Functions of the Environment in Behavioral Evolution

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This paper explores some of the ways in which the environment functions with respect to behavior within an explanatory framework analogous to that of evolutionary biology. In both the behavioral and organic domains, the environment functions differently with respect to individual occurrences and evolutionary units. Within the behavioral domain, the problem of accounting for an occurrence of an operant instance differs from that of accounting for the existence of the operant unit of which the instance is a part. Maintaining these distinctions in levels of analysis within the behavioral domain, we focus first on operant units and operant instances as products of evolutionary processes occurring in the behavioral domain and second upon the causal role of the environment with respect to the existence of operant units and the occurrence of operant instances. The environment's function is selective with respect to origin, maintenance, suppression, and extinction of behavioral populations. At the level of operant instances, the environment has *instantiating* functions—*evocative* or *alterative*. Evocative functions are exemplified by discriminative relations, and alterative functions include both conditional and motivative relations. Implications are considered regarding extension of the analogy to more complex behavior–environment relations.

Key words: evolutionary analogy, behavioral selection, behavior stream, operant unit, behavioral instance, instantiating function

Similarities between behavioral principles and the explanatory principles of organic evolution have been recognized for decades (e.g., Campbell, 1956; Skinner, 1953; Staddon, 1973). After Skinner's 1981 article on selection by consequences was reprinted with commentary (1984, 1986), exploration of this parallel increased in frequency (e.g., Alessi, 1992; Glenn, 1991;

Palmer & Donahoe, 1992; Robinson & Woodward, 1989; Skinner, 1984, 1986; Smith, 1986). Unlike organic evolution based upon natural selection, behavioral evolution occurs during the lifetime of individual organisms. The evolution of the behavior of individual organisms results from a "second kind of selection" (Skinner, 1986, p. 12).

From the present perspective, organic evolution accounts for the existence of behavioral *processes* that are part of the genetic endowment of the human species—our phylogeny. These processes, in turn, provide the explanation for much of the content of individual human repertoires[1]—our ontogeny. Processes

[1] A *repertoire* is the collection of behavior–environment relations that exist with respect to a particular organism at a particular point in time. But it is not an unrelated collection of operant units. A repertoire can be compared to a biosphere in organic evolution. Changes in the content of a repertoire (or a biosphere) are a function of prior relations between its parts and environmental events. The changes brought about by those relations make possible new relations between parts of the repertoire and the environment. Changes in some parts of a repertoire can affect the way in which other parts of a repertoire can enter into relations with environmental events. A repertoire includes behavioral units of ontogenic origin (e.g., playing scales on piano) as well as behavioral units of phylogenic

that account for behavior acquired during a human lifetime have been lumped together under the general term *learning.* To attribute ontogenic behavior change to learning is somewhat like attributing changes in the organic world to *evolution,* an attribution that was common even before Darwin. Darwin's great achievement was to identify processes accounting for the origin and evolution of the organic content of the biosphere (Mayr, 1982, chap. 11).

In organic evolution, relatively few principles account for a great complex web of interrelated phenomena of the biosphere. In this paper, we pursue the possibility that simplicity similarly underlies complexity in the behavioral realm. Our goal is to consider ways in which the environment functions with respect to behavior within an explanatory framework that parallels in some ways the explanatory framework of evolutionary biology. The evolution at issue in this paper is not organic evolution, but behavioral evolution during ontogeny. We concentrate here on the explanatory role of contingencies of reinforcement in the evolution of operant content in individual organisms. We leave to the future, and perhaps to other writers, the examination of nonoperant behavioral content and additional causal forces that may be involved in behavioral evolution.

OPERANT UNITS AND OPERANT OCCURRENCES

It is important first to distinguish between the *existence* of operant *units* and the *occurrence* of operant *instances.* Glenn, Ellis, and Greenspoon (1992) traced the development of the operant concept in the early work of Skinner and found that Skinner (1935, 1937) distinguished, implicitly or explicitly, among (a) occurrences of operant behavior, which he sometimes called responses (e.g., a single occurrence of a lever press); (b)

operants as existing units (e.g., Rat 404's lever pressing as shown on a cumulative record); and (c) operant behavior as a *kind* of behavioral phenomenon (e.g., behavior having its origin in contingencies of reinforcement).

Glenn et al. (1992) suggested that operants in Skinner's second sense are individuals in the same sense that Ghiselin (1974) argued that species are individuals. Although not *things* (any more than species are), specific operant relations exist in the repertoires of specific organisms. They are as much a part of the world of natural, historical phenomena as are organisms and instances of action—the difference is the difference in the time spans of their existence. Thus, each operant has a beginning and an end, as does each species. Although it may not be possible to pinpoint their beginnings or endings, scientists can say with some confidence that certain species did not yet exist at certain times and no longer existed at later times.

Individual species and operant units are the result of selection processes operating in the domains, respectively, of organic evolution and behavioral evolution. An individual species is composed of a population of organisms that can be traced historically to a common origin (i.e., all members of the population share a common evolutionary history and therefore share chromosome configurations that allow them, in the case of a sexually reproducing species, to interbreed). A particular species is a "natural population" and is to be distinguished from a population that merely has common characteristics (e.g., chairs or organisms with wings). Similarly, an operant unit is a "natural population" and is to be distinguished from a population of responses that have similar structures or functions, within or across organisms. The common origin of an operant population is in the history of reinforcement accounting for characteristics of the population (see Table 1).

One way in which operants and species differ as individuals is that the parts of an individual operant (i.e., instances of behavior) do not exist concurrently,

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origin (e.g., salivary reflex). A repertoire is the result of the history of the species (and all ancestor species) of which an organism is a part and the history of the individual organism with respect to its postconception environment.

TABLE 1

Kinds of Individuals Produced by Evolutionary Processes in Two Domains

Domain	Natural populations	Population members
Organic evolution	Species (*H. sapiens*)	Organisms (Jane Doe)
Behavioral evolution	Operant units (Jane's toothbrushing)	Operant instances (Jane's brushing her teeth at 8:00 a.m. on July 18, 1994)

whereas some of the parts of a species (i.e., organisms) do exist concurrently. That is, many organisms of a single species exist alongside one another in space at any particular time, but only one member of an operant unit is likely to be occurring at any particular time. Both operants and species do extend across time, however, as a succession of responses and organisms. And it is across the dimension of time that evolution of any kind occurs. An operant, then, is a natural population of instances of operant behavior, and it is an evolutionary individual.

The members (organisms) making up a particular species may be simple in structure (like the single-celled organisms of bacterial species) or may be more complex in structure (like multicelled organisms with interrelated parts, such as those of fish or mammalian species). Similarly, members (instances or responses) of an operant may be single-component instances (like lever presses) or multicomponent instances (like waterings of a plant). One of the characteristics of evolutionary processes is that componentry becomes more complex over time.

The existence of operants and species, as well as the characteristics of their members, are among the natural phenomena to be explained by scientific principles or laws. The laws (or principles) do not "refer to *particular* individuals" (which are localizable in space and time) but "are generalizations that are spatiotemporally unrestricted" (Hull, 1984, p. 145, emphasis added). The laws or principles refer to "any entities that have the appropriate characteristics" (Hull, 1984, p. 145). As applied to be-

havioral evolution, principles of operant conditioning make no reference to the particulars of behavioral content (lever pressing or watering a plant) or to the particulars of the environment having function with respect to behavior (food pellets or money or applause); they refer to any and all entities (operants) that enter into the kinds of functional relations described by these principles. Behavioral principles describe generalized lawful relations between organismic activity and environmental events.[2] They describe the relations involved in operant behavior as

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[2] We use *event* here as a generic term that covers all the ways in which the environment can be fractured into functional elements by selection processes, organic or behavioral. Some of those functional elements include single properties (e.g., hue), combinations of stimulus properties (e.g., hue and form), and relationships among properties (e.g., smaller) and among compound properties (e.g., identity). An environmental event may appear to an observer to be instantaneous (a flash of lightning), distributed across time or space (a drum beat or a swarm of bees), or spatially and/or temporally continuous (a chair or humming of the air conditioner). Relations among temporally and spatially distributed parts of the environment that enter into behavior–environment relations are included. For example, the beat of a drum at a particular tempo can be described as the relation between punctate drum beats, separated in time, functioning to control the response "4/4 time." The relation between beats is the controlling aspect of the environment, of which the beats are only a part.

There is considerable debate surrounding the issue of molecular versus molar aspects of the environment in selection contingencies (Baum, 1973, 1989; Hineline, 1984; Skinner, 1984). It is beyond the scope of the current paper to address this issue except at the terminological level, noting that to the extent that relations between aspects of the environment enter into relations, they are included in the current analysis as events.

a *kind* of phenomenon—Skinner's third sense of the term *operant*. It is in this third sense that one may consider the functions of the environment in a generic sense.

In organic evolutionary theory, the evolutionary unit is the species (populations of reproductively interchangeable organisms, like humans); in behavioral evolutionary theory, the comparable unit is the operant (populations of interchangeable responses, like Rat 404's bar pressing). Principles accounting for the origins of species and operants do not allow us to answer questions such as "Will Ann's first child have sickle-cell anemia?" or "Will John come to the table when I call him this time?" In these examples, the focus has shifted from individual species and individual operants to their parts—a particular organism and a particular instance of behavior. In the behavioral case, the question about John's coming to the table has to do with an instance of an operant occurring in an ongoing behavior stream. Such an instance is part of an operant unit, and its occurrence is ultimately explained in terms of the evolutionary history of the unit. But the occurrence of the instance at a particular moment in time is not an evolutionary issue any more than the conception of a particular child is an evolutionary issue. Accounting for an individual occurrence is a different problem than accounting for an evolutionary unit of which the occurrence is part.

Questions about individual occurrences are questions about moment-to-moment changes in a behavior stream. Questions about operant units are questions about enduring changes in a behavioral repertoire. What *can* occur in a behavior stream is constrained by the current existence of operants in a repertoire. What *does* occur is a function of a current environment. And the current functioning of the environment is, in turn, the result of evolutionary processes (both organic and behavioral) that account for the current repertoire itself.

Michael (1983) drew this distinction by classifying environmental functions as either *evocative* or *repertoire altering*. The environment's function is evocative when it produces "an immediate but momentary change in behavior" and is repertoire altering when it produces a "lasting effect which can best be observed when the conditions that preceded the event are again present" (Michael, 1983, p. 21). Although we have been strongly influenced by Michael's conceptual clarifications, our goal here is to recast the evocative versus repertoire-altering distinction in a more explicitly evolutionary framework. Specifically, we want to distinguish the functions of the environment as they affect behavioral phenomena at the level of instances and the level of operant units. The issue has to do with the kinds of entities that are explained by evocative and by repertoire-altering environmental events.

Evocative and repertoire-altering environmental events are viewed here as functioning with respect to different kinds of entities. Evocative events function with respect to instances of an operant that exist momentarily in a behavior stream; they have a causal role in the *occurrence* of operant *instances*. Repertoire-altering events play a causal role with respect to the *origin* and maintenance of operant *units*, which exist over extended time as part of a behavioral repertoire. Both the instances and the units are individuals that must be accounted for.

In what follows we focus on (a) operant units and operant instances as products of evolutionary processes that occur at the behavioral level of analysis and (b) the causal role of the environment with respect to the existence of operant units and the occurrence of operant instances.

FUNCTIONS OF THE ENVIRONMENT IN THE SELECTION OF OPERANT UNITS

The environment's function with respect to the origin and continuing existence of operant units is a selective one. As Skinner (1981) pointed out, selection is a kind of cause different from the traditional causes of the physical sciences, being separated in time from evidence of

its effects. One of the difficulties in understanding selection as a cause may lie in the character of what is caused *by* selection—or what is the consequence of selection. One consequence of natural selection is a population of organisms distributed over space and time that exists as an evolutionary unit—a species. One consequence of behavioral selection is a natural population of responses distributed over space and time that exists as an evolutionary unit—an operant.

Selection accounts for many measurable characteristics of operants. Among other things, it accounts for the distinguishing characteristics of the member parts of a population (e.g., downward pressing on a lever); for the frequency and relative frequencies of instances (rate and relative rate); for the distribution of the parts' characteristics in the population (e.g., many presses of n force, fewer of $n + x$ and $n - x$ force); and the distribution of the population in space and time (e.g., fixed-interval scallop). We shall briefly consider behavioral selection as it pertains to the origin, maintenance, extinction, and suppression of operant units.

Behavioral Selection and the Origin of Operants

Experimenters have developed several ways to generate operants in a repertoire. One way is to select accidental occurrences by putting a hungry animal (e.g., rat) in a small enclosure and arranging a "constraining contingency" between downward excursion of a lever and food delivery (Schnaitter, 1987). In such circumstances, the rat's movements are highly likely to include downward pressing of the lever with the result of food delivery.

The selection of a first appearance may result in something like a population explosion—an immediate and dramatic increase in frequency of instances (Skinner, 1938); or the frequency of presses may increment gradually with repeated reinforcement. That the situation was arranged virtually to guarantee that some movements of the rat would result in lever excursion

(hence food delivery) in no way makes the resulting operant "unnatural." The *contingencies* were contrived or artificial, not the resulting behavior of the rat. The experimenter-contrived contingency took advantage of a process that occurs in nature: operant conditioning. Similarly, experimentalists in biology "cause . . . speciation events" (Sober, 1993, p. 13), which are assumed to be of the same order as the speciation events that account for extant species. The experimenter-contrived contingencies make use of the same processes that occur in nature: natural selection and behavioral selection.

If the particular movements necessary to depress the lever were less likely to occur by chance, the experimenter could use a method of successive approximation to bring into existence a particular operant. In so doing, the experimenter takes advantage of variations among members of successive populations. When reinforcement follows a particular instance of an operant "we observe, along with an increase in the frequency of the specific topography we reinforced, the novel appearance of other topographies" (Segal, 1972, p. 2). By judiciously selecting responses with particular characteristics, the experimenter directs the evolutionary process. Within a short time, an entirely new operant can be brought into a repertoire.

If the activity is already part of a behavioral unit in the repertoire of an experimental subject, the experimenter may be able to arrange conditions so that the activity occurs "for other reasons" and then capture the activity in a new operant unit by way of a selection contingency. Autoshaping is such a procedure. In autoshaping, a lighted key is established as a conditioned stimulus for respondent pecking. By making food delivery contingent upon key pecks, the experimenter produces a population of *operant* key pecks, which may exist in the repertoire along with continued respondent key pecking (cf. Marcucella, 1981). If the experimenter does not deliver food after the initial autoshaped key peck, key pecking may quickly disappear

or may occur for an extended period (Brown & Jenkins, 1968), a phenomenon that has engendered considerable scientific investigation.[3]

Role of Motivative Events in the Origin of Operant Units

Food deliveries contingent on lever presses and key pecks were conceptualized above as having selective function. A consequence made contingent on some activity may function to generate an operant unit. But it is not necessarily the case that the consequence will function this way under all conditions. This qualification speaks to the topic of motivation.

The selective function of food in a contingency, for example, often depends on the motivative variable of food deprivation. The generation of operant units, whether in the laboratory or in the everyday environment, requires that the consequence in any reinforcement contingency *currently* have selective function. The selective function of primary reinforcement, in particular, often must be established by environmental operations before that particular event can have a reinforcing effect. Withholding food (deprivation) temporarily establishes food or the opportunity to eat as reinforcing; likewise, increasing aversive stimulation temporarily establishes reduction in that stimulation as reinforcing. Such operations have been designated as *establishing operations* because they temporarily establish the function of particular events as effective consequences (Keller & Schoenfeld, 1950; Michael, 1982, 1993b). If a response enters into a contingency with those events while the establishing operation is in effect, selection occurs. In the case of many reinforcers, their selective function comes and goes; establishing operations account for the comings and goings.

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[3] We are not proposing that all preexisting occurrences of behavior are equally amenable to this type of selection. For instance, Thorndike (1911) demonstrated that the behavior of a cat scratching itself is not particularly susceptible to operant selection.

Unconditioned reinforcement is a consequence whose selective function is highly dependent on the occurrence of a particular establishing operation. This dependency makes it difficult to use unconditioned reinforcement to generate operant behavior in the everyday environment. The human social community obviates this problem by conditioning some environmental events as generalized reinforcement, which has the effect of freeing the selective function of these events from the anchor of specific establishing events.

Behavioral Selection and the Maintenance of Operants

The role of the selecting environment in the maintenance of operant units and its associated role in producing changes in distributions and characteristics of extant populations have been studied extensively in operant laboratories. Skinner (1938) initiated schedule research, and Ferster and Skinner (1957) set the course of experimental analysis for generations of researchers by explicitly focusing experimental analysis on "the processes through which [behavior is maintained] in strength after it has been acquired" (p. 1). The dependent variable of interest was operant rate, but more specifically it was the distribution in time of natural populations of operant occurrences—the natural populations being operant units. From the present perspective, Ferster and Skinner's text is seen as a systematic exploration of the effects of different contingencies on extant operant populations. The characteristics of operant occurrences composing the population were not the focus of experimental interest; rather, *population characteristics* were the focus of interest. In other words, Ferster and Skinner (1957) were not interested in lever presses or key pecks, or their specific dimensions, per se; they were interested in the frequency and distribution of operant populations as a function of various kinds of contingencies. They and many others have found that each kind of selection contingency has characteristic effects across many subjects, many re-

sponse forms, and many species, and thus have established "spatiotemporally unrestricted generalizations" (Hull, 1984, p. 145).

Many lines of research have evolved out of the early work of Skinner (1938) and of Ferster and Skinner (1957); a great majority of that research appears to have focused on the role of selection in maintaining operants and accounting for changes in their population characteristics. One such line of research, initiated by Herrnstein (1961), involves quantitative analysis of concurrently extant operant units as a function of their joint contingencies. The matching theory derived from this experimental work has provided mathematical equations that describe relative frequencies of different operant populations in a repertoire (Davison & McCarthy, 1988, for review). Lawful relations among population frequencies can provide the basis for new kinds of intervention tactics (McDowell, 1982) and the basis for better understanding of behavior that occurs in the everyday environment (Martens & Houk, 1989; McDowell, 1988).

A recent line of research directs attention to the role of variation among operant occurrences in an operant population. Page and Neuringer (1985) demonstrated that variation among occurrences can itself be a function of contingencies. That is, reinforcement contingencies can be arranged to select for (or against) variation among occurrences. Because variation among member parts of natural populations is required in all evolutionary processes, this line of research seems to offer the possibility of balancing a highly productive focus on the role of behavioral selection with a comparably productive focus on the role of variation in behavioral evolutionary processes. Possible mechanisms underlying variation have been considered by Neuringer (1991) and by Machado (1992).

Extinction of Operant Units

As in the case of natural selection, behavioral selection entails variations among members of a population with respect to those characteristics that may "match" the selecting environment. In behavioral selection, the match is between those responses having specified characteristics and the requirements of the constraining contingency (cf. Schnaitter, 1987). The result of the selection process is a population of responses that constitutes a "functional operant" (cf. Catania, 1973), the members of which owe their existence to the contingency that generated the population but some of which fall outside the requirements of the constraining contingency. Once such an operant unit exists, both the characteristic dimensions (e.g., downward movement of lever) of member parts of the constituent population and the unit's population characteristics (such as rate or variability) continue to be accounted for by the contingencies that maintain the unit's existence in a repertoire. If the contingencies remain the same as those that accounted for the unit's origin, characteristics of the population become stable and variations among member responses may decrease, unless selection favors variability in the population.

If the contingencies change, one of the "nonstandard" variants (i.e., an instance with properties outside the requirements of the constraining contingency) may fit the new constraints, giving rise to an evolved population of responses with more of the characteristics of that variation. Over time, the unit may evolve into an entirely different operant unit, as it does when shaping is accomplished. A change in contingencies sometimes, however, results in such a serious mismatch between characteristics of members of the unit and the new constraining contingency that no variants meet the requirements of the new contingencies. In such circumstances, that operant undergoes extinction—the population decreases in frequency, and eventually no further instances occur. Such an eventuality may parallel extinction in evolutionary biology, wherein a species ceases to exist as an evolutionary entity.

There may be no evolutionary concept more difficult to characterize than ex-

tinction; even so, we shall attempt to consider operant extinction as an evolutionary process. We shall consider two issues. The first has to do with "what counts" as extinction, and the second has to do with what is extinguished.

"What counts" as extinction depends on "what counts" as an operant. We suggested that an operant (in Skinner's second sense) is a population of interchangeable responses that characteristically produce a particular environmental effect and that the population is a behavioral individual because all of its parts (operant instances) result from a particular history of reinforcement. Any particular operant, then, could be said to exist so long as member instances occur under conditions in which they have occurred in the past. But how long must one maintain these conditions before one can conclude that no further responding will occur under these conditions? No answer is currently available. Similar problems plague questions of extinctions of biological species. In how many places and for how long does one have to look for a species thought to be undergoing extinction in order to state with some confidence that the species is extinct? (Biologists have an easier time of it when the issue of extinction pertains to species that are known only as fossils.)

The second question, that regarding what is extinguished, may pose even thornier problems due to the fluid and changing characteristics of evolutionary individuals. For example, when a particular species ceases to exist in the biosphere or a particular operant ceases to exist in a repertoire, fragments of the lineage may be found in other species or operants that predated the species or operant undergoing extinction, or that evolved from the lineage before the current extinction occurred. These fragments are carried in the species lineage by genes; it seems likely that they are carried in the operant lineage by neural pathways. In the operant case, such fragments may account for the fact that reacquisition of an operant may be faster than was the original acquisition.

The difference in rate of acquisition and reacquisition has been viewed as the result of "incomplete experimental control over the relations between the organism's behavior and the controlling environment" (Sidman, 1960/1988, p. 101). From the present perspective, "complete" experimental control would be impossible if fragments of the extinguished operant existed as parts of other extant operants. These fragments would not, of course, be parts of "the same" operant as the extinguished operant, any more than sparrows are parts (members) of "the same" species as extinct archaeopteryx. A particular operant is an evolutionary "whole," albeit a whole with fuzzy boundaries; if fragmentary elements have split off and become parts of other wholes in branching lineages, the continuing existence of that lineage does not entail the existence of the operant now extinguished. Existence of the fragments in the other lineage may make it easier, however, to "reconstruct" the previously existing operant.

Extinction of some operant units may be far less likely to occur in the natural environment than extinction of others. That is so because some operants may not only exist in their own right, but their instances may occur embedded in other operants. For example, if a generalized operant such as "twisting objects" can once be acquired, that operant may also be embedded in the more complex operants of opening (some) doors, setting kitchen timers, and removing toothpaste caps, to name a few.

For obvious reasons, extinction of an operant having some of its member parts embedded in a large number of more complex operants would be difficult. Operants with members embedded in more complex operants are likely to be primitive in the same sense that bacteria are primitive. In their respective evolutionary universes, organic and operant primitives represent early and simple forms having enormous survival potential. This is different from the issue of fragments just discussed. Embedded operants are not fragments of previously existing operants. Both the primitive and the complex operants currently exist as intact units with their own evolutionary trajectories. The more primitive species or op-

erants (e.g., twisting objects) continue to exist as entities in their own right. If twisting toothpaste caps were to undergo extinction (say, because caps were redesigned to snap off), twisting objects continues to exist as a primitive operant as well as being embedded in other operants in the behaver's repertoire. Similarly, if *H. sapiens* (a host species to *E. coli* bacteria) were to become extinct, *E. coli* would continue to exist because some members of the species *E. coli* are embedded in many other extant species.

The parallel between operant extinction and species extinction may be complicated by the fact that extinction and reemergence of species are not likely in the biosphere. This is so because earlier selection contingencies cannot recur in the biosphere due to the coevolution of the selecting environment. Within the confines of the experimental laboratory, however, scientists attempt to replicate conditions thought to exist when life began in order to replicate the emergence of the kind of proto-cells thought to be the precursors of known species, both extant and extinct (Curtis & Barnes, 1989, pp. 87–90).

Changes in the contingencies that result in extinction of an operant have a number of interesting effects on other operants in the organism's repertoire. One such effect is that of extinction-induced resurgence: the recurrence of previously reinforced behavior when recently reinforced behavior is no longer effective. In most of the studies reported (see Epstein, 1985, for a review), an operant is reinforced and then reinforcement contingencies shift; a second operant is reinforced while the first now fails to produce reinforcement (extinction contingency). Reinforcement is then discontinued for the second operant; after the rate of the second operant is greatly decreased, instances of the first operant reappear at a high rate.

From the present perspective, the first operant has not been eliminated from the repertoire, because concurrent contingencies favor emission of the second operant; this effectively eliminates the opportunity for mismatches between the first operant and the selecting environ-ment. On the basis of recent work by McDowell, Bass, and Kessel (1993), it seems possible that the point at which the first operant will reappear may be predictable mathematically in terms of its "age" relative to the second operant and the number of reinforced and unreinforced emissions relative to the second operant. In a study done with humans, Mechner, Hyten, Field, and Madden (1991) found an immediate increase in variability in key selections and their rhythmic patterns when a reinforcement contingency in place for an extended period was replaced abruptly by a far more stringent contingency. Examination of the changes in temporal patterning revealed much of the variability to be made up of the recurrence of previously occurring variants of the operant; that is, there was a disproportionate increase in "old" versus "new" sequences among the variations that emerged.

Punishment of Operant Units

If extinction of operants parallels extinction of species, an operant whose instances always fail to match constraining contingencies decreases in frequency and eventually disappears from a repertoire. But operants may decrease in frequency as a result of operations other than the lack of reinforcement. Punishment, like extinction, also results in decreasing frequency of instances of an operant. An open question is whether punishment ever has the effect of eliminating the operant from the repertoire; there is again the question of how long one must observe before concluding that the operant is no longer in the repertoire.

Procedurally, punishment contingencies always overlie either reinforcement contingencies or extinction contingencies. This is so because a punished response is either (a) a member of an operant unit that is currently being maintained by reinforcement or (b) a member of an operant unit for which reinforcement has been discontinued (extinction).

When punishment contingencies are in effect, single occurrences (or local populations) of an operant may enter into a

punishment contingency while other (or even the same) occurrences of that operant enter into a reinforcement contingency. For example, a child who steals a candy bar may eat some of the candy before a parent takes away his quarter. The eating of the candy may function to increase the frequency of stealing candy, and the loss of the quarter may function to decrease the frequency of stealing candy. Such conflicting contingencies suppress occurrences of the operant to a greater or lesser degree, depending on the values and probabilities of the different consequences and current motivational conditions (cf. Azrin & Holz, 1966).

If there is a parallel to punishment in organic evolution, it may be those cases in which a population-suppressing agent is introduced in an environment that otherwise maintains a species. An example might be seen in such conflicting contingencies as those that produced and maintained sickled red blood cells (RBCs) in subpopulations of the human species (Curtis & Barnes, 1989, pp. 87–90). There must have been a time when no human organisms contained sickle-celled RBCs. A malarial environment was overlaid on the survival contingencies maintaining the existence of a subpopulation of humans. Many of those people exposed to the malarial environment died, decreasing the frequency of the human subpopulation exposed to malarial environments. The sickle-cell mutation occurred, introducing a new subpopulation into the evolutionary stream as a result of the fortuitous protection from malaria afforded members of that subpopulation. However, humans who inherited this characteristic from both parents died of anemia before reproducing. Thus, contingencies suppressed the frequency of a subpopulation of organisms with sickled RBCs (homozygotes) while another subpopulation (heterozygotes) had a modified version of the characteristic that was (and is) maintained by other contingencies.

It is possible that punishment and extinction will eventually be seen as different ways in which contingencies remove operants from repertoires. This view would be supported if it could be shown that the physiological mechanisms underlying removal in the two cases were the same. In the absence of such information, we are inclined to accept what is perhaps the prevailing view: Extinction and punishment are two different behavioral processes—one has the effect of removing an operant from the repertoire, and the other has the effect of suppressing emission of an extant operant or a subpopulation of that operant.

Summary

We have outlined selection processes that describe evolutionary functions of the environment with respect to operant units. Reinforcement contingencies account for the origin and continued existence of operants in repertoires. If contingencies fail for a given operant, that unit becomes extinct. Punishment contingencies account for alterations in the frequencies of subpopulations of operant units.

Discriminated Operants

Most of the behavioral units used as examples in the foregoing pages are composed of "one-element" instances. That is, the constituent members of the population are irreducible in the sense that a single operation (pressing the lever with x force) is required to meet the reinforcement contingency. Such operants, composed of one-component instances, may be likened to prokaryote species, which are composed of single-celled organisms without nuclei (Watson, Hopkins, Roberts, Steitz, & Weiner, 1987). Species composed of multicelled organisms awaited the emergence of eukaryotes (single cells with nuclei). Ontogenic behavioral complexity also appears to depend on units composed of two-component instances. Discriminated operants are so composed.

Laboratory experimenters bring discriminated operants into existence by arranging contingencies so that reinforcement follows operant instances that occur in the presence of some particular environmental condition and do not occur in

the absence of that condition. When a contingency is itself contingent on the prior presence of some particular environmental event, the *correlated contingencies* account for the origin of a discriminated operant. A discriminated operant is a population of two-component operant instances. The first component of each instance is a stimulus event of specified dimensions, and the second component is activity of specified dimensions. The two components may on the first occasion occur concurrently for any number of reasons (cf. Ray & Sidman, 1970), but selection accounts for the subsequent increase in the population. Discriminated operants, like their one-component precursors, can have their origins in systematic differential reinforcement of successive approximations (Etzel & LeBlanc, 1979; Stella & Etzel, 1986).

A discriminated operant is a two-part operant that appears to make possible the building of operants that are composed of instances having multiple components—those such as watering plants or brushing one's teeth. Put another way, discriminated operants make possible complex operant units composed of instances each having many parts. Although one may wish to reserve the term *operant* for units such as lever pressing or chain pulling, an evolutionary perspective suggests that operant units in a particular repertoire may be composed of increasingly complex forms as ontogeny proceeds.

In accounting for the origin of any discriminated operant, consequences function concomitantly in two ways. They select the particular relation currently occurring between environmental antecedent and activity, and they endow that environmental antecedent with an evocative function with respect to future occurrences of activity (cf. Michael, 1993a). The characteristics of any extant discriminated operant are specified in terms of both its components—the activity component (e.g., lever presses) and the antecedent environmental component (e.g., a tone). Thus, selection contingencies account for (a) the parameters of the stim-

ulus component, (b) the parameters of the activity component, and (c) the functional relation between the stimulus and response components.

Acquisition of discriminated operants allows an organism's activities to become increasingly interwoven with environmental events. Reinforcement brings environmental events *into* a behavioral repertoire. The concept of an operant repertoire blurs the distinction between organism and environment: An operant repertoire is a system in which environmental events and organismic activity become integrated in increasingly complex patterns.

The existence of discriminated operants in the repertoire of an organism (and that is the only locus at which they can exist) can lead to any number of evolutionary eventualities that are not otherwise possible. If we assume that at least some of the environmental events entering into discriminated operants have no function at all until correlated antecedent/response and response/consequence contingencies occur, the occurrence of those contingencies may result in the functional existence of some part of the environment that can then enter into other functional relations more readily. For example, the antecedent in one discriminated operant can function as conditioned reinforcement in the selection of another operant, and it might more readily acquire a discriminative function in a third discriminated operant.

Variability in a natural population plays an important role in both phylogeny and ontogeny. One effect of population variability can be observed in generalization. Once a discriminated operant unit has been selected, antecedent events with characteristics that vary in some ways from those that previously entered into contingencies can evoke a response. If a reinforcing consequence follows, the parameters of the operant unit are broadened to include the new values of the characteristic. The broadening may occur along any number of dimensions (structural, relational, or functional), and generalization may occur along one or

more of those dimensions. Training for generalization is often required if generalization is to occur along the dimensions desired by practitioners (Stokes & Baer, 1977).

FUNCTIONS OF THE ENVIRONMENT IN THE BEHAVIOR STREAM

In the foregoing discussion, we have focused on operants as individual units composed of populations of operant instances and on the selective role of the environment in the origin of such operant units. The instances making up an operant unit also are individuals, just as organisms that are members of a particular species are also individuals. And the occurrence of a particular operant instance, like the existence of a particular organism, cannot be fully explained in terms of selection. That is so because selection accounts for individuals at the population level, or operant units in the behavioral case. Operant instances require consideration of additional functions of the environment.

Once an operant unit exists as part of a repertoire, its instances are typically distributed unevenly in the behavior stream. In the everyday environment, successive instances of an operant population rarely occur one after another as they do under the specially designed conditions of the laboratory. Instead, behavior flows continuously in an ever-changing stream of organismic activity that is exquisitely coordinated with changing environmental events. An occurrent part of one unit is followed by an occurrent part of a different unit, and then another, and so on. Occurrences of a complex operant unit (e.g., tooth brushing) may be observed only once or twice per day. Instances of hundreds of other units are interspersed between such occurrences.

The environment's function with respect to moment-to-moment changes in organismic activity will be designated here as an *instantiating* function. The term seems fitting both because of its etymological relation to *instance* and because of its connotation of "making manifest." Instantiating events account for the

constant shifts in the flow of the behavior stream.

In the next two sections we consider two kinds of instantiating events. We call these environmental functions *evocative* and *alterative*. Although there are undoubtedly other ways of classifying environmental effects on ongoing operant behavior, we have found the present classification to be useful in our own efforts to conceptually relate experimental analyses, clinical phenomena, and effective interventions. Again, the distinctions drawn here were strongly influenced by Michael (1993a, 1993b) and Skinner (1953), but there are significant differences.

Evocative Function of Environmental Events

Once a discriminated operant exists as part of a repertoire, occurrences of its environmental component (S^D) can affect the ongoing behavior stream. Under certain conditions these environmental events *evoke* the activity component previously reinforced in their presence. The occurrence of reinforcing consequences on the present occasion is irrelevant, of course, with respect to the current evocative function of the environment.[4] Many of the concrete instances observed in a behavior stream are members of well-developed discriminated operant units. That membership is difficult to discern, however, because the members of the population constituting the operant unit are often separated in space and time from one another (i.e., the unit is spatiotemporally dispersed and thus not immediately observable *as a unit*). What is immediately observable are isolated instances within a never-ending flow of changing activity.

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[4] It seems unnecessarily confusing to say that the environment evokes a response/consequence relation. No such relation may occur in the present; past consequences account for the existence of the unit (the discriminated operant) and, concomitantly, for the current evocative effect of the environmental event. As suggested above, when we speak of environmental events, we are speaking of any part or relation among parts of the environment that can enter into behavior–environment relations.

Assuming a repertoire of discriminated operants, the behavior stream at any given time is highly dependent on the flow of environmental events that have previously acquired evocative function (S^Ds). Moment-to-moment changes in the environment account for moment-to-moment changes in behavior. There is no straightforward one-to-one relation, however. A particular kind of change may have an evocative effect on one occasion and have no such effect on another occasion. For example, when a person sees the written word *cat*, they may say "cat" or they may say "dog." They may also say "cat" when they see one.

The challenge is to understand the additional variables that account for the fact that a stimulus event sometimes evokes one activity, sometimes another, and sometimes does not have any current effect on the behavior stream. The traditional solution to understanding such functional vagaries is to appeal to mental states, cognitive processes, or emotional constructs as mediators of the current environment. We shall appeal to additional environmental events.

Alterative Functions of Environmental Events

A single occurrence of an environmental event may function concurrently in several different ways, for example (a) to maintain the existence of one operant, (b) to evoke an occurrence of another operant, and (c) to elicit a respondent event (see Michael, 1993a). Whether an environmental event has some, all, or none of these effects, or others, on any given occurrence of the event often depends on the more-or-less concurrent presence or absence of one or more other environmental events. The organism's behavioral history, of course, accounts for the function of those events.

Once ontogenic contingencies bring about a discriminated operant in a repertoire, environmental events of particular dimensions have an evocative function with respect to the activity component of the discriminated operant. Both elements of the behavior designated as a discriminated operant—environmental event and neuromuscular event—

are often parts of one or more other discriminated operants. Some ways in which additional environmental events account for temporary alterations of acquired evocative functions are discussed below.

We give the name *alterative* events to environmental events that momentarily alter the evocative function of other events. Alterative events affect occurrences in an ongoing behavior stream, not the composition of a repertoire. Their effects are on the momentary occurrence of operant *instances*, not on the existence or organization of operant *units*. Thus, the alterative effects of the environment are not the same as Michael's repertoire-altering events or Schlinger and Blakely's (1987) function-altering events.[5] Repertoire-altering events include reinforcement and punishment; they increase the frequency of a population and they endow environmental events with evocative function. In both of these roles, they bring about changes in a repertoire. Alterative events, on the other hand, do not alter the repertoire; they alter the behavior stream that flows within the confines of the units currently comprising the repertoire. We discuss below two kinds of alterative functions the environment has with respect to the ongoing behavior stream: conditional functions and motivative functions.

Alterative Effects of Conditional Stimuli

Conditionality is one of the variables that account for the dynamic nature of

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[5] Blakely and Schlinger (1987) and Schlinger and Blakely (1987) renamed Michael's concept of repertoire-altering events *function-altering events*, and Michael's later work (e.g., 1993b) reflects this change. But the name change obscures distinctions that are implicit in Michael's original terminology and that are pertinent to the present effort. The category name "repertoire altering" comes closer than does "function altering" to specifying that which is changed by events in this category. Further, it may help to determine what might be done to assess the usefulness of Schlinger and Blakely's formulation of "contingency-specifying stimuli" (CSSs) as having some functional similarity to consequences with respect to operant units. In current terminology, a CSS would not be an alterative event if it is a repertoire-altering event.

stimulus control. Although conditional control of discriminative responding has been studied in the laboratory for decades (Carter & Werner, 1978, for review; Cumming & Berryman, 1965; Lashley, 1938), its role in behavioral complexity has become increasingly apparent as research on stimulus equivalence has proceeded (e.g., Hayes & Hayes, 1992; Sidman, 1971; Sidman, Wynne, Maguire, & Barnes, 1989; Spradlin, Cotter, & Baxley, 1973). Sidman's (1986) systematic exposition of the extended control of the environment in higher order operant units suggested a seemingly unique role of the fourth term in equivalence relations. Sidman's exposition also leads to other considerations, some of which will be addressed here.

As mentioned earlier, two discriminated operants in a repertoire may have in common their stimulus component. For example, when a child is told it is time for bed, he or she may sometimes say "why" and at other times may hop into bed. What must be explained is that a stimulus having particular characteristics sometimes evokes one activity and sometimes another.[6] In the present example, closer observation of the behavior stream might reveal that the child asks "why" when his or her uncle says it is time for bed but goes to bed when his or her father says it is time for bed. The discriminative stimulus "time for bed" has two different functions; the presence of the father instantiates one function and the presence of the uncle instantiates the other. The evocative function of the vocal stimulus is conditional—it depends on the presence of another environmental event, a particular speaker.

The function of a conditional stimulus on any given occasion may itself be con-

ditional on the occurrence of yet another environmental event, and so on through "successive levels of conditionality" (Hineline, 1992, p. 1280). Such higher order conditional control further extends the dynamic functions of environmental events that account for an ongoing behavior stream. The conditional control of evocative functions of environmental events is itself accounted for by the contingencies that extend the functions of the environment beyond the evocative function of discriminative stimuli. Contingencies that account for conditional control of discriminated operants such as those described above would likely be the differential consequences provided by father and uncle for saying "why" and/or for hopping into bed.

Alterative Effects of Motivative Events

Recall that motivative events account for the power of a behavioral consequence's function as a selecting event. The function of food in a reinforcement contingency is dependent on the passage of time without food. Contingent relations between activity and food most reliably result in the origin of an operant unit under such conditions. Once in the repertoire, occurrences of the operant appear sporadically in the behavior stream. For example, food-getting activities depend, at least in part, on the reinstatement of food deprivation.

The establishing operation of food deprivation, then, is a causal variable, both in the origin of operant units and in the occurrence of operant instances. With respect to occurrences in the behavior stream, the effect of the establishing operation is to alter the local frequency of occurrences that are members of a particular operant unit. The instances of operants that appear are members of the unit that was historically generated under deprivation like that currently in effect.

In the case of discriminated operants, the establishing event alters their local frequency by momentarily altering the evocative function of discriminative

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[6] When an environmental event, specified in terms of its structural characteristics, is found to have multiple functions in a particular repertoire, structuralist explanation becomes impossible. Complaints about "the poverty of the stimulus" as a causal variable derive from such commitment to structural accounts. Such multiplicity of function is evidence, in behavior analysis, of the complexity of causal relations in a repertoire.

stimuli. Consider the following example. A tone acquires discriminative control over a rat's lever pressing in an operant chamber as a result of food deliveries that are contingent on pressing in the presence of the tone. Observation of the behavior stream reveals that when the tone is on, the rat presses until food is delivered and then eats. If the tone is still sounding, the rat returns to lever pressing. The rat does not return to pressing if the tone is off, and it stops pressing if the tone ceases while it is pressing. The tone is functioning as an evocative event in the rat's behavior stream; it evokes lever pressing. If, on a given day, the rat eats a large amount of food just before entering the operant chamber, the tone is not likely to evoke lever pressing. One could not conclude that the discriminated operant was no longer in the rat's repertoire or that the tone was no longer a discriminative stimulus for the rat's lever pressing. Even a naive observer might conclude that the meal had something to do with the failure of the tone to evoke lever pressing. The function of the meal was to temporarily alter the evocative effect of the tone with respect to the rat's behavior stream. It did not alter the repertoire.

The alterative effect of food deprivation on the evocative effect of the tone on lever pressing has its origin in the conditioning history. Lever pressing is under discriminative control of the tone because pellets were contingent on pressing in the presence of the tone. But the contingent pellets were effective as selectors because the contingencies were originally in effect under the condition of food deprivation. The discriminated operant would not exist at all if contingencies had not occurred when an establishing operation was in effect. In the case of the rat's lever pressing, an establishing operation accounted for the *selective* function of food pellets in the origin of the operant unit. Later occurrences of that establishing operation account for the evocative effect of the tone on the lever presses in the behavior stream. Thus, *alterative* functions of establishing operations operate with respect to occurrences of the discriminated operant in the behavior stream.

Skinner (1938, chap. 9 and 10, 1953, chap. 9 and 10) gave considerable emphasis to motivational variables. The foundational text of Keller and Schoenfeld (1950) also emphasized motivational variables (chap. 9 and 10). In recent years, Michael (e.g., 1982, 1993b) has sought to clarify the different functions of antecedent stimuli by distinguishing between their discriminative and motivative properties. We would say that antecedent events that function evocatively with respect to the behavior stream function as parts of discriminated operants. Establishing events have alterative functions with respect to those evocative functions.

Some establishing events acquire an establishing function during the lifetime of an individual. Such conditioned establishing events are often confused with discriminative stimuli because they are stimulus events that precede deflections of the behavior stream. As pointed out by Michael (1982), however, discriminative stimuli are correlated with the *likelihood* of a particular consequence. Establishing events (whether they involve an operation such as presentation of a bowl of unsalted soup, or an operation such as withholding food) are not correlated with increased likelihood of a particular consequence. Rather, they temporarily establish the selective function of consequent events, thereby making modification of the repertoire possible. Later, they can also alter the evocative function of other events in the behavior stream.

Summary

We have discussed two ways in which the environment may function with respect to operant instances in the behavior stream. First, discriminative stimuli have an evocative function with respect to the activity components of discriminated operants. But the presence of the stimulus component of a discriminated operant does not always result in the activity component. Whether or not the

stimulus has the evocative function sometimes depends on the occurrence of alterative events. Two kinds of events having alterative functions are conditional stimuli and motivative events.

CONCLUSIONS AND IMPLICATIONS

We have explored what it might mean to consider behavioral principles in explicitly evolutionary terms. We see our efforts as an extension of Skinner's characterization of operant conditioning as an evolutionary process occurring at the behavioral level of analysis during ontogeny. We have used the explanatory structure of evolutionary biology to consider how parallel evolutionary concepts might apply to behavior analysis. The present attempt may be viewed as an extended analogy (Glenn, 1994).

In environment-based accounts of behavior, behavior–environment relations are the focus of theory; the organism that behaves recedes into the conceptual background (Hineline, 1986, 1992). One reason environment-based accounts of behavior may be so difficult to understand is that behavior analysts have not clarified for themselves or others that repertoires, like our biosphere, are *evolving systems* composed of parts that are interrelated in complex ways. Traditionally, the focus has been on one or two isolated parts of such systems.

One reason that behavior analysts have not systematically explored repertoires as complex systems may be that there has been no clear distinction between the ways in which the environment functions with respect to the behavioral stream and to the repertoire of individual organisms. We have combined our interest in clarifying that distinction with our interest in viewing changes in repertoires as the result of evolutionary processes occurring at the level of individual organisms. These processes were considered to be analogous to the processes involved in organic evolution.

We have found that some of the distinctions drawn here allow behavioral interventions to proceed more explicitly from a behavior-analytic conceptual framework than they otherwise might. Distinguishing between interventions designed to affect behavior at the level of natural populations and those designed to affect behavior at the level of momentary occurrences in the behavior stream help to clarify the goal of intervention and, consequently, to choose the form of intervention needed. If management of the current repertoire will suffice, intervention may be limited to rearranging those events that have current function with respect to the behavior *stream*. If it is important that a *repertoire* be changed, environmental events must acquire new functions. The distinction is implicit in "rules of thumb" such as the following: "Figure out whether the person knows what to do and how to do it but doesn't do it; or whether he doesn't know what to do, or doesn't know how to do it." Despite its usefulness, the "rule of thumb" does not derive from a behavior-analytic conceptual framework. Although it is consistent with such a framework, it is a "commonsense" rule.

An explicitly evolutionary behavior-analytic framework can also affect the way in which experimental data are collected and analyzed. For example, in the senior author's human operant laboratory, the standard stimulus equivalence preparation is being used to examine each conditional stimulus control operant as a natural population. Certain characteristics of the populations (as they exist at the end of original-relations training) are examined to determine whether they predict the emergence of symmetrical, transitive, or equivalence relations. Rather than grouping the data from all emergent symmetrical relation trials, as is usually done, we group data from all trials belonging only to a single operant population. Although it is too early to say whether such an approach will be productive, it seems reasonable to explore such an approach.

At present, behavior analysis does not appear to have a conceptual framework that can be used to understand how the parts of complex repertoires are related to one another or to predict many of the

changes that are observed and sometimes even systematically produced. Recent research reports of Gewirtz (1991) and Gewirtz and Pelaez-Nogueras (1992) do provide examples of the experimental analysis of the role of reinforcement in the early development of complexity in behavioral repertoires.

Ecological research in the biological sciences makes clear that changes in one part of the biosphere result in changes in other parts. Similarly, applied behavioral research suggests that intervention designed to change one part of a repertoire may also alter other parts of that repertoire (e.g., Parrish, Cataldo, Kolko, Neef, & Egel, 1986). Recognizing that behavioral repertoires simply are systems is not sufficient, however. They are *evolving* systems, and it is important to understand all of the functions of the environment that account for that evolution.

Gewirtz and Petrovich (1982) and Petrovich and Gewirtz (1991) have explored substantive relations between behavioral evolution during ontogeny and organic evolution during phylogeny. Another approach to making use of our knowledge of organic evolution is to understand and make use of the explanatory structure of evolutionary biology in developing an analogous explanatory structure for behavior analysis. This might be feasible because selection as a fundamental causal process appears to be operating in the origin and evolution of both organic and behavioral entities (Skinner, 1981).

Summary

We have conceptualized behavioral units selected at the operant level as individuals existing as a part of the natural world. These individuals endure over extended periods of time, and the particulars of their evolution are accounted for in terms of processes *originating* through natural selection but *operating* during the lifetime of individual organisms. These individuals, in turn, can be selected as component parts of larger, more complex units.

The distinctions we have proposed may

also be relevant in the analysis of similarities and differences between operant and nonoperant relations. Repertoires include both. Although the present account has made no attempt to include nonoperant relations in the formulation, the question could be posed as to the extent this formulation might prove to be applicable to Pavlovian or other nonoperant ontogenic relations (cf. Hineline, 1986). Research on Pavlovian conditioning increasingly involves hierarchical controlling operations (e.g., Balsam, 1985). The role of environmental stimuli as context, as modulators (facilitators or inhibitors), or as occasion setters of Pavlovian relations is receiving considerable attention. For example, Rescorla (1985) and Holland (1985) have distinguished between the inhibitory/facilitative and excitatory functions of the environment. This distinction may be similar to our distinction between alterative and evocative functions. In addition, explicitly distinguishing between environmental operations affecting nonoperant occurrences and operations affecting nonoperant behavioral units may prove to be useful.

Experimental analysis of both operant and respondent relations is proceeding to increasingly complex kinds of behavior–environment relations. Behavior-analytic verbal repertoires must also continue to evolve in order to deal more effectively with interrelated operant units of varying levels of complexity. If the current effort aids that evolution in any way, we shall be pleased.

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