

UNITS OF ANALYSIS AND KINETIC STRUCTURE OF  
BEHAVIORAL REPERTOIRES

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It is suggested that molar streams of behavior are constructed of various arrangements of three elementary constituents (elicited, evoked, and emitted response classes). An eight-cell taxonomy is elaborated as a framework for analyzing and synthesizing complex behavioral repertoires based on these functional units. It is proposed that the local force binding functional units into a smoothly articulated kinetic sequence arises from temporally arranged relative response probability relationships. Behavioral integration is thought to reflect the joint influence of the organism's hierarchy of relative response probabilities, fluctuating biological states, and the arrangement of environmental and behavioral events in time.

*Key words:* behavioral units, units of analysis, response class, organization of behavior, behavioral taxonomy, relative response probability

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PROTASIS

An impala gamboling across an East African Serengeti plain or a 16-month-old child confronted with a novel toy presents seamless streams of kinetic motion, free of beginnings or endings. The scant frequency with which behavioral scientists have concerned themselves with identifying the fundamental units of behavioral phenomena is, in part, due to the conspicuous integrity of such naturally occurring episodes; indeed, at times they seem to defy scientific analysis. Of the unresolved issues facing behavior scientists, none is more central than the analysis and synthesis of the fundamental units of behavior. Analyzing continuously flowing behavior into basic components and then resynthesizing it is a major aim of behavioral science. This goal is predicated on an understanding of the fundamental units of which behavior is composed. Knowl-

edge of such units is not axiomatic but as in the case of our knowledge of other biological units, must be arrived at empirically. Whether fundamental behavior units *can* be discovered depends largely on the criteria used for assessing and selecting behavior classes. Given criteria, establishing which units satisfy those criteria is an empirical matter. Approximately three quarters of a century have been devoted to research dealing with a range of behavioral units without explicit criteria for assessing their scientific significance. One of the purposes of this paper is to discuss the *criterion of scientific significance* as applied to the selection of behavioral units. Based on the stated criterion and available evidence, three types of functional units emerge from our analysis: emitted, elicited, and evoked response classes.

The combination of these fundamental units to form larger behavioral aggregates (i.e., functional behavioral composites made up of two or more fundamental units that covary collectively) is a secondary concern of this paper. It is proposed that once combined, some combinations of fundamental units can no longer be analyzed into those constituents. We will outline a behavioral taxonomy for analyzing extended behavioral samples into their constituent components.

Finally, the mechanisms involved in behavioral syntax (i.e., the process by which simpler behavioral components are integrated to form highly organized, complex behavioral reper-

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toires) will be explicated. Our treatment of these issues will include a discussion of the apparent uniqueness of naturally occurring behavioral episodes; some suggestions for finding order in these phenomena are offered.

## SELECTING BEHAVIORAL UNITS

### CRITERION OF SCIENTIFIC SIGNIFICANCE

Behavior, like any other physical phenomenon, cannot be studied scientifically in its entirety. Portions of the continuous stream of an organism's activity sharing certain common features must be abstracted for study from the whole. These individual behavior instances are important to the extent they can be shown to be members of replicable behavior classes. Although members of such classes are necessarily something less than behavior in its original form, they are the basis of all scientific assertions concerning behavior. Clearly, the availability of significant behavior classes is of prime importance, for it determines the kind and number of lawful relations that can be established. It follows that the way continuous behavioral repertoires are divided into fundamental units is critically important in determining the success of the entire scientific study of behavior. The selection of behavior units cannot be arbitrary, but must be based on consistent criteria that "carve nature at its joints."

A common criterion applied in evaluating any unit is its scientific significance: the extent to which the unit enters into a wide range and number of lawful relations (Sidman, 1960; Spence, 1948). Theoretically rich but empirically unreliable measures fail to satisfy this criterion, as do highly reliable measures with extremely narrow conceptual implications. To qualify as scientifically significant, a unit must reliably relate to an array of phenomena. This status cannot be established by argumentation, but must be shown empirically.

### EMERGENCE OF FUNCTIONAL RESPONSE CLASSES

Historically, behavior scientists have paid little systematic attention to the search for scientifically significant units of analysis. Indeed, Loevinger (1957, p. 644) has asserted, "there are no natural units for the study of behavior." Whereas nearly every other area of biology has placed a premium on isolation and

classification of fundamental units, behavioral science has largely disregarded these issues. It was not until the turn of the 20th century that the foundations of our current concepts of behavior units were laid, growing out of three traditions. Thorndike (1911) observed that behavior could be acquired by instrumental conditioning, and he isolated components of behavior by arranging some consequences of classes of movements that would control their future recurrence. Pavlov (1927) showed that behavior could be conditioned by pairing a neutral stimulus with an effective eliciting stimulus. His behavior units were specified as whatever muscle contractions or glandular secretions occurred immediately following presentation of the eliciting stimulus. The third tradition originated independently with Whitman (1899) and Heinroth (1911), who suggested that large portions of behavior were of fixed forms, elicited by complex patterns of stimuli, and were inherited rather than conditioned. The segments of behavior in the latter case were less well defined, since they involved not only simple muscle contractions, but also complex patterns of coordinated movements. Nonetheless, regular families of behavior patterns could be isolated as elicited by specific stimulus configurations.

The emergence of these three schools was important in the development of our current notions of behavior classification and units. All three groups succeeded in abstracting and simplifying behavior, from a scientifically incomprehensible flux to relatively simple and observable segments, based on the conditions controlling those behavior segments. In Thorndike's case, the consequences of behavior that controlled recurrence of members of a class were the basis for identifying response units. Pavlov's behavioral unit was specified by identifying the eliciting stimuli. Whitman and Heinroth specified their units as inherited effector patterns covarying with species-specific stimuli.

### FUNCTIONAL BEHAVIORAL CLASSES AND NATURAL BEHAVIOR

Behavioral units can be grouped together if they are controlled by the same variables, characterized as functional (Skinner, 1938) or causal (Hinde, 1966) classifications of behavior. This method of describing behavior couples the classification with its method of anal-

ysis. The success of isolating functional behavior units experimentally depends on the diversity of the controlling conditions. If there were as many uncorrelated controlling conditions as there are behavior instances, we would be at no scientific advantage. However, the conditions controlling behavior are distributed into several disjunctive categories. Insofar as each of these categories is relatively homogeneous and the number of categories is limited, there is some possibility of studying behavior systematically in less than its entirety.

A common complaint about functional behavior classes, especially operant responses, is that they do not seem natural, whereas segments of behavior selected from the behavior of free-moving animals outside the laboratory are viewed as being more natural. No class of events examined experimentally is ever "natural" in the sense that it is identical with dated historical occurrences under uncontrolled circumstances. This criticism applies to all units isolated by biologists inasmuch as these units are necessarily abstractions possessing certain common properties but otherwise differing in many respects. Such biological units as protein molecules, neurons, ganglia, or the spinal cord are not natural entities existing in isolation as classes of matter. Instead, they share common properties but differ widely among themselves. These classes of matter are classified by observers in much the same sense that functionally defined response units are so classified. Functional behavior units are in a very real sense more natural than experimenter-selected behavior segments, for segments of behavior naturally existing in an organism's repertoire are enabled to emerge rather than being imposed by the observer. Behavioral units cannot be imposed upon an organism by manipulating a variable that naturally controls that behavior.

### THREE FUNCTIONAL BEHAVIOR CLASSES

The fundamental units of behavior are all *response classes*. The response class is an inherently interactive concept, defined as a *disposition* to exhibit responses of a given functional type when appropriate stimulus events are provided (Hocutt, 1967; MacCorquodale & Meehl, 1954, pp. 218–231; Skinner, 1938). The term encompasses a heterogeneous collection of entities that display both inter- and intra-species variations in strength, molarity,

and specific nature. Behavior can be divided into three functionally different response classes according to its major controlling conditions: *elicited* behavior, *emitted* (or *operant*) behavior, and a derivative of the former two classes, *evoked* behavior. *Elicited* behavior is identified as behavior whose probability is determined by antecedent eliciting stimuli, and conditioned via antecedent stimulus pairings; *emitted* behavior is defined as constituent movements of an organism, the probability of which varies as a function of a stimulus consequence of previous instances of members of that class; and *evoked* behavior is induced by the temporal arrangement of current stimulus events.

The defining features of these three behavior classes are inherent in the variables controlling them (e.g., US, CS,  $S^{R+}$ ,  $S^{-}$ , etc., and their temporal presentations). The more diverse these variables, the more difficult it is to specify behavioral classes. Specific responses within these three functional classes may be further subclassified by identifying the *specific functions* of the controlling variables: (a) antecedent conditions, (b) current stimulus circumstances, and (c) response consequences (Thompson & Schuster, 1968).

### *Elicited and Emitted Behavior*

Distinctions have commonly been made between unconditioned and conditioned elicited behavior. Elicited behavior has also been subclassified on the basis of the motivational significance of controlling stimuli—that is, of appetitive and aversive stimuli (Mackintosh, 1974). Unconditioned behavior has often involved complex response sequences and topographies, elicited by species-specific stimuli. Mono- and polysynaptic reflexes have been distinguished from fixed action patterns, the former invariable in form and physical properties, the latter more variable, depending on the controlling stimulus and state of the organism. Presenting an eliciting stimulus for a fixed action pattern produces a topographically complex response sequence—a stochastic series of conditional response probabilities. Typically, the first component response of the series is highly predictable and circumscribed, but as the fixed action pattern unfolds, the terminal components are less predictable (Tinbergen, 1948). Some investigators have suggested referring to FAPs as "modal action patterns" (MAPs) to reflect this variability

(Barlow, 1968). In addition, attempts at classically conditioning fixed action patterns (e.g., Thompson & Sturm, 1965) have produced new reflexes in which only a subset of the components of the fixed action patterns are elicited. Although reflexes and fixed action patterns differ in complexity, they nonetheless are primarily controlled by an antecedent eliciting stimulus, and are treated here as being members of the same functional class (i.e., elicited).

Although in respondent conditioning no new responses are ever conditioned (only new reflexes), the units within operant repertoires may combine to form seemingly new response topographies. Elements of coordinated movements existing prior to operant conditioning are modified by their consequences and emerge to form functional components of new operants. Such elements may, initially, be parts of respondents, fixed action patterns, or components of other operants unified by their distinct environmental consequences. As elicited behavior may be subclassified according to the nature of the controlling stimuli, emitted behavior is similarly categorized. For example, operant behavior patterns are described as *escape* or *avoidance* responses, depending on the nature of the controlling negative reinforcer. Operants are negatively reinforced by removal of a primary negative reinforcer in the former case, and removing a conditioned negative reinforcer in the latter.

#### *Adjunctive and Other Evoked Behavior*

Jean-Paul Sartre (1938) wrote, "I think they do that to pass time, nothing more. But time is too large, it refuses to let itself be filled up." The terms "displacement activity," "interim behavior," and "schedule-induced behavior" have been used to refer to members of this class. We view adjunctive behavior as a higher order behavior class because it emerges when stimulus conditions regulating the probabilities of fundamental ("first-order") units are temporally structured in a particular fashion. The probabilities of these response classes are controlled by interstimulus interval parameters, not by the specific nature of the scheduled environmental events per se.

Falk (1977, p. 325) has defined *adjunctive behavior* as "behavior that is maintained at a high probability by stimuli which derive their exaggerated reinforcing efficacy primarily as a function of schedule parameters governing

the availability of another class of reinforcing events." Zeiler (1977) proposed a distinction between *direct* and *indirect* variables determining effects of reinforcement schedules. Direct variables arise from formal properties of schedules (i.e., the conditions that must be satisfied for the presentation or withdrawal of a stimulus event). "Indirect variables are those that are imposed without being explicitly prescribed by the schedule" (page 204). Direct variables engender *stereotypic* performance, whereas indirect variables tend to produce regularly *fluctuating* performance. Performances maintained by ratio schedules are primarily controlled by direct variables, whereas performances controlled by interval schedules reflect the products of both direct and indirect variables.

The causal significance of indirect variables determining the temporal structure of behavior can be profound, with adjunctive behavior providing the most significant examples. Falk (1961) describing excessive drinking by water-satiated rats exposed to a 60-s variable-interval food-reinforcement schedule, called the phenomenon "schedule-induced polydipsia." Rats drank as much as 10 times their normal daily water intake under these schedule-generated conditions. Originally believed limited to a unique food-water relation in rats, similar phenomena occur with other responses such as eating, fighting, escape, running, and across several species such as mice, pigeons, monkeys, and chimpanzees (see Falk, 1971, 1977; Staddon, 1977).

#### *Generator Schedules*

Schedules capable of evoking adjunctive behavior are labeled *generator schedules*, and their formal properties may be defined by either response-contingent or noncontingent stimulus presentations, that is, variable-interval (VI), fixed-interval (FI), fixed-time (FT), and variable-time (VT) schedules. The constituents of the behavior patterns evoked by schedule induction must previously exist at some strength, but in the absence of the generator schedule exhibit low probability (e.g., drinking by a water-satiated animal). The indirect effects of generator schedules arise from their increasing the probability of otherwise low-probability behavioral units with no contingent or direct eliciting relations to the behavior in question.

Generator schedules are characterized by

two parameters, their *effective range* and their *optimal value*. Simple stimulus-presentation schedules capable of functioning as generator schedules exhibit an effective range (i.e., a range of values capable of evoking adjunctive behavior). Within the effective range there is an optimal value for engendering adjunctive behavior. The optimal value represents the vertex of a biotonic inverted U-shaped function; and, as the value of the generator schedule deviates from this value (in either direction), the probability of a given adjunctive behavior pattern diminishes. Although the quantitative characteristics of this function may vary, the optimum interval for simple fixed and variable schedules for several species (pigeon, rat, monkey) is 1 to 3 min. Adjunctive behavior in humans has received less attention; however, some aspects of human performance seem susceptible to schedule induction (Cantor, Smith, & Bryan, 1982; Clarke, Gannon, Hughes, Keogh, Singer, & Wallace, 1977; Falk, 1986; Fallon, Allen, & Butler, 1979; Frederiksen & Peterson, 1974; Kachanoff, Leveille, McLelland, & Wayner, 1973; Lasiter, 1979; Porter, Brown, & Goldsmith, 1982; Wallace & Oei, 1981; Wallace & Singer, 1976). For example, generator schedules have enhanced the probability of certain aspects of cigarette smoking (Cherek, 1982, Wallace & Singer, 1976) and "motor excitability" (Muller, Crow, & Cheney, 1979; Wallace, Singer, Wayner, & Cook, 1975).

Generator schedules have highly predictable effects on the temporal distributions of the evoked responses. Staddon and Ayres (1975; see Figure 1) studied the time rats devoted to eating, drinking, running, and hovering near a food area when food was presented at regular fixed intervals. They, like Falk, found that the probability of drinking increased sharply after food-pellet ingestion. Then drinking probability declined and running increased; finally, as the probability of running declined, hovering near the feeder area increased. The regularity of these temporal modulations of relative response probabilities of adjunctive responses as a function of a concurrent food schedule is striking (see Figure 1).

This property of generator schedules highlights their capacity to structure the temporal distributions of relative response probabilities. In addition to enhancing certain response probabilities, generator schedules temporally

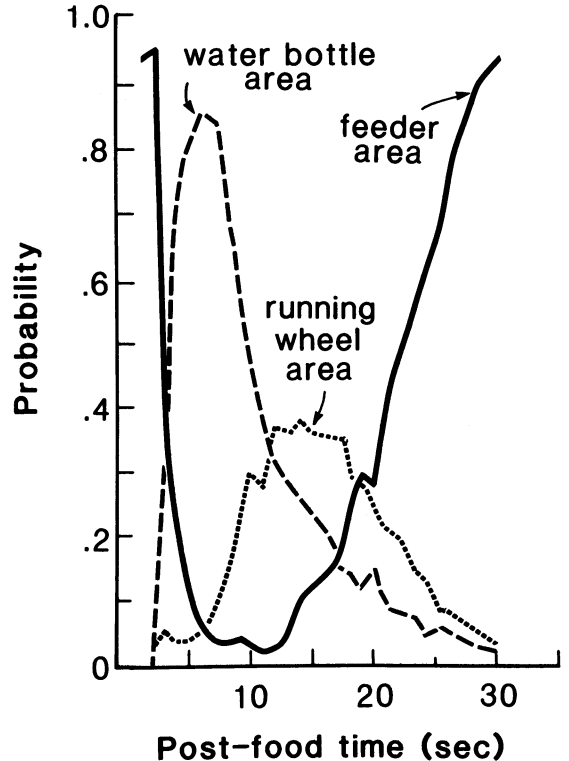


Fig. 1. Distributions of relative response probabilities generated by a rat in an experimental chamber that permitted drinking, wheel running, and food delivery. The gradients were temporally structured by an FT 30-s generator schedule of food reinforcement (from Staddon & Ayres, 1975).

integrate evoked responses with the response patterns controlled by the formally specified direct variables. Generator schedules do not evoke novel responses; rather, they shift the temporal patterns of relative response probabilities correlated with the stimulus presentations regulated by the generator schedule.

#### Other Emergent Behavior

Falk (1977) has argued that the evolutionary utility of adjunctive behavior lies in its maintaining an organism in a problematic but overall favorable situation. However, other schedule-induced emergent behavior patterns can be traced to generator schedules regulated by unconditioned aversive stimuli, and are not obviously "favorable" in an evolutionary sense. For example, Hutchinson, Renfrew, and Young (1971) studied patterns of biting and lever manipulation by squirrel monkeys exposed to unavoidable tail shock. Immediately following shock, the probability of biting in-

creased sharply and then declined. As the time for the next shock approached, the probability of manual responses progressively increased to the time the unavoidable shock was presented. That is, the temporal distribution of the two recorded responses (biting and lever manipulation) came under the control of the fixed schedule of unavoidable shock. Similarly, Kelleher and Morse (1968) demonstrated that under the right schedule conditions, electric-shock presentation can come to function as a maintaining event. Using squirrel monkeys as subjects, a noncontingent FI 5-min shock was superimposed onto an established VI 2-min food baseline. At first, this manipulation suppressed response rate as the end of the 5-min interval drew near. After a number of sessions, the temporal distributions of the monkeys' responses began to change. The pattern of responding became positively accelerated (with the highest response rate preceding the shock). At this point, the VI food schedule was discontinued, leaving response-produced FI shock as the only consequence for responding. The monkeys continued to display positively accelerated responding maintained only by shock presentations. Furthermore, these shock-maintained performances did not extinguish over time. Shock-maintained performances have been widely replicated and constitute a robust set of phenomena (see Branch & Dworkin, 1981; Hutchinson & Emley, 1977; Malagodi, Gardner, Ward, & Magyar, 1981; Morse & Kelleher, 1966). These findings suggest adjunctive behavior belongs to a broader class of *evoked emergent behavior*, which is produced by indirect schedule variables. They are otherwise low-probability behavior patterns that are slow to develop and are schedule induced.

Hineline (1981, 1986) proposed extending the concept of *resonance* from physics to describing phenomena we have termed *evoked behavior*. Resonance, a dispositional characteristic of inorganic systems, refers to their responsiveness to sinusoidal or pulsed inputs. Resonant systems have two important properties: (1) their degree of *tuning*—that is, the extent to which a system responds to periodic inputs that differ from the system's resonant frequency (resonant frequency corresponds to what has been called *optimal value* here)—and (2) *damping*—that is, how quickly a system returns to rest when periodic inputs are discontinued.

According to this formulation, elicited and evoked behavior patterns are viewed as ends of a single continuum of *induction*, that is, "action produced without proximal contact" (Segal, 1972, p. 12). This dimension is anchored by phasic induction (i.e., critically damped and highly tuned systems—that is, simple reflexes) and periodic induction (i.e., moderately damped and moderately tuned systems—that is, adjunctive behavior). If the concepts of tuning and damping function uniformly along a continuum, an argument can be made for only two behavior classes. However, if a discontinuity exists between phasic and periodic induction, then consideration should be given to a third response class.

Although Hineline's account of evoked behavior is appealing, two distinctions between inorganic and organic systems pose potential difficulties in applying an inorganic resonance model to behavioral phenomena. In inorganic systems, when periodic stimulus inputs exceed the system's range of tuning, the system returns to a resting state. However, when the parameters of a generator schedule exceed the critical range, direct schedule effects continue to control the probability of the baseline behavior and only the indirect adjunctively induced behavior drops out. Moreover, in inorganic systems, periodic stimuli typically engage the same type of motion individually or phasically when their intensity is increased. In behavioral systems, generator schedules evoke different types of responses, the specific forms of adjunctive behavior being determined largely by the available stimuli. Indeed, generator schedules calibrated to an optimum value may not evoke *any* adjunctive behavior if the ambient stimuli within the organism's purview are not germane to the dispositions the organism brings to the stimulus situation.

### Summary

The foregoing three behavior classes reflect our current knowledge regarding the fundamental units of behavior. These behavioral units are defined by their relational, not their intrinsic, properties. The intrinsic (topographical) properties of several responses may cut across all three behavioral classes, yet their functional class membership may vary. Nearly all of the laws or principles forming the foundation for our current knowledge base vis-à-vis the behavior of infrahuman organisms (e.g., acquisition, extinction, discrimination, gener-

alization, habituation, schedule control) are based on these three fundamental units (Cattania, 1984; Ferster & Skinner, 1957; Hinde, 1970; Honig & Staddon, 1977; Locurto, Terrace, & Gibbon, 1981; Mackintosh, 1974; Rachlin, 1976; Rescorla, 1980; Staddon, 1980; Thompson & Zeiler, 1986). The conceptual implications of these behavior classes are deeply rooted in 20th-century behavior theory. Collectively, they meet the criteria of scientific significance and function as the rudimentary components for synthesizing more molar streams of behavior. What kinds of combinations of basic components can be constructed, and in what arrangements can these components combine?

#### THE COMBINATION AND ARRANGEMENT OF FUNCTIONAL BEHAVIOR UNITS

Virtually no behavior of an adult organism is a pure instance of a single functional unit; a behavioral instance is nearly always composed of multiple individual units (Hinde, 1966). Indeed, some early formulations of mediation theory (Mowrer, 1947; Spence, 1956) were based upon the presumed embedded Pavlovian relationship contained in instrumental learning (Rescorla & Solomon, 1967). This consideration is also central in more contemporary "two-process" behavioral accounts (Overmier & Lawry, 1979). Nonetheless, it is useful to identify the minimal units (emitted, elicited, and evoked) of which such behavioral compounds are composed, in the same sense that it is useful to show that water is composed of oxygen and hydrogen atoms. A given segment of behavior may be constructed of parts that are indistinguishable in the concatenated segment but that were essential in the origin of that segment.

Some have argued that distinctions among behavior units are of doubtful value. Having gotten the "learned-instinctive" arguments of several decades ago well behind them (Hinde, 1968), some writers view distinctions among behavioral constituents as anachronistically naive (Hinde & Stevenson-Hinde, 1973). According to this reasoning, a question such as "Which components of an infant's approach to its mother are operant and which are fixed action patterns?" must be viewed rhetorically, because it is rarely possible to adequately tease them apart. In our view, the interrelatedness

of behavioral components is a given, as is the interrelatedness of constituent cells of the colonial flagellate, *Volvox*, or the component behavior patterns prerequisite to emergent verbalizations in young children. One must understand how each cell of *Volvox* functions in relation to its companions to grasp how this colonial animal navigates through its aqueous medium, and one must understand the component behavior patterns developed by a young child to understand how transitive verbal responses emerge without being specifically taught (Sidman, Rauzin, Lazar, Cunningham, Tailby, & Carrigan, 1982; Sidman & Tailby, 1982). That an organism's constituent responses are often inextricably intertwined is cause for perspicuous curiosity, not analytic nihilism.

We assume that much of the behavior of all but the simplest or the youngest organisms is constructed of constituents that are tenaciously combined, much as protein molecules are composed of individual elements that cannot readily be recovered, once denatured. However, our later discussion will show that some behavior can be analyzed into constituent parts and resynthesized again, and that complex behavior patterns are, at times, subject to partial dissolution into components. An understanding of the basic units and the ways in which they combine is important to an understanding of complex behavior.

#### *Functional Behavior Combinations*

Functional behavior combinations are composed of two or more units that collectively covary to form an aggregate response class. The constituents of these combinations may be of the same type (e.g., elicited or emitted responses) or of different type (e.g., elicited and emitted). Combinations of the same type can be called *homogeneous* combinations, and those composed of two or more types of units can be called *heterogeneous* combinations.

Homogeneous behavior combinations involve two or more simple components of the same functional type. The simplest case involves a single response occurring recurrently, such as a bird song occurring repeatedly in the same form (e.g., Thorpe, 1961). Such bouts of fixed action patterns can be contrasted with two or more fixed action patterns of different forms occurring as a unit. A single operant, such as key pecking, can be repeated several times, leading to food reinforcement. The form

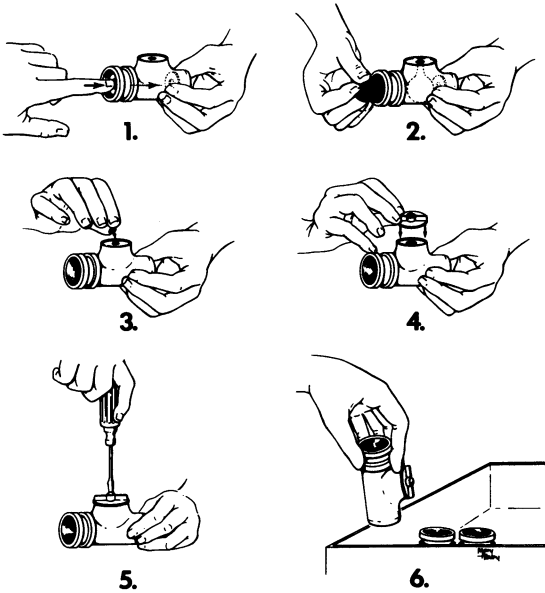


Fig. 2. A six-component homogeneous behavioral combination composed of responses emitted by moderately retarded workers. These topographically disparate responses are all members of a single functional class (Thompson & Grabowski, 1972).

of each response may vary but will be similar. Such a combination of discrete responses comprises the simplest homogeneous operant combination. Homogeneous response sequences may also involve topographically dissimilar operants, all of which are under the control of a given consequence, such as industrial assembly operations (see Figure 2).

Combinations of behavior units from different types of response classes (heterogeneous combinations) have been studied less extensively than homogeneous combinations, and are more difficult to interpret. Rats placed in close proximity in an enclosed space will fight if presented with painful foot shock. Reflexive fighting is reliably elicited by shock and can be classically conditioned (Vernon & Ulrich, 1966). The fighting of a rat in an environment in which shock has repeatedly elicited fighting will be partially a classically conditioned and partially an unconditioned fixed action pattern elicited by the shock. The foregoing combination of a fixed action pattern and a classically conditioned aggressive pattern is simpler and more stereotyped than the combination of fixed action patterns and operant responses. Young chickens and ducklings

stepping on a treadle can be conditioned with a stimulus light as reinforcer. The light elicits approach during imprinting, although these birds had not previously been imprinted. The birds' approach to the light is a fixed action pattern elicited by the conspicuous stimulus (Bateson, 1966; Bateson & Reese, 1968). The resulting sequentially integrated operant and fixed action pattern comprises a new heterogeneous unit. Integrated sexual responses also involve combined operants and elicited responses (see Hinde, 1970; Masters & Johnson, 1966). Human sexual behavior comprises a diverse collection of heterogeneous behavior combinations; however, although the emitted components of these combinations do vary considerably, the elicited components are rather stereotyped.

#### *Behavior Combinations in Humans*

Just as the power of a microscope must be adjusted as a function of the phenomenon under study, so too does the level of behavior analysis need to be adjusted to the functional unit of behavior-environment interaction. To be specific, when order is not apparent at a molar level, a more molecular analysis may be necessary. . . . Conversely, if one fails to find an immediate stimulus that controls a response, perhaps the response is only an element of a larger functional unit which is controlled by currently operating variables not immediately attendant to that element. (Morris, Higgins, & Bickel, 1982, pp. 119-120)

Similarly, Himeline (1984) has remarked, "In conjunction with the quantitative evaluation, we need techniques for efficiently identifying the most effective scales of analysis for particular situations, thus establishing the complementarity of molar and molecular analyses" (p. 506). So far, our discussion of response classes (i.e., minimal units and behavioral combinations) has focused on dispositions typically studied by experimental psychologists and ethologists (e.g., Catania, 1984; Dewsbury, 1978; Drickamer & Vissen, 1982; Hinde, 1970; Honig & Staddon, 1977; Locurto et al., 1981; Mackintosh, 1974). Traits are broader response classes (Falk, 1956; Meehl, 1978, p. 808; Tellegen, 1981) consisting of emitted and/or elicited components. They are often referred to as "dispositional clusters" or "response families," because the class of behavioral components defining a par-



Table 1

An eight-cell taxonomy based on the functional response types (e.g., emitted and elicited) and temporal combinations of functional types. The examples in each cell are discussed in the text.

Temporal combinations	Response type	
	Homogeneous	Heterogeneous
Sequential and parallel	Conjoint schedules Catania (1966)	Conflict analysis Lewin (1935)
Compound	Behavioral trees Findley (1962)	Courtship displays Hinde (1970)
Complex	Interlocking schedules Reynolds (1975)	Shock-avoidance adjusting schedules Sidman (1962)
Superordinate	Higher order reinforcement schedules Kelleher (1966)	<i>Betta splendens</i> Higher order: operants-CS-FAPs Thompson (1966)

ticular trait often contains seemingly disparate mega-topographical constituents (Lubinski & Thompson, 1986; Meehl, 1986).

Although traits are much less circumscribed than fixed action patterns, monosynaptic reflexes, and the behavioral combinations mentioned above, they nonetheless manifest common dispositional properties (Carnap, 1956; Pap, 1958; Sellers, 1958). That is, in a stimulus situation of a given kind, a response of a given type will occur (Tellegen, 1981, pp. 218–219). The extent to which traits are composed of emitted and elicited responses depends on the response class under consideration. The purest examples of homogeneous behavioral combinations at this level of analysis appear to be response classes typically called skills (e.g., verbal, numerical, and spatial skills), dispositions composed exclusively of emitted responses.

“Extraversion” refers to the tendency to display members of a heterogeneous response class composed of emitted and elicited components. The strength of clusters of social responses are controlled by classes of social consequences (i.e., they are emitted), whereas affective responses are conditioned through associative pairing (i.e., they are elicited) and typically have characteristic interoceptive discriminative-stimulus properties. For example, the probability that access to social gatherings will serve as maintaining events may be estimated by indices of *extraversion*. People scoring above the normative mean on “extraversion” on certain personality inventories are likely to seek out social contact, whereas individuals scoring at the low end of this dimension will exhibit little emitted behavior

under the control of group social consequences.

#### TEMPORAL BEHAVIORAL COMBINATIONS

Sir Charles Sherrington (1906), in attempting to understand integration of spinal reflexes, noted: “The outcome of the normal reflex action . . . is an orderly coadjustment and sequence of reactions. . . . The coordination involves orderly coadjustment of a number of simpler reflexes occurring *simultaneously* (or in) . . . orderly *succession*” (p. 8). The temporal arrangement of behavioral units can also be useful in characterizing behavior combinations: (a) sequential or parallel, (b) compounds of sequential and parallel, (c) complex, and (d) superordinate arrangements (Thompson & Grabowski, 1972). Hence, behavioral complexes can be classified into eight disjunctive categories according to the combination and arrangement of their component functional units (see Table 1).

#### *Sequential and Parallel Combinations*

In *sequential behavioral combinations* the completion of certain preceding behavioral units is a necessary condition for occurrence of the succeeding unit. Such behavioral sequences have been discussed in detail by Hinde and Stevenson (1969). Chain reflexes, such as the chewing movements of decerebrate cats (Sherrington, 1906), are among the simplest homogeneous sequential arrangements. A piece of meat dropped in the mouth elicits contraction of the masseter muscle lifting the mandible. When proprioceptive feedback from the contracted muscle reaches a specific level, the jaw falls open. On the same continuum,

but far more complex, are chains of fixed action patterns, such as the sexual behavior patterns of Stickleback fish (Tinbergen, 1951). Operant behavior frequently involves sequential combinations (Catania, 1984; Fantino & Logan, 1979; Ferster & Skinner, 1957; Pierrel & Sherman, 1963). In chained reinforcement schedules, responding in the presence of one discriminative stimulus with a given set of reinforcement contingencies (e.g., FR 25) produces a different discriminative stimulus. Responding in the presence of the second discriminative stimulus under specific reinforcement contingencies (e.g., FI 60 s) produces an unconditioned reinforcer (e.g., food). The topographies comprising successive units in chains may be similar (e.g., lever presses) or may be quite dissimilar (e.g., cutting a piece of meat with a knife, followed by picking up the piece of meat with a fork). Multicomponent performances under chained schedules serve as entire behavior units, the probabilities of which are manipulable as a whole (Findley, 1962; Gollub, 1977; Kelleher & Gollub, 1962). Everyday activities frequently involve chains of operants, each with its own integrity but under the control of a single consequence (e.g., rising and preparing to go to a job, completing units of work in school, preparing a meal).

Although it is common to assume that the organization of behavior in time is intrinsic to neural circuitry (see Church, 1978; Fodor, 1981), in most cases the sequential organization of human behavior seems to be imposed largely by external environmental events. The key must be inserted in the lock of the car door before the door can be opened, and the key must be inserted in the ignition before the engine will start, and so on. Nothing about neural circuitry requires that such behavioral sequences be organized in such a fashion. The functional organization of behavior by extrinsic proximal controlling variables interacting with existing dispositions and biological state modulators provides an adequate account in most instances.

In *parallel behavior combinations*, two or more units occur concurrently. A stuffed owl was presented to a chaffinch and elicited a characteristic mobbing call ("chink") and concurrently elicited erection of the crest feathers. The two responses occurred independently but were often elicited by a com-

mon stimulus (Hinde, 1954). Similarly, dogs prepared with parotid fistulas were trained to emit an operant response leading to the presentation of a food reinforcer under an FI 2-min schedule. The number of drops of saliva produced by the parotid gland was recorded as well as operant bar presses. As the time when reinforcement was forthcoming approached, the number of drops of saliva increased progressively; the salivation curve parallels the operant responding curve (Shapiro, 1961). The conditions controlling salivation (elapsed time) seem to be the same as those controlling operant responding, although there does not appear to be any direct interaction between the two behavior patterns.

Most parallel combinations of two or more behavioral units involve some form of interaction. Chaffinches frequently fly toward a stuffed owl while producing a characteristic mobbing call, or they may suddenly turn and fly away from the owl. Both responses have simultaneously high probabilities. The observed behavior is often some combination or rapid alternation of the two (Hinde, 1966). Under concurrent reinforcement schedules (Ferster & Skinner, 1957) two operants controlled by two discriminative stimuli and two reinforcement schedules are in effect simultaneously. Instead of generating performance characteristic of either individual schedule, the resulting performance often reflects an interaction of the two. Key-peck performance of pigeons maintained by a concurrent FR 100 FI 5-min schedule of food reinforcement reveals sequences of responses at intermediate to high rates during the interval component, alternating with long pauses. This behavior pattern is more characteristic of ratio schedules (Catania, 1966).

The clearest case of interaction in concurrent operants involves behavior combinations engendered by *conjoint* reinforcement schedules. Two reinforcement contingencies are in effect simultaneously, but only one response operandum is provided. The resulting combined performance has features of two individual performances (Catania, Deegan, & Cook, 1966). In the natural environment conjoint contingencies are familiar. A worker's high rate of productivity may be reinforced by an employer (ratio schedule), whereas a modest rate of output is reinforced by his co-workers (e.g., a pacing schedule). The resulting

integrated performance reflects the combined contingencies.

Interactions between parallel conditioned and unconditioned behavioral arrangements have received less attention. Two rats that could avoid painful shock by lever pressing reached very high levels of successful avoidance when separated by a transparent partition. When the partition separating the animals was removed, avoidance responding deteriorated and was partially replaced by reflexive fighting. Thus, the combined behavior included components regulated by avoidance contingencies and by the eliciting stimulus for reflexive fighting (Ulrich, Stachnik, Brierton, & Mabry, 1966). Lewin's (1935) conflict analyses (i.e., approach–approach, approach–avoidance, avoidance–avoidance, and double approach–avoidance) can be analyzed in similar ways. The construct of “conflict” seems to be employed when these consequences of a particular response *both* involve positive and negative reinforcement with equal momentary effectiveness (approach–avoidance), or when the consequences both involve positive reinforcement (approach–approach), or in yet another case, both involve negative reinforcement/punishment (avoidance–avoidance), again with equal intensity.

#### Compound Combinations

*Compound combinations* involve sequential and parallel functional behavior units, yielding highly complex behavior. A single behavioral unit composed of a single operant leading to an option of two or more operants has been called a *behavioral tree* (Findley, 1962). Figure 3 shows a behavioral tree composed of 80 lever presses leading to an option of 80 lever presses maintained by food or 80 lever presses maintained by water. The *tree* functioned as a reinforceable unit, engendering performance similar to that maintained by a two-member chained schedule. Complex and extended segments of behavior have been brought under control by integrating behavior units of these types. One of the more elaborate demonstrations involved bringing 90 to 95% of a normal adult human's time in an experimental environment (24 hr per day for 5 months) under control of scheduled contingencies (Findley, 1966). Twenty-four different operant units were combined in serial and parallel arrangements and groups of serial and

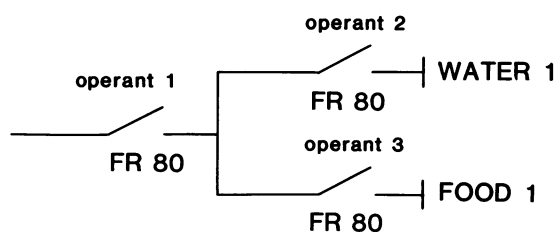


Fig. 3. A behavioral tree composed of a single operant FR 80 leading to an option of FR 80 reinforced by food or FR 80 reinforced by water. Following the completion of either food or water reinforcement, the conditions of operant 1 are reinstated, as indicated by the numerals following the reinforcement designations (after Findley, 1962, Figure 39).

parallel response classes (i.e., compound behavioral units). Bernstein and Ebbesen (1978) have extended the analysis of multioperant repertoires to include Premack's formulation of reinforcement, and Emurian, Emurian, Bigelow, & Brady (1976) have employed this design to analyze cooperation in a three-person environment (see also Bernstein & Brady, in press).

Symbolic communication between animals can be analyzed in terms of a series of interlocking compound arrangements (Epstein, Lanza, & Skinner, 1980; Lubinski & MacCorquodale, 1984; Savage-Rumbaugh, Rumbaugh, & Boysen, 1978). In these experiments, organisms' exchanging of discriminative stimuli was conditioned via arbitrary matching tasks when only one of the organisms had access to the stimuli correlated with reinforced responding (hence, the options encountered in certain links of these arrangements were contingent on the behavior of another organism). For example, Savage-Rumbaugh et al. conditioned chimpanzees' supplying geometric symbols that were discriminative for another subject's food-reinforced responses. And Epstein et al., using two adjoining experimental chambers separated by a Plexiglas divider, conditioned pigeons' interacting in a similar fashion by pecking lettered response keys. Lubinski and MacCorquodale demonstrated that pigeons can perform such communicative exchanges in the absence of a primary establishing operation (e.g., deprivation, aversive stimulation, or unconditioned reinforcement).

Probably the most clear-cut examples of heterogeneous compound arrangements are

courtship and sexual behavior (Hinde, 1970). Sexual behavior includes several emitted and elicited components temporally linked both sequentially and in parallel. Organisms may initiate such compounds in several ways (e.g., "display behavior," "posture," or "increasing proximity"); upon the completion of the first component, additional options ensue until the culmination of the series.

### *Complex Combinations*

*Complex combinations* are temporally joined by the confluence of ratio and interval contingencies. There are two main subtypes of stimulus arrangements that combine behavioral units in this fashion: (a) arrangements in which the value of the ratio and interval contingencies are fixed, independent of behavior, namely, *conjunctive* and *alternative*, and (b) arrangements in which the value of the ratio or interval values vary as a function of previous behavior, namely, *adjusting* and *interlocking* (see Ferster & Skinner, 1957; Thompson & Grabowski, 1972).

A conjunctive schedule requires both an interval and a ratio to be satisfied before reinforcement is forthcoming. Herrnstein and Morse (1958) employed a conjunctive FI 15-min FR  $n$  to investigate the variables responsible for maintaining the number of responses emitted in FI performance. They found that a response requirement as few as 10 conjunctive FI 15 FR 10 reduced responding significantly. Conjunctive arrangements are also seen in certain work settings, where a fixed amount of work must be completed in an 8-hr shift.

In alternative schedules, reinforcement is contingent upon completion of either an interval or ratio requirement, whichever comes first. Elementary school teachers implement alternative schedules when they announce (after assigning 20 math problems, 30 min before recess), "Those of you who complete the assignment before the bell may begin recess early"—such an arrangement would be designated alternative FI 30-min FR 20.

Ferster and Skinner defined interlocking schedules as contingencies

in which the organism is reinforced upon completion of a number of responses; but this number changes during the interval which follows the previous reinforcement. For example, the number may be set at 300 immediately after

reinforcement, but it is reduced linearly, reaching 1 after 10 minutes. (1957, p. 6)

This is an instance of a *decreasing* interlocking schedule (i.e., as time passes, the number of responses required for reinforcement decreases). In *increasing* interlocking schedules, as time passes, the number of responses required for reinforcement increases. In regard to increasing interlocking schedules, Reynolds (1975) commented: "This is the sort of insidious schedule that exists in cumulative educational systems in which, as time passes, the requirements for success become larger and larger" (p. 93).

An adjusting schedule is one

in which the value of the interval or ratio is changed in some systematic way after reinforcement as a function of the immediately preceding performance. . . . For example, a fixed ratio is increased or decreased by a small amount after each reinforcement, depending upon whether the time from the preceding reinforcement to the first response is less than or greater than an arbitrary value. (Ferster & Skinner, 1957, pp. 6-7)

Adjusting schedules are characteristic of "work deadlines," when a fixed number of responses must be completed in a fixed period of time. Training programs and employment situations frequently employ interlocking and adjusting schedules, as well as alternative and conjunctive schedules. Such instances are examples of homogeneous complex arrangements. (For further discussions of these arrangements, see: for conjunctive schedules [Katz & Barrett, 1979]; for alternative schedules [Harzem, Lowe, & Spencer, 1978; Rider, 1980]; for interlocking schedules [Berryman & Nevin, 1962; Rider, 1977]; and for adjusting schedules [Kelleher, Fry, & Cook, 1964; Olvera & Hake, 1976; Sidman, 1962].)

### *Superordinate Combinations*

Behavior segments may be structured *superordinately*—that is, one behavior class may incorporate several subclasses into an entire functional unit. A phenomenon not normally used to generate superordinate behavior combinations contains the rudiment of the basic relation. Pavlov (1927) conditioned a dog's salivation in the presence of a metronome by repeatedly pairing the metronome with food on the tongue. Subsequently, a black square was repeatedly presented followed by the met-

ronome. Pavlov found that the dog came to salivate when presented with the black square, a procedure called *higher order classical conditioning*. Although the robustness of this phenomenon has been questioned, there appear to be replicable cases of higher order classical conditioning (see Razran, 1955; Rescorla, 1980).

The functionally equivalent procedure applied to operants also occurs far more frequently than was initially recognized (Kelleher & Gollub, 1962). These higher order operant behavior units are specified by the controlling contingencies, or *higher order reinforcement schedules*. A behavior unit controlled by a single specified schedule contingency (e.g., FI 4-min) that is in turn reinforced on another schedule contingency (e.g., FR 15) is called a higher order schedule. In the preceding example, the FI 4-min is treated as if it were a single response reinforced according to an FR 15 schedule (Kelleher, 1966).

Kelleher (1957) studied a chimpanzee's lever pulling maintained on a schedule such that each individual FR 125 unit was followed by token presentation and five 125-response units produced access to food. That is, a 125-response unit functioned as if it were a single operant. In experiments with hospitalized psychiatric patients and with people who are mentally retarded, as well as with nonhandicapped children in classrooms, tokens have been used in similar ways; however, each component of the first-order schedule typically differs topographically from other components—that is, typically the responses are different adaptive educational or clinically relevant performances (Ayllon & Azrin, 1965; Kazdin, 1977; McConahey, Thompson, & Zimmerman, 1977). Outside of laboratory settings, the integration of large samples of human behavior is often accomplished under basic schedules by token (money) reinforcers, which in turn are exchangeable for other reinforcers when enough tokens have been accumulated (Skinner, 1953).

The conditioned reinforcers embedded in superordinate arrangements are capable of evoking adjunctive behavior. Rosenblith (1970) conditioned rats' lever pressing with deliveries produced according to an FR 3 (FI 1-min) second-order schedule (i.e., the first response emitted after 1 min produced a brief flash of light and the first response after three such intervals produced the brief flash and

food delivery). The FI 1-min component of this schedule generated typical FI 1-min scallops and also evoked polydipsia; excessive drinking preceded the brief flash in all intervals (i.e., whether it occurred alone or in conjunction with food delivery).

Studies on higher order multioperants have provided the most compelling evidence that superordination of operant units is a powerful method for synthesizing complex behavior (Thompson & Grabowski, 1972). Using a baboon as the subject, Findley (1962) shaped a behavioral tree (a single operant leading to an option of two operants) composed of FR 80 units. This behavioral unit was then reinforced under other schedules. In one case, successive trees had to be spaced 2 min apart if they were to be reinforced (a DRL 2-min schedule). The emission of trees came under the control of these scheduled contingencies, indicating that the tree was reinforceable as a unit. Similarly, another tree was established that was composed of FR 80 units, and then occurrences of the tree produced food or water on an FR 4 schedule (i.e., four successive trees composed of FR 80 s were required per reinforcer). Trees occurred in runs at a high constant rate, followed by long pauses, much as one would expect with simple FR 4 schedules. Finally, a tree composed of FR 20 units was reinforced under one set of stimulus conditions on an FR 4 schedule, and under another set of stimulus conditions on a DRL 2-min schedule. The following units were synthesized and independently manipulable: (a) individual lever presses, (b) ratios of lever presses, (c) trees of ratios of lever presses, (d) ratios of trees, or DRL 2-min controlled trees, of ratios of lever presses, (e) multiple schedule controlled ratios or DRL 2-min controlled trees of ratios of lever presses (see Figure 4).

In the foregoing case, as with many laboratory operants, the basic first-order response unit was topographically uninteresting (i.e., the lever press). However, an operant is defined as the behavioral segment the probability of recurrence of which is controlled by a particular reinforcing consequence. Operants are not restricted to lever presses, chain pulls, or key pecks. More natural heterogeneous response combinations have been brought under superordinate operant control. The behavior of the Siamese fighting fish (*Betta splendens*) illustrates such superordinate control.

*Betta splendens* exhibit complex uncondi-

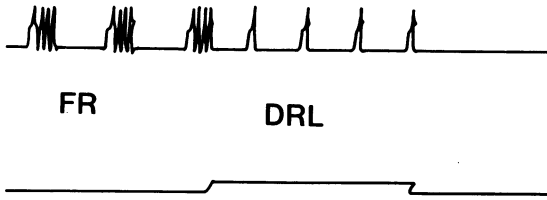


Fig. 4. Cumulative records of chain pulls emitted by a baboon on a higher order multiple schedule in which a tree composed of an FR 20 leading to an option of FR 20 food or water was reinforced on an FR 4 schedule alternating with a DRL 2-min schedule. The event pin was down during the FR schedule and up during the DRL schedule. The schedule control exerted by the two contingencies is apparent from the spacing of successive trees (after Findley, 1962, Figure 43).

tioned aggressive displays when confronted with its own image or another *Betta splendens* (Fantino, Weigele, & Lancy, 1972; Lissman, 1932; Simpson, 1968). A common naturally occurring type of behavior such as swimming through a channel suspended in the aquarium can be strengthened if emission of that response leads to presentation of the mirror image or a model of another *Betta splendens* (Fantino et al., 1972; Thompson, 1963). The mirror image elicits an unconditioned aggressive display. After many such mirror presen-

tations contingent on swimming, stimuli paired with mirror presentation elicit components of aggressive display through classical conditioning (Adler & Hogan, 1963; Thompson, 1966; Thompson & Sturm, 1965). If the entire behavior sequence of a male *Betta splendens* is observed under these circumstances, the fish first emits the swimming operant, then begins to display aggressively to the classically conditioned eliciting stimuli, and finally exhibits a fixed action pattern elicited by the presence of the mirror image itself. A portion of this sequence can be brought under superordinate control. The swimming operant and classically conditioned display can be reinforced under a fixed-ratio schedule in which the mirror is produced by several transits through the channel. On each transit, the subject exhibits classically conditioned aggressive display, and on the final transit all three components occur. This heterogeneous behavior combination closely resembles behavior of the *Betta splendens* in a more natural setting (see Figure 5).

It is possible to construct complex repertoires involving serial arrangements and choices of activities involving not only operant behavior or fixed action patterns, but heterogeneous combinations as well. A key integrat-

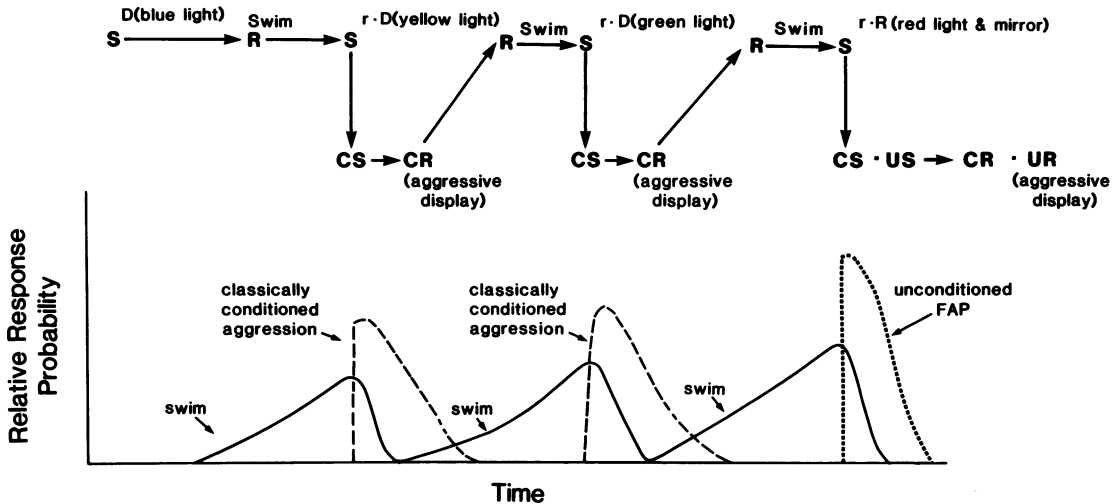


Fig. 5. A heterogeneous behavior combination exhibited by male Siamese fighting fish (*Betta splendens*) maintained and integrated by access to a mirror image that elicits an unconditioned aggressive display (UR). The sequence involves swimming through a channel in the presence of blue, yellow, then red lights (presented one following the others). The onset of the discriminative stimuli for succeeding components in the series (e.g., yellow light) served as a conditioned reinforcer, a discriminative stimulus, and also elicited classically conditioned aggressive display. The lower curves indicated the relative probabilities of the swimming operant and the conditioned and unconditioned display that merged to form a smoothly coordinated response sequence (after Thompson, 1966).

ing variable combining behavior under superordinate control is the arrangement of consequences for groups of units. The extent to which the kinds of units determine the degree and kind of control is unclear.

#### *Analysis and Synthesis of Complex Repertoires*

The proposed taxonomy is intended to provide a conceptual framework for analyzing complex systems of behavioral flux into mutually exclusive and exhaustive categories. The rudimentary units of such temporal combinations may be identified by manipulating the parameters of the component schedules regulating the synthesized repertoire. The component schedules are used to tease apart adjacent components. By varying the stimulus presentations that temporally link individual components, the constituent units may be demarcated within the concatenated repertoire.

The degree to which an analysis can be achieved varies with the extent to which the minimal components are integrated. Certain behavioral combinations, once synthesized, cannot be readily decomposed into their basic components again. Complex skills (such as riding a bicycle or playing a musical instrument) are *compound combinations* consisting of several sequential and parallel components. Once acquired, the possibility of experimentally breaking down such behavioral combinations into fundamental units is questionable.

As more highly integrated performances are achieved, the control of certain facets of the individual's repertoire may shift from exteroceptive or verbal discriminative stimuli to more subtle interoceptive kinesthetic or proprioceptive stimulation. Because many of these controlling stimulus events are not accessible, manipulation of individual components is often impossible. For example, it is often very difficult for a skilled musician to teach a novice beginning fingering technique, because the minimal units no longer exist individually in the experienced musician's repertoire.

If such highly coordinated performances cannot be analyzed into minimal units, perhaps behavioral integration is a unidirectional process—that is, once integrated, may analysis into minimal units be no longer possible? In fact, behavioral sequences that appear irreversibly integrated can, at times, be shown to be constructed of independent units. The

classic observations of egg-retrieval by the grey-lag goose (Tinbergen, 1953) revealed that although the sequence typically occurred in a smoothly integrated pattern, the retrieval response is composed of two independent components—the side-to-side orienting response and the pulling toward the breast with the beak—controlled by distinctive variables. Similarly, the nest-building sequence of the female canary is composed of independent behavioral units, some under the control of evocative stimulus antecedents, others maintained by stimulus consequences, and yet others regulated largely by hormonal state variables (Hinde, 1958). Some brain-damaged patients suffering from *apraxia* (the inability to perform skilled movements, typically resulting from a lesion on the sensorimotor cortex) display fragmented behavior composed of numerous minimal behavioral units out of synchrony. Individuals suffering from apraxia provide rare instances for observing rudimentary behavioral units of previously synthesized skilled performances. These fundamental units may appear aberrant, because the mechanisms for maintaining their internal consistency are impaired. However, emergence of these individual units provides a means of corroborating the hypothesis that molar behavioral streams are aggregate entities composed of several temporally combined fundamental units, even in highly overlearned skilled performances.

Analyzing individual components of highly integrated performances in the natural environment may be no more possible than resynthesizing a denatured protein molecule. Under such instances an *interpretation* is the only feasible objective, rather than analysis (Schnaitter, 1978; Skinner, 1969). A behavioral interpretation involves inferring a plausible causal analysis from incomplete data on the system under consideration combined with generalization from similar cases studied in isolation or partial combination.

#### NEXUS: BEHAVIORAL INTEGRATION

Sherrington, in *The Integration of the Nervous System* (1906), wrote, "The main secret of nervous co-ordination lies . . . in the compounding of reflexes" (p. 8). To solve this problem, Sherrington proposed "the principle

of the common path" (p. 117), the notion that two or more independently elicited reflexes converge on a common efferent output. Sherrington suggested that "since each instance of convergence of two or more afferent neurones upon a third . . . affords . . . an opportunity for coalition or interference of their actions, each structure at which it occurs is a *mechanism for co-ordination*" (p. 147). This paper has suggested a functional taxonomy of behavioral units and has explored several types of combinations and arrangements of such units. How fundamental units and their various combinations become integrated remains to be explicated. Although no structural analog provides a behavioral final common path, functional mechanisms by which behavioral sequences and patterns become integrated can be identified. The most basic phenomenon involved in behavioral integration appears to be *temporally structured relative response probability*, a cardinal concept in modern behavior theory.

Skinner (1953) suggested that response probability is an estimate of response strength and that response frequency is an estimate of response probability. The notion that relative response probabilities (and by illation, response strength) are critical to reinforcement concepts is embedded in the fabric of current learning theory (see Premack, 1965, 1971; Timberlake & Allison, 1974). In this final peroration we shall argue that the temporal structure of relative response probabilities binds functionally defined short-term behavioral units into larger combinations. The temporal structure of behavior of an individual organism is a function of three factors: relative response probability hierarchies, fluctuating states, and the scheduled presentation of environmental events. Hierarchies of relative response probability reflect the nature and strength of all behavioral dispositions within the organism's repertoire. Fluctuating states are organismic conditions enhancing or attenuating the strength of these response classes (e.g., fatigue, illness), and the scheduled arrangement of environmental events with respect to recurrent behavioral events shifts the local probabilities of those response classes. The idiosyncratic flow of natural behavior of each individual depends on these three sets of behavioral factors.

#### HIERARCHIES OF RELATIVE RESPONSE PROBABILITIES

An organism's hierarchy of relative response probabilities represents the *nature* and *strength* of the sum total of behavioral dispositions within its repertoire. The constituents of these hierarchies range from individual fundamental units to functional behavioral combinations (i.e., concatenated behavioral units combined collaterally and/or temporally). The strength of a disposition refers to the probability of a given functional unit when appropriate environmental events are provided.

#### *Enduring Dispositions*

Enduring dispositions are dimensions of response classes, as is true of other response classes. Such a disposition is a persistent readiness to exhibit responses of a given functional type when appropriate environmental events are provided. These response classes are long-term (often life-time) characteristics of an organism. For example, the probability that a healthy adult male Siamese fighting fish will exhibit gill-cover erection, fin spreading, and tail beating when visually confronted with a conspecific male approaches unity under a wide array of circumstances (Lissman, 1932; Simpson, 1968). This genetically determined aggressive display is extremely high in the hierarchy of response probabilities of *Betta splendens*. Eating is among the most probable responses displayed by people suffering from *Prader-Willi Syndrome* (Prader, Labhart, & Willi, 1956). This disorder, associated with an insatiable appetite and life-threatening obesity, is apparently regulated by a neurological defect similar to hypothalamic hyperphagia in laboratory rats (Hetherington & Ranson, 1942; Teitelbaum, 1955). These biologically determined dispositions have enduringly high probabilities within the behavioral repertoire of the respective subjects.

Weiner (1964, 1969) found exposure to fixed-ratio or DRL schedules had lasting effects on the operant performance of humans subsequently exposed to fixed-interval reinforcement schedules. Such enduring historical influences can also determine the behavioral actions of drugs (Barrett, 1977; Urbain, Poling, Millam, & Thompson, 1978). When we



say that someone is "extraverted," we refer in part to enduring response classes under the control of social consequences having major genetic determinants (see Eysenck, 1956; Gottesman, 1963, 1966; Scarr, 1969). In contrast, when someone frequently displays a particular religious ritual, we are presumably referring to an enduring effect of reinforcement history (Herrnstein, 1966).

Distinctions between dispositions that are primarily genetic in origin, rather than established by the organism's experience, are familiar; "constitutional" versus "environmental-mould" traits (Cattell, 1950) and "phylogenic" versus "ontogenic" distinctions (Skinner, 1969) are examples. In humans, most molar response classes are products of both biological and environmental influences (in varying proportions, depending on the response class under consideration). For our purposes, estimates of enduring dispositions need only reflect the current strength of the response class in question, not the relative contributions of the etiological sources. This is not to deny the utility of understanding the relative contributions of genetic and historical factors. Indeed, for therapeutic intervention such understanding may be crucial. However, there is no a priori reason to suppose that knowledge of the relative contributions of biological and environmental sources for a particular enduring disposition will be helpful in predicting the moment-to-moment temporal structure of behavior.

#### *Fluctuating States*

The strengths of behavioral dispositions are modulated by state variables fluctuating relatively rapidly over time (e.g., hours, days). Such variables are often of biological origin (e.g., deprivation, drug, fatigue, illness, and hormonal states or opponent processes [Solomon, 1980; Solomon & Corbit, 1974]). These fluctuating states modulate the level of a disposition across a range of values, which determines the degree to which an environmental event can engender behavioral changes. In psychiatric manic patients, for example, an array of response probabilities shift, and normal control by socially mediated reinforcement and punishment contingencies diminishes or stops. In a study by Thompson, Golden, and Heston (1979), several manic pa-

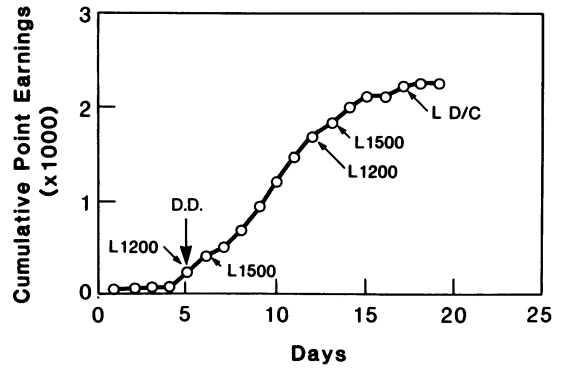


Fig. 6. Cumulative point (token) earning by an adult psychiatric patient suffering from an affective disorder (mania) treated with lithium carbonate, over 19 days of hospitalization. Daily lithium dosages are given in total milligrams and the day on which a significant discontinuity occurred in rate of point earnings is marked with an arrow (DD). Lithium blood-level data indicate that the day of discontinuity corresponds to a lithium blood level of 1.25 mEq/liter of plasma (from Thompson, Golden, & Heston, 1979).

tients in an acute unit were exposed to a token reinforcement program in which tokens were administered contingent on a variety of socially appropriate responses (Pickens & Thompson, 1984). Tokens were exchangeable for supplementary goods and services. The rate of token earning was negligible until the patients were administered lithium. After 5 to 6 days of lithium (at which point blood level of lithium reached 0.75 to 1.25 mEq/liter of blood), there was a statistically significant discontinuity in the rates of daily point earning (see Figure 6). Hence, the disposition associated with mania was manipulable by a state variable that manifested itself in recovery of control by normal environmental contingencies.

#### SCHEDULED ENVIRONMENTAL EVENTS

The constellation of an organism's relative response probabilities and fluctuating states constitutes a hierarchical substrate upon which stimuli act to determine the momentary probability of a given response class (see Figure 7). The foregoing hierarchies of response probabilities are modulated by short-term scheduling of environmental events. Recurring environmental events shift the temporal distributions of response probabilities in the behavioral repertoires of organisms. Behav-

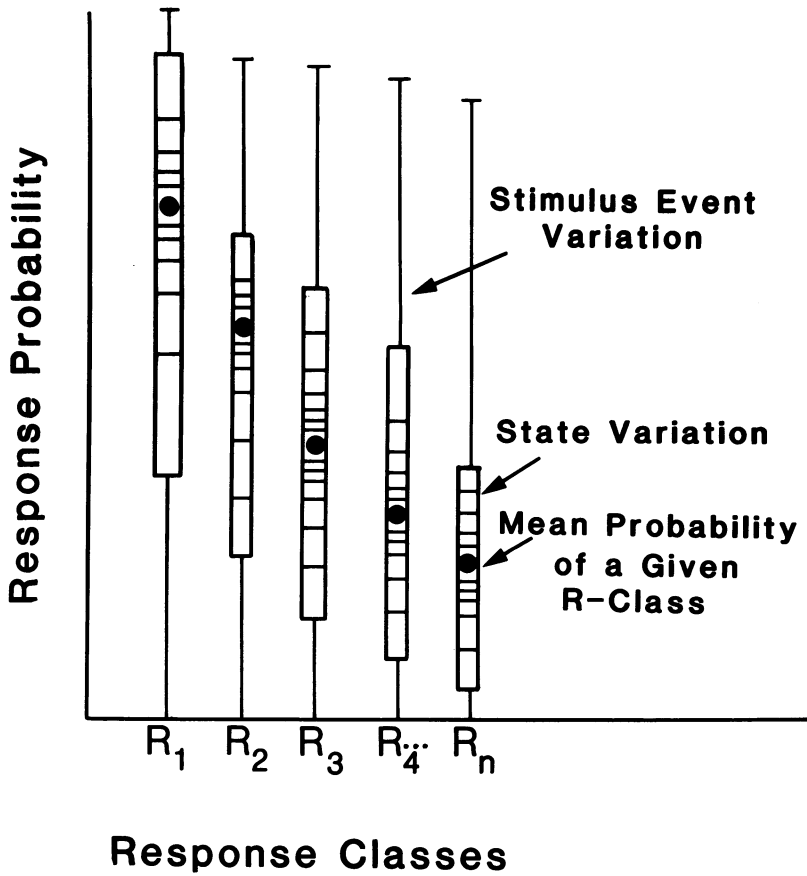


Fig. 7. The hierarchy of an organism's relative response probabilities.  $R_1, R_2, \dots, R_n$  = the organism's dispositional profile (each "R" represents a specific disposition, the average strength of which is illustrated by a black circle). The short horizontal lines extending from each circle illustrate short-term fluctuations due to state variables. Dispositions vary in the extent to which state fluctuations moderate their strength, which is highlighted by the larger variance of  $R_1$  compared to  $R_n$ . Strength modulations due to variations in the intensity, configuration, and temporal structure of exteroceptive stimulus events are shown by the narrow vertical lines extending from the bars marking variations due to state fluctuations.

ioral units occurring temporally antecedent and contiguous to such scheduled events are regulated largely by the law of effect. Response classes regularly following such events are elicited (as in classical conditioning) or evoked (as in the case of adjunctive behavior). Falk (1961) demonstrated that the induction of high-probability drinking between successive food pellets presented under a variable-interval schedule established access to drinking as a reinforcer for a second operant. The specific operant that bridges eating to drinking is important insofar as it characterizes the idiosyncratic features of a given organism's behavior in its environment. For one animal, consuming a small amount of food may lead to a running operant that brings the organism to a nearby stream; for another, food presen-

tation may produce climbing to a crotch in a tree where rain water collects. Although an organism's hierarchy of relative response probabilities determines the most likely classes of behavior, exteroceptive environmental stimuli determine the *specific* (idiosyncratic) topographical patterns.

Such adjunctive responses linked by idiosyncratic operants occur in humans as well. One person who sips a cocktail and then reaches for a cigarette in his pocket may differ from another individual in the topography of the operant binding drinking and cigarette smoking. The second person may instead ask a companion for a cigarette (Falk, 1984). Thus, the effect of recurring scheduled events is to cause regular shifts in the temporal structure of the probability of various response

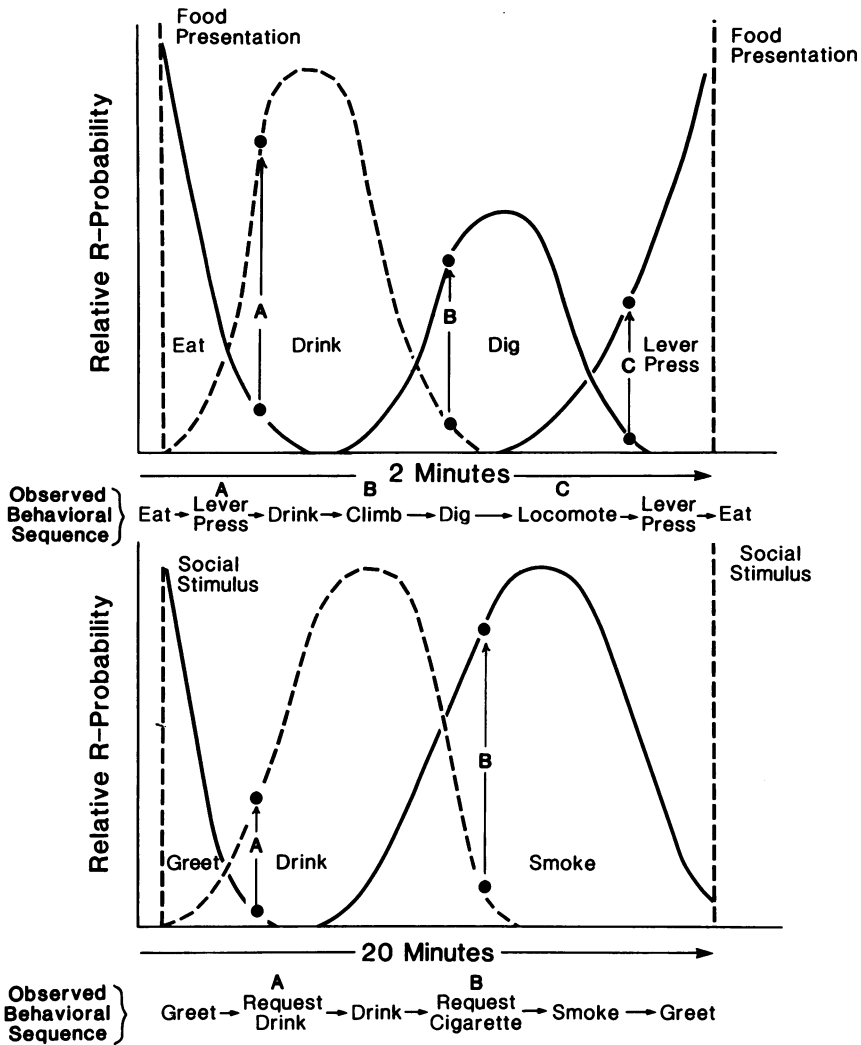


Fig. 8. Hypothetical response probability relationships in a schedule-induced polydipsia situation (top) and in a schedule-induced cigarette-smoking situation (bottom). Evoking stimulus events are indicated by the vertical dashed lines (food-top; social stimulus-bottom). The evoked response probability shifts (e.g., drinking and smoking) are linked to the preceding moderate to high-probability response by arbitrary operants (e.g., lever pressing-top; requesting a cigarette-bottom). When the probability of a given evoked response (e.g., smoking) is higher than the preceding response (e.g., drinking), access to the higher probability response will strengthen an arbitrary operant (e.g., requesting a cigarette [B]). The resulting behavioral sequences are observed as a series of events flowing one into the next, rather than as a chained set of stimulus response units.

classes (see Figure 8). Organisms differ in the specific relative response probabilities upon which these short-term influences are superimposed and in the specific operants available to bridge schedule-modulated responses of varying probabilities. These idiosyncratic response topographies lend the apparent unpredictability to schedule-modulated response patterns and impress us with the uniqueness of an individual's behavior. Uniqueness results from the idiosyncratic constellation of

fluctuating states, relative response probabilities, the scheduled presentation of environmental events, including the available operants (Rachlin & Burkhard, 1978; Rachlin, Kagel, & Battalio, 1980), and the dynamic interplay between these variables. Lacking information on any one of these three classes of variables reduces the possibility of predicting behavior on a moment-to-moment basis. For example, given precise information concerning the scheduled presentation of environmen-

tal events, the accuracy of point predictions concerning response classes within the kinetic structure of behavior is increased, just as predicting in detail the motion of a leaf dropped from a tree is improved by knowing relevant meteorological information (e.g., wind velocity, temperature, and humidity).

### KINETIC ENODATION

Relative probabilities of members of functional response classes emanating from diverse biological and historical sources are directly measurable in infrahuman animals and frequently can be assessed in humans through verbal behavior. The momentary probabilities of members of several response classes are determined by the temporal arrangement of stimulus events that shift the response-probability hierarchies. The specific manner in which the probabilities of members of various classes are regulated in time (i.e., elicited, evoked, or emitted) is less important than the quantitative relations among instances of members of temporally contiguous response classes. The time ( $t$ ) between successive responses of two classes and the differences in the relative response probabilities ( $Pr_A - Pr_B$ ) determines the degree to which access to one response ( $R_A$ ) serves as a maintaining event for emission of another response ( $R_B$ ). Because the form of response ( $R_B$ ) that may be strengthened in this fashion will vary widely, the specific resulting sequence of behavior will vary within and across individuals over time. Although the product may appear inchoate, the sequence of events is very orderly and, in principle, predictable (Lubinski & Thompson, 1986).

The conspicuous continuity of successive instances of response classes, with no obvious boundaries demarcating the sequenced performances, puzzles the observer expecting to find discrete behavioral monads. The problem arises because the observer attempts to apply the statistical concept, "response class," to a particular instance. Given that many instances of response  $N$  are measured in time, and comparable sampling of instances of response  $N + 1$  are recorded, such data can be used to estimate the probability of those two response classes in successive temporal slices. When the probability of response  $N + 1$  (typically measured in terms of relative frequency of occurrence) significantly exceeds the prob-

ability of response  $N$ , it can be said that response  $N$  has ended and response  $N + 1$  has begun. This is a communicative convention, which bears no meaning when applied to a particular instance, since in reality components of the two response classes merge at their interface, producing an integrated performance. Only in the foregoing statistical sense of relative response probability can one speak of the beginning and end points of members of successive response classes.

Temporally arranged relative response probabilities provide the mechanism and force behind behavioral syntax. Arrangements of momentary response probability are products of recurring environmental events acting on the substrate of behavioral dispositions and fluctuating states. The relational power of such sequentially arranged response probabilities is indirectly observable in the same sense that the osmotic gradient along which a solvent moves across a semipermeable membrane that separates solutions of two concentrations is indirectly observable. By using a dye to track migration of solvent across the membrane, the osmotic gradient becomes observable. Similarly, the operant lever press linking food presentation and eating to drinking makes the response-probability relations observable in the schedule-regulated eating-drinking situation. The relative response strength relations created by temporally structured relative response probabilities are revealed by the operants linking successive lower and higher probability responses. Operant responses differ from the dye used to identify osmotic concentration gradients in that the operants are active components in the kinetics of behavioral syntax, whereas the dye is purely a tool revealing the basic mechanism underlying osmotic equilibrium. Formally specified reinforcement schedules are abstractions of naturally occurring environmental events and response-contingency relations regulating these kinetic processes and, as such, are useful in understanding behavioral syntax.

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