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State Notation for Teaching About Behavioral Procedures

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Complex operant procedures are not easy to describe unambiguously and several abstract notation systems have been developed for such description. Although they have not been generally adopted, such systems could be especially valuable to the teacher and student of behavior analysis, functioning like other figures and graphs as visual aids to ordinary verbal description. One of these systems, state notation, is described in some detail, and examples are provided of its use in teaching about behavior analysis.
Key words: schedules of reinforcement, state notation

Behavior analysis is primarily concerned with the effects of various environmental events (the independent variable) on the frequency, magnitude, latency, duration, and so forth, of different forms of behavior (the dependent variable). Respondent conditioning procedures usually consist of the occurrence of stimuli according to a prearranged temporal plan, with the organism's behavior having no effect on the procedure. Because such procedures consist of sequences of independent events, they can usually be described with a corresponding sequence of words or with simple diagrams that require no special training to understand.

Operant procedures, however, typically involve one or more response contingencies in which an environmental change is dependent upon some aspect of the organism's behavior. The independent variable cannot be described simply as a sequence of environmental changes taking place in time. This would not be a problem for students if there were only a few such procedures to be learned, but an important area of knowledge expansion is the discovery, investigation, and use of increasingly complex contingency relations in research and application. And even simple schedules of reinforcement are often described erroneously. For example, fixed-interval (FI) 30-s reinforcement is often referred to as providing reinforcement every 30 s (erroneously omitting the response requirement), requiring the organism to wait for 30 s (erroneously implying the necessity of not responding prior to the end of the 30-s period, and unclear about whether a response is required or not for reinforcement), providing reinforcement 30 s after the response (erroneously overlooking the immediate reinforcement in a fixed-interval procedure), and providing reinforcement for 30 s (complete confusion). Erroneous descriptions are even more likely when they are the correct descriptions of other commonly studied procedures, as with the first three examples above (fixed-time [FT] reinforcement, differential reinforcement of other behavior [DRO] or differential reinforcement of low-rate [DRL] behavior, and delayed reinforcement).

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Skinner (1957) identified an important aspect of scientific verbal behavior as follows:

> To dispose of irrelevant controlling relations [the scientific community] sets up new forms of response as arbitrary replacements for the lay vocabulary—not only the special vocabulary of science but graphs, models, tables, and other ways of "representing nature." . . . Representing an equation on Cartesian co-ordinates, constructing a three-dimensional model of a complex molecule, and setting a pointer on a dial are all verbal responses supplying scientific "readers" with "texts" which often correspond with their relevant stimuli in one or more dimensional systems. (p. 419)

Teaching about complex behavioral procedures would clearly be facilitated by something analogous to a graph or model or diagram that uses a two-dimensional system that corresponds with the relevant controlling variables. Several efforts have been made to develop such diagrams, and we will describe three of those systems in this paper. The state notation of Snapper, Kadden, and Inglis (1982) will then be presented in some detail, and in the process we will show how that system can be used to facilitate the teaching of complex contingency relations.

THREE APPROACHES TO DIAGRAMMING REINFORCEMENT SCHEDULES[1]

Skinner's Cumulative Record Diagrams

In 1958 Skinner described a system for diagramming some of the schedules defined in Ferster and Skinner (1957) using a graphic display based on the design of a cumulative record. The various schedule requirements are represented by lines of differing slopes, with a few special symbols used to depict such conditions as variable contingencies and time-out. Seven diagrams of this type are shown in Figure 1. Although the Skinner diagrams provide a picture of the general relation between behavior and consequence, they do not provide an unambigous representation of the details of a procedure. For example, there is no indication of how the different components of the multiple schedule shown in the figure are programmed. They could alternate, changing after each reinforcement; they could each be present for a fixed or variable period of time; they could alternate after a fixed or variable number of reinforcements on each; and so on. As far as we know, little use has been made of this system by others, although it seems to be useful for contrasting the basic schedules, and at the same time familiarizing students with the cumulative record.

The Mechner Notation System

Mechner (1959) proposed a notation system designed to represent the temporal and response relationships in most operant procedures and contingencies. The five basic symbols of the Mechner notation system are:

- R → "If R occurs then . . . ." Note that R never means that R *has* occurred, only the condition that *if* R occurs, it will produce a certain consequence.
- T → "At the end of time T . . . ." T can be shown as a specific time, such as 30 s.
- S The onset of a stimulus condition, which then prevails until replaced by another stimulus condition. (Note that the basic symbols of the system do not permit an arrow ever to lead away from a stimulus. In Mechner notation there is *no* occurrence of the traditional S → R notation indicating that a stimulus causes a response. The same is true of state notation described later.)
- [A bracket to indicate that the conditions listed vertically within the bracket start simultaneously.

[1] The reader more interested in learning about the use of diagramming in teaching may skip to the section entitled State Notation for Instructional Purposes.

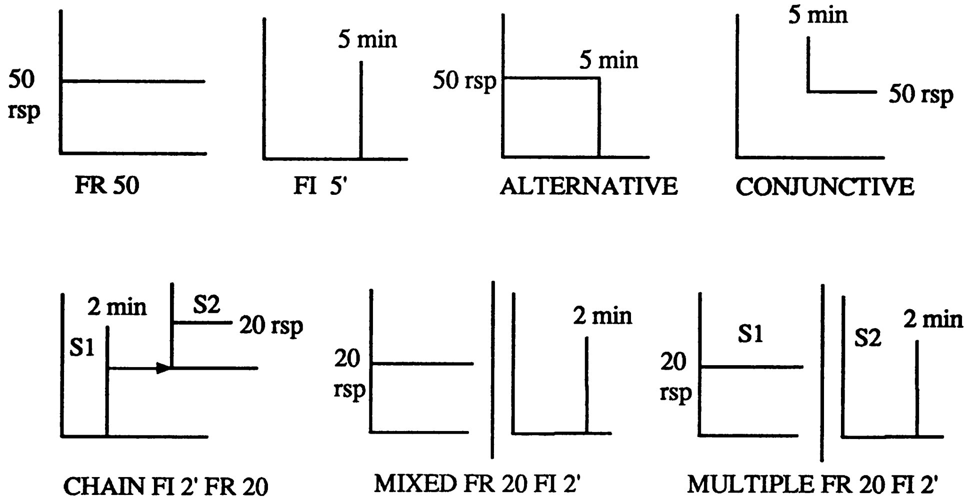


Figure 1. Skinner's schedule diagrams: The requirements can be understood by noting where the organism has to drive the cumulative record to be reinforced.

⇟ A vertical terminating arrow, which prevents the consequence of any horizontal arrow it cuts.

When a diagram shows more than one type of response, stimulus, or time interval, subscripts can be used to distinguish them. Various symbols can be imported and used as adjectives (e.g., N for the number of responses, vN for a variable number, + and − signs to show whether a stimulus is reinforcing or aversive, vT for a variable-time interval, ⇸ to show that the produced event has a probability of less than one, logical union or intersection symbols (∩ or ∪) to show that either or both Rs are required, and others.

Figure 2 shows Mechner diagrams of the FI schedule and four of the time-based procedures discussed earlier that are often confused with it. They are arranged vertically as a way of emphasizing key similarities and differences.

With a surprisingly small set of symbols, Mechner's system can represent the essential features of most complex contingencies or schedules; the components of the diagrams correspond with the relevant controlling relations in a two-dimensional system, much as in an electrical circuit diagram. Such diagrams, like graphs showing quantitative relations, control the viewer's behavior with respect to the relevant components much more effectively than an ordinary verbal description.

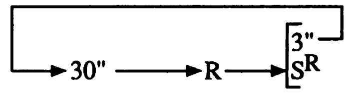
Although he advocated the use of such a notation system in teaching, Mechner's main audience was the community of researchers and scholars in the experimental analysis of behavior. He suggested that a notation system would not only facilitate communication among such scholars, but could serve

> as a catalyst for the development of theory in providing a framework within which existing knowledge could be systematized. . . . By presenting a set of intricate interrelations in a concise and schematic form, a diagrammatic or symbolic notation can often lay bare the essential structural features of these interrelations, thereby facilitating their analysis. (Mechner, 1959, p. 133)

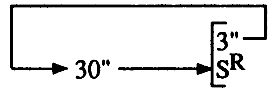
One of us (Michael) began to use the Mechner notation system at Arizona State University around 1961 in both undergraduate and graduate courses. In 1963 a program for teaching Mechner notation was privately distributed by V. Mechner. In the same year a laboratory manual (Michael, 1963) for an introductory behavior analysis course was published that used Mechner notation to describe the experiments.

In spite of obvious advantages, the Mechner notation system has not been

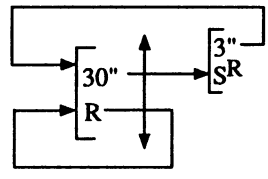
A. FI 30" (fixed interval 30").



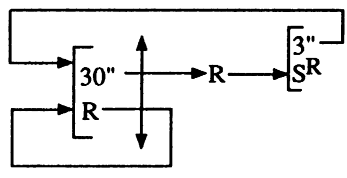
B. FT 30" (fixed time 30").



C. DRO 30" (differential reinforcement of other behavior, or more accurately non R > 30")



D. DRL 30" (differential reinforcement of low rate, or more accurately, IRT > 30", or interresponse time greater than 30"



E. 30" Delayed Reinforcement

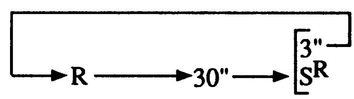


Figure 2. Mechner diagrams of five procedures involving a 30-s time period.

widely adopted within the behavior analysis community. An article on the contingency as an independent variable in social relations (Weingarten & Mechner, 1966) made extensive use of the notation system, and a form of it was also used in the first edition of Millenson's *Principles of Behavior Analysis* (1967). An application of the Mechner notation was made by Mawhinney in a paper presented at the 1991 meeting of the Association for Behavior Analysis, and it is used throughout the recently published text on behavior analysis by Pierce and Epling (1995). The editors of the *Journal of the Experimental Analysis of Behavior* and experimenters who publish in that journal have shown little interest in it, and few Mechner diagrams have appeared in print. It is used by a few college teachers in the U.S., Canada, and Brazil.

The State Notation of Snapper and His Colleagues

A notation system somewhat like Mechner's and a computer program for behavioral experiments were described in a paper presented at a meeting of the Digital Equipment Computer Users Society in 1967 (Snapper, Kadden, Knapp, & Kushner) and at the annual convention of the American Psychological Association (Snapper, Knapp, & Kushner, 1967). The notation was also mentioned in Kushner, Knapp and Snapper's (1967) report on the construction of a special-purpose computer that could program most reinforcement schedules. In a research paper published in the *Journal of the Experimental Analysis of Behavior* in 1969, Snapper, Ramsay, and Schoenfeld used their notation system to describe the procedure.

In the first extensive written description of state notation (Snapper, Knapp, & Kushner, 1970), the notational language is described as

> based upon the theory of finite automata (Mealy, 1955; Moore, 1956), a generalized mathematical model of sequential systems of which reinforcement schedules are one example. The major advantage of the model is that the structure of its notational language has received rigorous mathematical treatment, resulting in a fully developed language capable of consistently and completely describing the infrastructure of schedules of reinforcement. (p. 259)

As Mechner (1959) had done with his system, Snapper et al. showed that theirs could be used to characterize a wide variety of different behavioral procedures. Mechner had further suggested that a good notational system could "implement the discovery of formal parallels between behavioral procedures, and generally suggest schemes for their classification" (p. 133). Snapper et al. provided an impressive demonstration of this possibility by presenting state diagrams of 12 common procedures and a generalized diagram representing each of these schedules by specification of various parameters.

In 1971 Snapper and Kadden contributed a chapter to a book on the use of digital computers in the behavioral laboratory, in which they described a time-sharing computer usage based on their state notation system. Finally, in 1982 Snapper et al. published a detailed treatment of state notation for use with the SKED® and SUPER SKED® software for programming behavioral experiments on a Digital Equipment Corporation (DEC) minicomputer.

The programming language of Snapper et al. (SKED®, SUPER SKED®, and SKED 11®) for DEC minicomputers and a modification of it for IBM microcomputers (and clones) are widely used by behavioral researchers, but most of these researchers do not use the state notation system itself. When Snapper and his colleagues developed state notation and the associated computer language, they saw the preparation of an accurate state diagram as an important first step. (Such first steps are currently referred to as *pseudocode* and often play an important role in the early stages of computer program development.) The state diagram would then be converted to a listing of the instructions to the computer (called a *state table*), which when keyed into the computer functions as the actual instructions for managing the experiment and recording the resulting data. But researchers can also go directly to the preparation of the state table, especially if they are already familiar with the use of a programming language like FORTRAN, and would not have to bother learning how to diagram their procedures in state notation. This is apparently what most researchers did and now do.

Like the Mechner system, state notation seems to have obvious advantages over verbal descriptions for the researcher and theory developer, but we believe its main value is for teaching about behavior analysis. Until now, however, little such usage has occurred. Several reasons can be suggested. The various descriptions of state notation have not been available in ordinary journal sources; the most extensive published treatment (Snapper et al., 1982) was aimed at the use of a microcomputer in basic research and contained too much programming detail to maintain the interest of the ordinary reader. Probably the major deterrents, however, are that the teacher would have to learn state notation for the special purpose of incorporating it into an instructional system, and then students would presumably have to spend a moderate amount of time learning the notation system before they could use it in learning about behavioral procedures. For many teaching situations, the use that would be made of the notation might not seem to justify the time teachers and students would have to invest. A further difficulty was that such diagrams could not be produced on a typewriter or word processor and had to be drawn and then added to a manuscript as figures.

Fortunately, none of these deterrents are really relevant to the current use of state notation in teaching. Most of the complexities that make the 1982 paper difficult can be omitted if state notation is to be used solely as an aid to ordinary instruction. For use in an introductory behavior analysis course, the state diagrams can be considered similar to other types of figures or graphs. The student is not expected to make such figures, but only to react to them as a supplement to ordinary verbal material being presented in lecture or in a text. The interpretive skill necessary for this type of passive use can be acquired without much deliberate instruction, simply by the instructor's gradual introduction of such material in his or her lecture or written presentations. Examples of this type of instructional activity will be given in the next section. Of course, the instructor has to have more than a passive knowledge of state notation, but a manual (Michael, 1988) describing a simplified version is available for reference, as is a programmed text (Shafer, 1988) that teaches how to draw state diagrams as well as read them, and takes no more than 5 hr to complete.[2] And if it is important for students to actually diagram complex procedures on their own, they can quickly acquire the necessary skill from the same manual and instructional program. As for producing the diagrams, they can now be easily prepared on a computer, as were the figures for this paper, with any object-oriented drawing program, such as Canvas® for the Macintosh or Visio® for Windows.

STATE NOTATION FOR INSTRUCTIONAL PURPOSES

State notation has been used in a junior level course in behavior analysis at Western Michigan University (Psychology 360, Concepts and Principles of Behavior Analysis) for the last 7 years. It is used to describe basic behavioral procedures during lectures, and in supplementary written material prepared by the instructor. It is also used to explain the procedures used by the students in the laboratory part of the course. State notation has also been used in graduate courses, where it plays the same role as in the undergraduate course; in addition, the students prepare state diagrams of the experimental procedures they are reading about in the *Journal of the Experimental Analysis of Behavior.* In what follows we will briefly describe the elements of state notation as we have used it in teaching, and then illustrate this use by describing and diagramming two respondent and several operant procedures.

Basic Elements of State Notation

A state—a static condition of the environment, defined in terms of the way it can be changed and the nature of the possible changes—is represented by a small circle with a number inside it. A set of states connected by transition lines (arrows) is called a state set. There are four kinds of input vari-

[2] The manual and the program of instruction are available from Jack Michael, Psychology Department, Western Michigan University, Kalamazoo, MI 49008. The price for each will be approximately $3.00 plus shipping. Both are currently being revised, so the exact price (based on the number of pages) is not currently available. Requests may also be made by E-mail (jack.michael@wmich.edu).

ables,[3] or events responsible for changing the environment: (a) START for beginning a procedure; (b) T for time; (c) R for a response contingency (R never appears except with a transition or reentry arrow); and (d) Z for an abstract input (described later). There are five ways that the environment can change, called output variables: (a) state transitions; (b) state reentries (both transitions and reentries are symbolized with arrows); (c) the onset and offset of stimuli (ON S, and OFF S), a special case of which is the onset and offset of reinforcement (ON S^R and OFF S^R)[4]; (d) Z for an abstract output (which functions as an abstract input in another place in the state diagram, as will be described later); and (e) STOP, an output that terminates a session or inactivates all state sets. Sometimes a transition is conditional, in which case the transition arrow goes into a decision diamond, with the nature of the conditionality (WITH $P = n$ and IF) shown in the diamond (described later). The symbols for input events are placed on a transition arrow and separated from output symbols by a colon. In looking at the state diagrams shown below, it is very important to realize and to keep in mind that the arrows leading *into* a circle are not inputs to that state; the inputs to a state are the symbols to the left of the colon on an arrow leading *away from* that state.

Respondent Procedures

Figure 3 shows a state diagram for a short-delay respondent conditioning procedure. In most respondent procedures[5] the only input variables are START and time passage, symbolized by T or by an actual time value as in Figure 3. START is an experimenter-produced input that starts a session or a procedure. It shows what state is in effect when a procedure begins, and is important when some particular stimulus is turned on at the beginning of a procedure or when multiple state sets must be synchronized. It can generally be omitted if the diagrammer's purpose is to describe the essential features of a repetitive procedure that would be the same irrespective of where it started. Two of the five output events are shown in Figure 3, state transitions (symbolized with arrows leading from a state to another state) and stimulus onsets and offsets (ON S and OFF S). When a change from one state to another occurs, the change is assumed to be instantaneous; when a state is entered, any timing or counting devices associated with that state are assumed to be reset to their starting value. A transition arrow must always have a symbol for an input variable on it. It is itself an output and must be caused by an input of some sort (START, R, T, or Z).

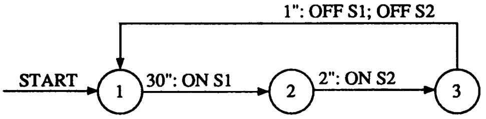


Figure 3. A short-delay respondent conditioning procedure.

Only one state in a state set can be in effect at the same time, and once a procedure is running, one is always in effect. In State 1 of the procedure shown in Figure 3, a 30-s timer begins timing as soon as the state is entered. The timing out of this timer is the input to State 1, and causes two outputs, a

[3] The terms *input* and *output* come from the use of a computer as a process control system, and unfortunately their everyday meanings are not very helpful in the present context.

[4] The occurrence of such symbols as S^R, CS, and US, which imply behavioral effects, is actually inappropriate for a notation that represents only the environment. When presenting behavioral procedures in an introductory context, however, the identification of a stimulus change in terms of the function *intended* by the experimenter or behavior-change agent seems to make for ease of understanding.

[5] State diagrams are not much of an improvement over ordinary ways of describing respondent procedures, but they are easy to diagram, and are sometimes a part of a procedure with both respondent and operant components, such as the conditioned emotional response described near the end of the paper.

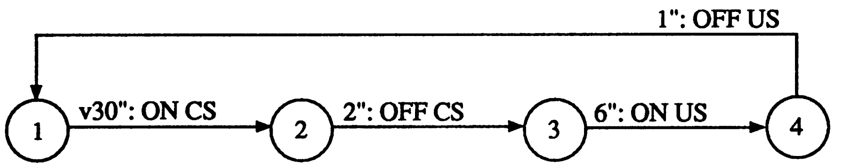


Figure 4. A trace conditioning procedure.

transition to State 2 and the onset of S1 (Stimulus 1). (To avoid confusion, the word *state* is not abbreviated as S, but rather is spelled out as above; S1, S2, etc., refer to stimulus conditions, not states.) The nature of S1 could be indicated in accompanying text (S1 = 500 Hz tone), or if no confusion will result S1 can be replaced by a brief description such as "tone" or "CS" (conditioned stimulus).

When State 2 is entered a 2-s timer begins, and its timing out causes a transition to State 3 and the onset of S2. In this case S2 would be an unconditioned stimulus of some sort, such as a squirt of meat powder into a dog's mouth, and S2 could be replaced by "meat powder" or "US" (unconditioned stimulus). When a stimulus is turned on, it stays on until it is turned off. Thus S2 is turned on when State 3 is entered, and S1, which was turned on earlier in the procedure, is still on. When State 3 is entered a 1-s timer begins, and its timing out causes a transition (back) to State 1 and the offset of both S1 and S2.

Note that input variables appear to the left of a colon and outputs to the right of a colon. When there are two or more outputs in addition to the transition, the outputs are separated by a semicolon (as shown in Figure 3 with respect to State 3). Also note that although the response to the unconditioned and the conditioned stimulus is a very important aspect of any conceptualization of respondent conditioning, no symbol for responses appears anywhere on the state diagram. Said another way, the organism's responding ordinarily has no effect on the *execution* of a respondent conditioning procedure, which is a fundamental contrast with operant procedures that involve a response contingency (R plus a transition or reentry) of some sort.

The trace conditioning procedure shown in Figure 4 illustrates how the actual stimulus condition during a given state can be determined by keeping track of stimulus onsets and offsets. Study the diagram and try to determine what stimuli are on during each state.[6] Some users of state notation try to make the diagrams easier to understand by writing stimulus conditions inside the circles, but this ultimately causes more confusion than it eliminates. Also illustrated in Figure 4 is the use of the lower case v to indicate a variable time period as input to State 1. The notation v30″ in the figure refers to a set of time periods with an average value of 30 s.

Operant Procedures

Simple schedules of reinforcement. Now let us consider a third input variable, the response contingency. (T and START were the other two input variables considered so far.) When the environment can be changed in some significant way by the organism's behavior, this is indicated by an R on the relevant transition arrow. Different types of responses are indicated as R1, R2, and so forth. When more than one response of a given type is necessary to change the environment, the number requirement appears to the left of the R symbol, thus 50R, or abstractly nR. At this point, it is important to reassert that state notation only describes the *independent variable*—the environment and how and when it changes. R

[6] State 1, no stimuli are on; State 2, CS is on; State 3, no stimuli are on; State 4, US is on.

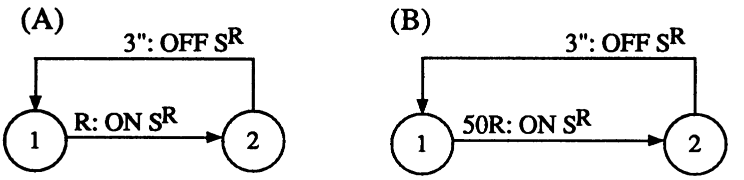


Figure 5. (A) CRF (continuous reinforcement); (B) FR 50.

does *not* indicate that a response occurs, but only what will happen *if* a response occurs. R is a way of indicating a response contingency, *not* the occurrence of a response. Said another way, in state notation R is a symbol for an independent rather than a dependent variable.

Response contingencies often involve a reinforcement operation, of which there are two main types: making something available to the organism for a fixed period of time (as with a typical pigeon grain feeder) and delivering something into the organism's presence and leaving it there (as with a rat pellet feeder). Common examples for humans are showing a cartoon or playing music for a fixed period of time and delivering a token or incrementing a counter showing the monetary units that will be provided later. Notation for the first kind of reinforcement is straightforward, and for the second kind a reasonable convention is to show the duration of the reinforcement operation as a very short period, for example 0.03 s, implying only the time necessary to operate a delivery mechanism.

Figure 5 shows a continuous reinforcement (CRF) and a fixed-ratio (FR) 50 procedure. Assume a pigeon as experimental subject, a key peck as the relevant response, and 3-s exposure to grain as reinforcement (a grain container rises up where the pigeon can peck in it, stays in that position for 3 s, then goes back down where it is inaccessible). The input 50R should be read "when the 50th response occurs a transition is made to State 2 and S^R is turned on." For variable ratio a lower case v is inserted before the number requirement, thus v50R, which refers to a set of number requirements with the average being 50.

A discrimination training procedure is shown as Figure 6A, and a closely related two-response chain is shown as Figure 6B; both are patterned after common student laboratory exercises. In the first procedure, after a variable time period with an average duration of 30 s, a light is turned on, and in the presence of the light a response produces reinforcement, which in this case is a pellet dropped into the feeder cup in the animal's chamber (as indicated by the 0.03-s duration of State 3). In the second procedure, a chain pull turns on the light, and in the presence of the light a lever press causes the pellet to be delivered.

As discussed in connection with the Mechner notation system, a number of procedures involving temporal relations are commonly confused with each other, but become quite distinguishable when represented in notation

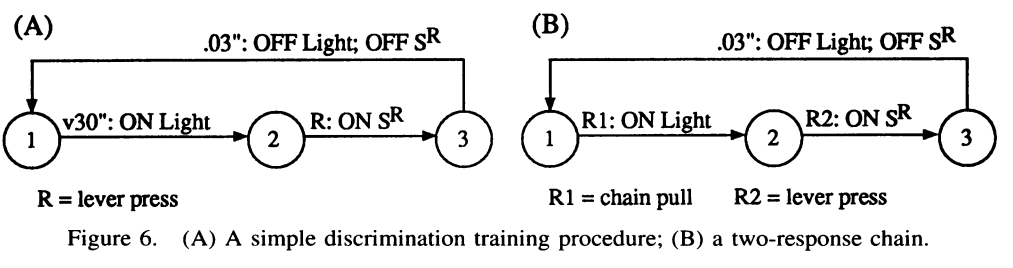


Figure 6. (A) A simple discrimination training procedure; (B) a two-response chain.

A. FI 30" (fixed interval 30").

B. FT 30" (fixed time 30").

C. DRO 30" (differential reinforcement of other behavior, or more accurately, non R >30".

D. DRL 30" (differential reinforcement of low rate, or more accurately, IRT > 30", or interresponse time greater than 30")

E. 30" Delayed Reinforcement

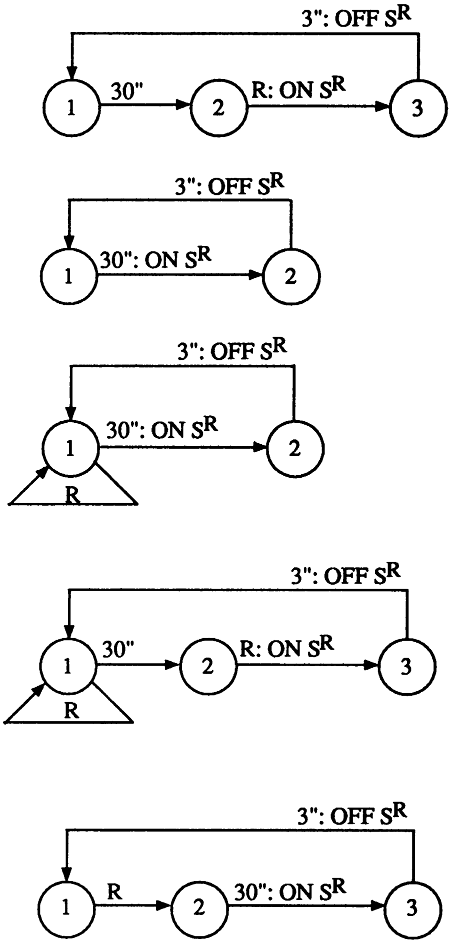


Figure 7. State diagrams of five procedures involving a 30-s time period.

form. Figure 7 shows the same five procedures involving temporal relations that were shown in Mechner notation in Figure 2. The procedures are arranged vertically as a way of emphasizing key similarities and differences. An instructor can make a number of useful points about behavioral contingencies by referring to such a set of diagrams. Fixed-time (FT) reinforcement (Figure 7B) is included in this set of procedures because beginning students often erroneously describe it when asked for a description of fixed-interval reinforcement (Figure 7A). A close comparison of the two state diagrams may decrease the frequency of this type of error. Fixed time is also the procedure used by Skinner (1948) to demonstrate "superstition" in the pigeon, a topic often discussed in introductory behavior analysis courses.

The DRO and DRL procedures (Figures 7C and 7D) illustrate another of the five output variables, state reentry or reset. (The other two considered so far are the state transition and ON or OFF S.) In both procedures there are two inputs to State 1, R (response) and T (in this case 30 s), and whichever occurs first causes its transition and outputs. Because timers and counters associated with a state are set to zero when the state is entered or reentered, the effect of R in State 1 is to reset the 30-s timer. State 1 in both procedures lasts until 30 s passes with no response, at which time reinforcement is provided in DRO and response-contingent reinforcement becomes available in DRL. A comparison of FT 30 s (Figure 7B) with DRO 30 s (Figure 7C) makes it clear that the latter is essentially FT reinforcement so long as the relevant response does not occur. DRO is a way to use reinforcement to decrease the frequency of the relevant response, and is a behavior-change procedure often used in applied work. DRO is often confused with DRL, but the diagrams make the difference quite clear. Similarly, a comparison of FI 30 s (Figure 7A) with DRL 30 s (Figure 7D) shows that they are the same so long as the relevant response does not occur in State 1 of the DRL procedure. Two instructive analogies regarding these temporal schedules can be made while referring to the state diagrams: FT is to DRO as FI is to DRL, and FT is to FI as DRO is to DRL. It seems to sharpen students' understanding of these contingencies when they have to work out the bases for the analogies, and the state diagrams help in this process.

When referring to these temporal contingencies, students have a fairly strong tendency to say that "the organism has to wait 30 s for reinforcement." Delayed reinforcement (Figure 7D) is included in this set of procedures to add one more possible interpretation of this type of statement and thus emphasize the fact that everyday language about behavior is not generally precise enough for technical or scientific description of behavior. Students can be asked which of the five procedures in Figure 7 is the true meaning of "has to wait 30 s for reinforcement," and there will be no general agreement.

Compound schedules. Four compound schedules of reinforcement are shown in Figure 8. They are arranged vertically so as to facilitate comparisons, and the mixed and multiple schedules alternate after reinforcement so as to be more similar to the tandem and chained schedules. (Some of the outputs are stacked so that the diagram will fit on a single page.) Again there are two useful analogies for the student to work over while looking at the diagrams: tandem is to mixed as chain is to multiple, and tandem is to chain as mixed is to multiple.

Escape and avoidance. State diagrams are also useful in teaching about escape and avoidance contingencies. Figure 9 shows two escape procedures, the common one without an S^D, and escape with an S^D. This latter procedure (Figure 9B) is a *thought experiment,* not an actual laboratory procedure, but is shown to clarify the status of the shock with respect to the escape response. In distinguishing between motivative and discriminative variables, it is important not to conceptualize the shock in an escape procedure as an S^D for the escape response (Michael, 1993). Escape with an S^D provides a true S^D situation with which to contrast the ordinary escape procedure, in which the shock should be considered to be an establishing operation rather than an S^D. Students' understanding of this issue can be aided by pointing out the similarity of escape without an S^D (Figure 9A) to the CRF procedure of Figure 5A. In both cases the only controlling variable is the relevant establishing operation (food deprivation assumed in Figure 5A and shock in Figure 9A). The role of the light in a basic discrimination procedure (Figure 6A) and the tone in the escape procedure with an S^D (Figure 9B) can then be contrasted with that of food deprivation and shock in the other two procedures.

The difference between discriminative avoidance/escape (Figure 10A) and nondiscriminative avoidance (Figure 10B) can be easily seen with state diagrams, where there is clearly no stimulus in the diagram of Figure 10B analogous to the tone in Figure 10A. State diagrams can also be used to address the problem of defining avoidance extinction. If the extinction procedure consists in response occurrence without reinforcement, and if the rein-

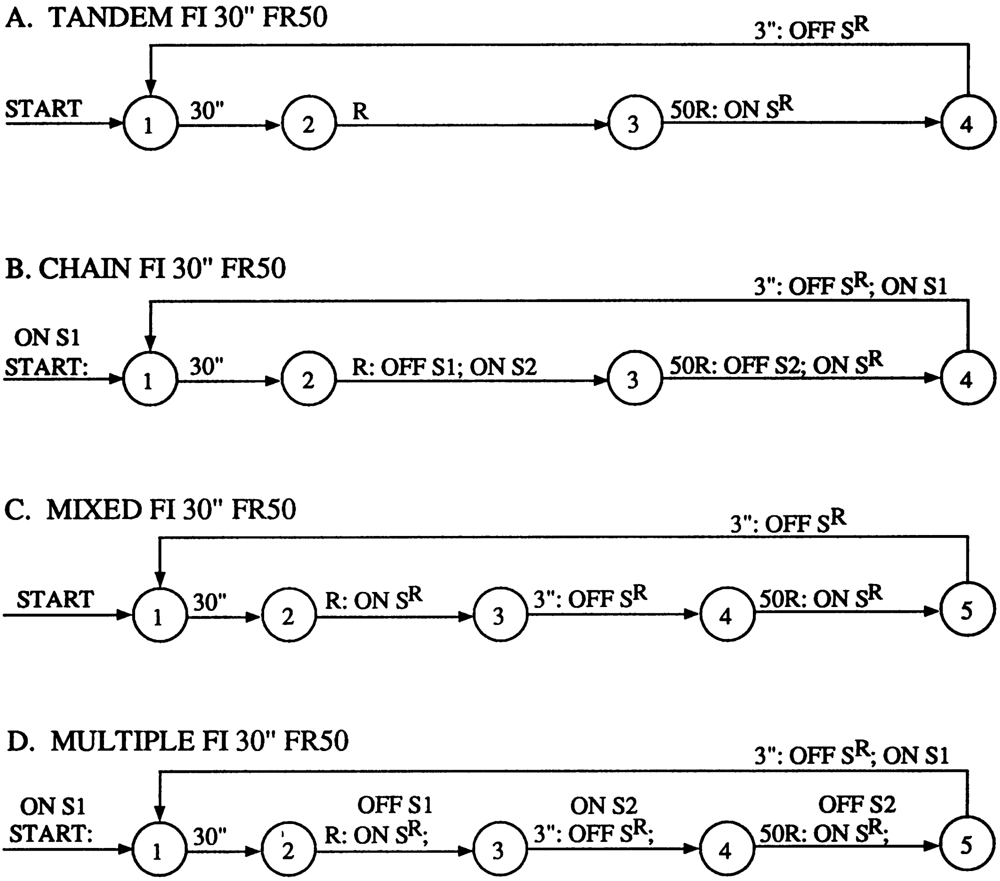


Figure 8. Tandem FI 30 s FR 50, chain FI 30 s FR 50, mixed FI 30 s FR 50, and multiple FI 30 s FR 50.

forcement of the avoidance response is the termination of the warning stimulus, then true extinction of avoidance consists in changing the procedure shown in Figure 10A into the one shown in Figure 10C, abolishing the transition back to State 1 that was produced by R.[7] The shock then occurs as usual at the end of the 5-s tone period. It seems to be a misuse of terminology to refer to eliminating the shock output from State 2 and making a transition back to State 1 at the end of the 5-s tone period (as shown in Figure 10D) as extinguishing the avoidance response, although that procedure will also lead to a weakening of the avoidance response. One can also weaken the avoidance response by allowing R to terminate the tone but giving the shock as usual when the 5-s period ends, whether or not the tone was terminated. (This can only be diagrammed with parallel state sets, and is not shown in the figures.) It is often said that avoidance behavior extinguishes very slowly, but what is usually referred to is not true extinction, as described above, but rather weak-

[7] It may seem to be excessive concern for terminological precision to insist on defining operant extinction as occurrence of the response without its reinforcement, but to use the same term for quite different weakening procedures is ultimately a source of confusion. Although the weakening effect may seem similar, there is clearly a *procedural* difference of some significance between not producing a consequence and continuing to produce it but with its reinforcing effectiveness steadily decreasing.

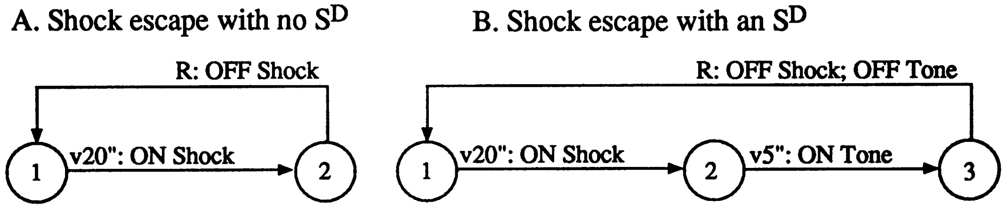


Figure 9. (a) Ordinary shock escape; (B) escape with an S^D.

ening the avoidance response by no longer providing the shock. Davenport and Olson (1968) showed that true extinction led to a quick and orderly decrease in the frequency of the avoidance response.

Random ratio and random interval. Four important features of state notation have not yet been described: the Z input and Z output, and the two types of decision function, WITH $P = n$, and IF. The WITH $P = n$ function is simpler than the others, and can be illustrated by describing two very common laboratory procedures in human and nonhuman research, the random-interval (RI) and random-ratio (RR) schedules shown in Figure 11. WITH $P = n$

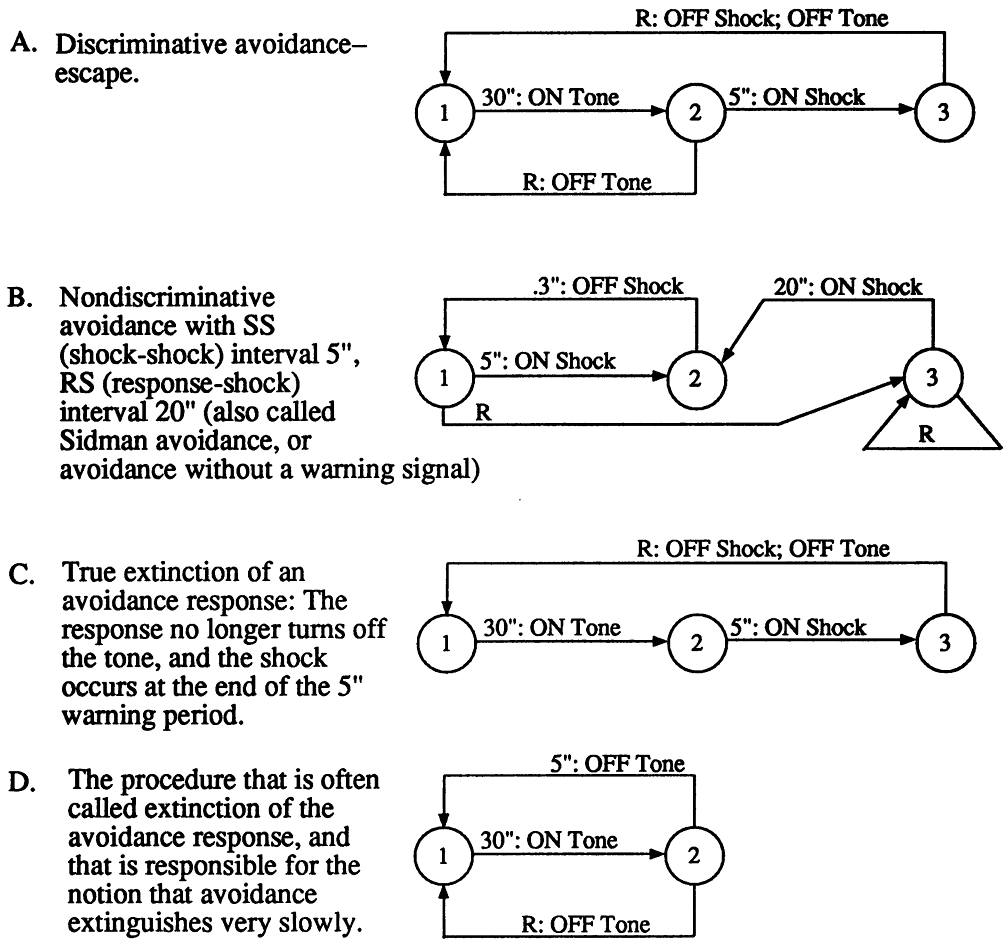


Figure 10. Avoidance procedures.

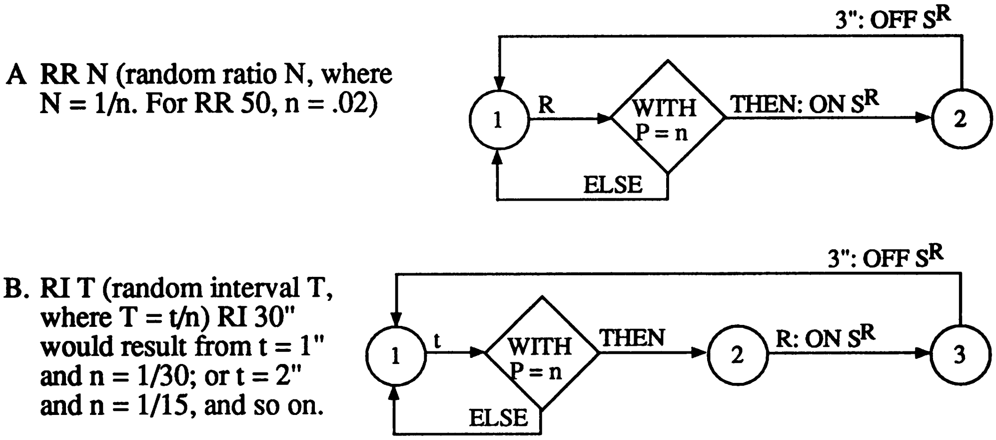


Figure 11. (A) Random-ratio reinforcement; (B) random-interval reinforcement.

appears inside the decision diamond, and n is typically replaced by an actual probability value; thus, WITH $P = .2$, which means that on an average of 2 times out of 10 the transition arrow leaving the diamond with THEN written on it will prevail, but on an average of 8 times out of 10 ($P = 1 - n$) the transition arrow with ELSE written on it will prevail. Which transition occurs on any particular occurrence of the relevant input variable is usually determined by some sort of electronic randomizing device analogous to spinning a roulette wheel.

With random ratio (Figure 11A) each response produces a transition into the decision diamond, and whether THEN or ELSE prevails is determined by the probability value programmed by the researcher and by chance. As with all transitions, the transition through the decision function is considered to be instantaneous. RR 50 is like VR 50 with one important difference; with VR 50 the way it is usually programmed, the actual and the programmed probability values will be exactly equal for every complete cycle through the set of number requirements that are being used, but with RR 50 the actual probability may vary considerably from the programmed value in the same way that the proportion of heads resulting from tossing a coin may vary considerably from .5. Like a gambler, the organism can have a run of bad luck or good luck, either of which could have a strong effect on the ongoing behavior.

The random-interval procedure (Figure 11B) involves a timing as well as a probability device. The t input to State 1 produces a transition through the decision diamond to State 2, but only on a probabilistic basis. The average temporal value upon which reinforcement for a response depends, T, is a combination of the values of t and P. For example, if t is 1 s and P is 1/30, a transition to State 2 will occur on the average every 30 s, as would also occur if t is 2 s and P is 1/15. The behavioral effects of RI schedules with the same T but with different t and P values will by no means be the same. Note that if t is 30 s and P is 1, the schedule is simply FI 30 s; if t is 15 s and P is .5, the schedule will be a sort of mixed FI 15 s FI 30 s FI 45 s and so forth, with the frequency of the FI values in the mix declining as the time interval becomes larger. Random interval has the same relation to variable interval that random ratio does to variable ratio, namely that the actual and programmed average interval may vary considerably, simply as a function of chance.

Parallel state sets. The procedures described so far can all be represented by a single state set, but some require

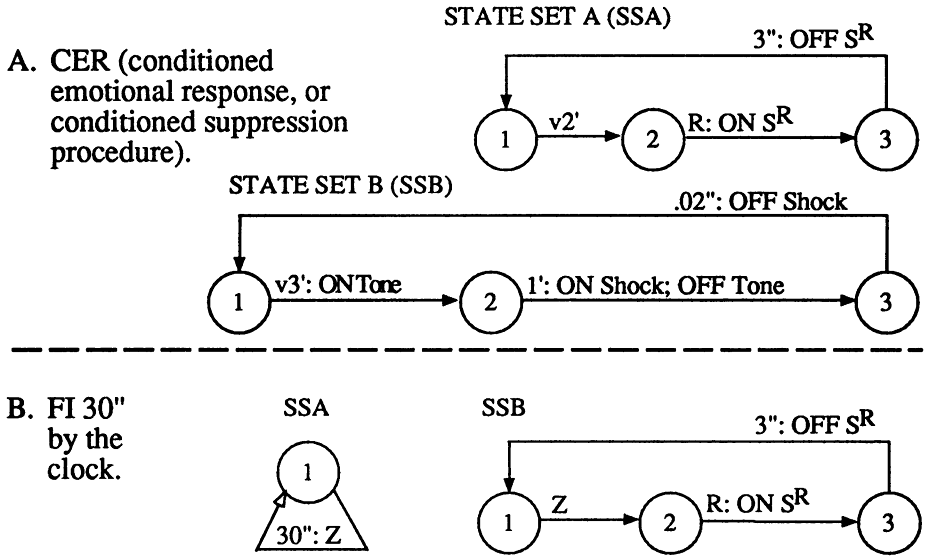


Figure 12. Two procedures requiring parallel state sets.

parallel state sets, which are either completely independent or interact with each other. Figure 12A shows a conditioned emotional response (CER) procedure similar to that of Estes and Skinner (1941) which consists of two independent state sets. Lever pressing is maintained by a VI 2-min schedule of water reinforcement. Independently, on a VT 3-min schedule, a tone is turned on for 1 min and at the end of the minute a brief shock is administered through the floor grid. The result of this type of procedure is that the rat presses steadily until the tone comes on, then stops or slows down considerably until the shock, then starts pressing again. The two state sets are completely independent, in that lever pressing has no effect on the onset of the tone or the shock; the availability of food for a lever press is not related in any way to the state that is in effect in the tone–shock state set.

When state sets are not independent, there are two means of interaction; Z pulse outputs in one state set function as inputs in another state set; and transitions in one state set depend on the state that is in effect in another state set, the IF decision function. Interacting state sets are necessary for describing many complex procedures, but are sometimes required in what seem intuitively to be quite simple ones. The use of Z pulses will be illustrated with a schedule that is closely related to the familiar fixed-interval reinforcement, FI *by the clock.*

In FI 30 s by the clock (Figure 12B), State Set A has only one state, in which a Z pulse is produced as an output every 30 s irrespective of the organism's behavior. In State Set B, a Z pulse (the one produced in State Set A) functions as an input to State 1 in causing a transition to State 2, where the next response causes delivery of a 3 s exposure to reinforcement. (In the particular procedure shown, Z pulses produced in State Set A after the transition to State 2 has occurred in State Set B have no effect, i.e., they do not set up additional reinforcement opportunities; sometimes in FI by the clock such additional opportunities are *stored* and the organism may then be reinforced more than once in a brief period.) Performance on FI by the clock is ultimately very similar to that on an ordinary FI schedule of reinforcement, but with FI by the clock the timing interval is not affected by the organism's behavior, whereas with ordinary FI the

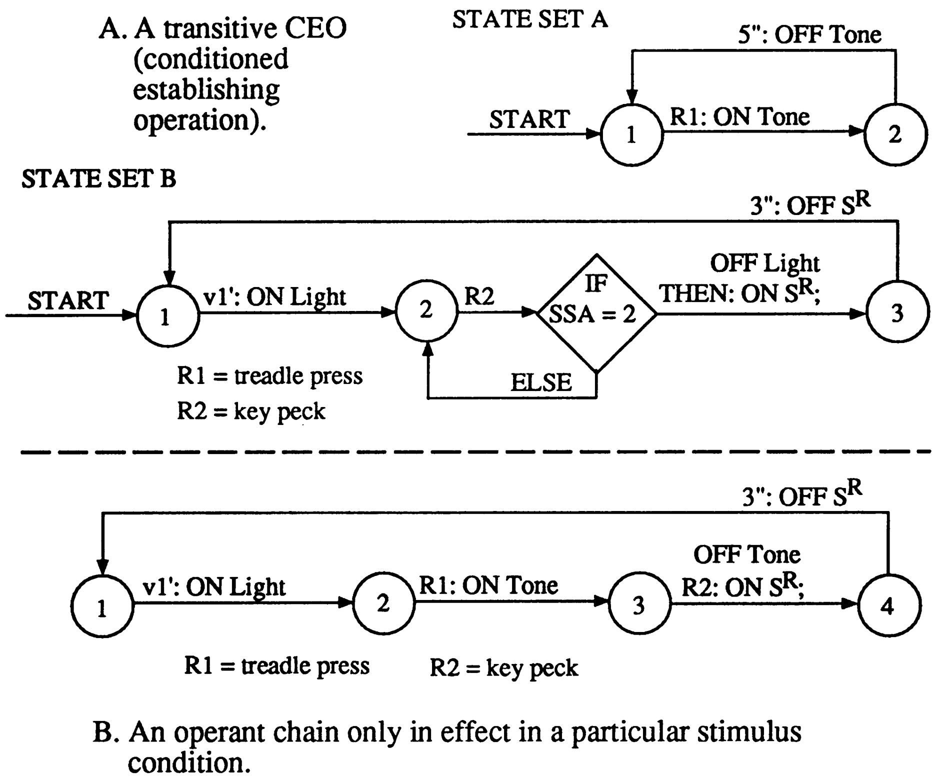


Figure 13. (A) A transitive CEO requiring parallel state sets and the IF function; (B) an operant chain in effect only in a particular stimulus condition.

timer stops when reinforcement is set up (when State 2 is entered). Such a subtle distinction may be of little significance in this particular case, but distinctions like this are easily overlooked when ordinary verbal descriptions are relied on, and are easily identified when state notation is used.

To illustrate the IF decision function, which is the other way that parallel sets interact, a procedure referred to by Michael (1993) as a transitive conditioned establishing operation (CEO) will be described (see Figure 13A). This is a procedure that has been used to define a form of learned motivative variable or conditioned establishing operation. In State Set A a treadle press (a pigeon is the subject) will turn on a tone that stays on for 5 s and then goes off. This contingency is unaffected by any events in State Set B, where on a variable-time basis a light comes on, and when it is on, IF the tone in State Set A is on, THEN a key peck will be reinforced. Although the treadle press will provide 5 s of tone at any time, the tone is an occasion for successful key pecking only when the light is on. The conceptual significance of the procedure concerns the role of the light onset in evoking the treadle press. In the simpler chain shown as Figure 13B, the treadle press will not turn on the tone unless the light is on, and once the tone is on, the key peck will be reinforced. The light is clearly an S^D for the treadle press, in that treadle pressing can achieve its (conditioned) reinforcement, the tone onset, only in the presence of the light. In the CEO procedure, however, the treadle press can produce the tone at any time, but the tone is effective as (conditioned) reinforcement only in the presence of the light. It is then argued that the light onset evokes the treadle press, not as an S^D but rather as an establishing operation, an operation that makes the tone valuable as a form of conditioned reinforcement, not a condition in the presence of which the tone is differentially available (Michael, 1993). A careful study of the state diagrams reveals the differences between the two procedures. The EO status of the light in the procedure shown in Figure 13A may still be contested, but at least not because it is misconstrued as the procedure of Figure 13B.

CONCLUSIONS

We have described and illustrated with relatively simple examples the main features of state notation. For introductory coverage, state diagrams are very effective supplements to verbal descriptions. We have also found them to be useful in examinations, where questions about procedures and concepts are made less ambiguous by an accompanying state diagram, or where the student modifies a diagram in such a way as to demonstrate understanding of a procedure or concept. The real power of state notation, however, can be seen when state diagrams are used to teach more complex procedures such as concurrent chains, matching to sample, observing responses, and procedures that are unique to particular experiments. State notation is also valuable in the less formal but critically important instruction that occurs when helping individual students with projects, theses, dissertations, and so forth.

Our description of state notation has most often been in the context of clarifying and distinguishing among laboratory procedures related to basic principles of behavior. But it would be a mistake to conclude that the value of accurate representation of environmental details is limited to this context. Such details are also important determiners of everyday human behavior, and of the kind of behavior that is the subject matter of applied behavior analysis.

It is likely that the main value of state notation at present is to the teachers and students of behavior analysis. It is a highly consistent and powerful device for unambiguously representing simple and complex behavioral procedures, and it is easily learned. Even though state notation is not currently used in communications among researchers and theoreticians, we believe that it would facilitate their research and theory and make their work more accessible to teachers and students.

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