbranson, Fremouw, & Shimp, 2002), memory, timing, counting, and many other phenomena (Shimp, Herbranson, & Fremouw, 2012; Zentall &

Wasserman, 2012). Why not develop a theory to handle these data as well as what is usually thought of as molecular and molar data? An especially striking challenge in my mind is defined by the recent discovery that pigeons under the control of operant methods respond to statistical sequential information in serial response-time tasks in a manner similar to how human infants respond to statistical information in natural language (Shimp, Froehlich, & Herbranson, 2007). Furthermore, operant methods can teach pigeons artificial grammars (Herbranson & Shimp, 2003, 2008). Together, these two results encourage the possibility that shaping and strengthening effects of reinforcement may significantly inform our understanding of natural language (Aslin & Newport, 2012). There is no obvious reason why a simulation theory could not be developed to integrate all these different kinds of phenomena. Recall from earlier in this paper that today’s computer software and computational power are already being used for simulations of similar behaviors. If Skinner could teach pigeons to play ping pong, if computer programmers can write commercial software so people eagerly pay to play interactive video games, why cannot ambitious young behavior analysts develop computer programs to teach pigeons to play ping pong and to behave like real organisms in all the various tasks I just listed?

CONCLUSION

The session of the Santa Fe conference at which this paper was given was called “What Counts as Behavior?” The three different categories of analysis answer that question differently. What Category 1, including molecular shaping, gains in everyday qualitative applicability, it loses in quantitative precision; it requires an experimenter to count very little or nothing. Category 2, molar analysis, relies on free-operant methods that

control behavior less precisely than shaping does but provides quantitative measures of aggregated behaviors. These cumulative measures can be counts of key pecks and lever presses or cumulative times allocated to behaviors extended in time, but apparently not to explicitly shaped behaviors quantitatively extended in time; molar analysis therefore is at risk for confounding shaping and strengthening effects. Category 3, the unified category, most rigorously controls behavior and unites molecular shaping of continuous behaviors extended in time with molar aggregates of those behaviors. It therefore permits counting unified higher order patterns of behavior and then plotting those counts against reinforcement parameters. These unified controlling functions seem less susceptible than those of Category 2 to confounding shaping and the strengthening effects of reinforcement. When I presented a version of this paper at the Santa Fe conference, I asked for a show of hands to indicate who had had practice in hand shaping of Category 1. Virtually everyone had. I then asked for a show of hands to indicate who had experience with computer programs that simulate hand shaping. Very roughly half of the audience had had experience with this example of Category 3. Finally, I asked who had read a recent important paper on computer simulation theory. One person had.

This is a problem for the future of behavior analysis. Even an audience interested in behavioral theory was unaware of one of the most successful moment-to-moment behavioral theories yet published. This imbalance presumably reflects the training now provided in behavior analysis. I believe that young behavior analysts need to be trained to write dynamic computer programs like the software used to run interactive video computer games that run from moment to moment. Automated shaping must be more fully developed and exploited so that a science of behavior can

be developed for more complex behaviors. I also believe that young behavior analysts need to be trained to see that a computer simulation of a behavior stream is a theory of that behavior stream. As several participants at the Santa Fe conference discussed, such theories may involve component processes with surprisingly little in common with traditional views about a science of behavior (e.g., McDowell, 2013). As a result, I believe behaving theories will demand greater emphasis on a more nearly unified and theoretically more sophisticated behavior analysis.

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