Digital data acquisition systems for observing behavior in laboratory and field settings*

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Electronic digital systems for recording behavior and for record keeping in hospital, clinical, laboratory, and field settings are now available from commercial sources. Behavioral events, occurring in real time, are coded by an observer who pushes buttons on an adding machine-type keyboard. Information is stored electronically on a cassette or other type of magnetic tape recorder. Tapes can be played, through appropriate interfaces, into a computer, keypunch, Teletype punch, or digital printer. Code frequencies, sequences, real-time durations, and modified frequency time-sample scores can be extracted from these records by hand or by computer. This paper describes such systems, detailing methods of coding behavioral events and problems encountered in the use of digital observational systems.

Human observers have traditionally employed paper-and-pencil methods to record the observed occurrences of arbitrarily chosen behavior categories on a time-sampled basis. Such methods generally do not yield information about response durations and behavioral sequences. Other techniques use clocks and counters to record total frequencies and durations of selected responses; and a few methods yield records of the occurrence, sequence, and individual durations of responses as they occur in real time. Recently, instrumentation has become available for building completely portable, digital devices for coding behavior under laboratory or field conditions. Such systems (Fig. 1) are composed of: (1) a keyboard for entering codes, (2) a battery-operated tape recorder which translates keyboard entries into magnetic tape signals, (3) an electronic interface, and (4) an output device that displays and/or prints the data and produces output suitable for computer summary and analysis. Output devices range from printing counters and typewriters to Teletype machines, $\frac{1}{2}$ -in. magnetic tape decks, or direct entry into a computer.

Two such digital systems are known to us. The Behavioral Observation Scoring System (BOSS), devised by Edward Stephenson, is not commercially available. However, the MIDCARS systems (Electro General Corp., 128 Jackson Street, Hopkins, Minnesota) can be

purchased. Although these two systems operate on different electronic principles, the operations performed by Os and the behavioral coding methods are essentially the same. Thus, our discussion of digital techniques and problems encountered in using these methods should apply to either of these systems or to similar methods.

KEYBOARD CODING SYSTEMS

Keyboard entries consist of codes of one or more digits (X-digit codes) that have either a fixed number of digits for a given coding scheme or a variable number of digits, depending on the type of information being coded at some point in time. Variable code lengths have the advantage of flexibility in designing codes when:

Fig. 1. Block diagram of a typical automated data acquisition system. Data recording employs a keyboard and a battery-operated tape recorder. Data recovery employs a tape playback unit; an electronic decoder interface; a device for producing a printed record of all information, such as the Teletype unit shown in the diagram; and a device for producing output compatible with a computer, such as a punched paper tape or a .5-in. magnetic tape deck.

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Table 1
Three-Digit Three-Dimension Scoring System for Behavior of Single Monkey S*

Major Category (Exclusive Behaviors)	Qualifier (Nonexclusive Behaviors)	Object Direction (Nonexclusive)
1 Sleep-Passive	0 None	0 None
2 Stereotypy	1 Visual (Only)	1 Self
3 Explore	2 Physical-Manipulation	2 Diaper
4 Play	3 Oral	3 Cage
5 Disturbance-Fear	4 Physical + Oral	4 Feeding Site
6 Aggress-Threat		5 Food
		6 Feces
		7 Genitals
		8 Outside Cage
		9 Special Code (see Table 2)
Vocalization Coding (Nested Code)		
0 Vocalization	1 Coo	0 Single Sound
	2 Screech	1 Repetitive Sounds
	3 Other	

**Digital codes and category labels are shown for each scoring dimension. Codes are entered in a keyboard in the sequence major category-qualifier-object, followed by pressing an enter key.*

(1) many responses can occur at the same time; (2) many Ss might be involved in social interactions and the O wishes to identify (ID) all interactors; or (3) much of the observation period has only a few responses occurring, while a small portion of the period has many.

If the code contains more than one digit, it can represent a nondimensional list of all behavioral events of interest; or it can represent a set of two or more independent scoring dimensions. For example, a two-digit code might represent any of 100 nondimensionalized unique responses (Digits 00-99). Alternatively, a two-digit code can represent two single-digit dimensions, with the first digit coding up to 10 behavioral categories (e.g., play, explore, aggress, sex) and the second digit coding up to 10 objects or directions of the behavior (e.g., self, cage, food, adult male). Such a code thus yields, with up to 10 possibilities in each dimension, all dimensional combinations of S's behavior/object of behavior. Similarly, code lengths of three or more digits can represent simple lists of responses or dimensionalized sets of behavior, object, direction, or interactor identification (ID) categories. Our experience indicates that fixed digit length dimensionalized codes having as few digits as possible per dimension minimize O training time and maximize O reliability and ease of summary and analysis programming.

Form of a Trial

In general, behavioral observations will consist of a set of event codes entered onto tape on a real-time base. The duration of a scoring period or trial may be fixed or may vary in response to factors such as disappearance of Ss from the field of view. The use of session START and END codes preserves a taped record of the actual length of each trial. Our experience suggests that individual trials should have the following features: (1) sets of arbitrary digits providing ID information (e.g., S and experiment number, O, date); (2) an arbitrary code indicating the START of the session; (3) response codes

occurring in sequence for each scorable behavior observed; and (4) an END code, indicating termination of the trial. In addition, several special, nonbehavior, codes may be constructed to indicate entry errors and aborted trials.

Information on Each Trial Record

The following summary information can be extracted by hand from a printed output or by computer from a magnetic or paper-punch tape: (1) the frequency of occurrence of each code (F_i); (2) the total number of behaviors scored (TF); (3) the duration of each code (D_i); (4) the total duration of the trial (TD); (5) the modified frequency score for each code (MF_i)¹; and (6) sequential information concerning the frequencies with which each code precedes or follows all other codes that occurred.

A Three-Digit System for Coding Behavior of a Single Individual

Table 1 presents a coding scheme for scoring a single individual (monkey) in a fixed environment (home cage). The system is a mutually exclusive, exhaustive categorization (arbitrary, as usual) of behaviors directed at selected portions of the environment. Scoring occurs in real time, with entries made whenever behavior changes in any scorable dimension.

Mutual exclusivity is accomplished by defining as one scoring dimension a set of "truly" exclusive categories comprising behaviors that do not occur simultaneously (e.g., sleep, play, withdrawal, eat). A second scoring dimension is composed of nonexclusive events that often occur simultaneously with the exclusive behaviors. Exclusive events are thus qualified by the presence or absence of the nonexclusive events, yielding a mutually exclusive set of responses in their combinations.

The criterion of exhaustiveness is accomplished in two ways. First, a "waste" category (passive) includes all behavior changes not defined by the other exclusive categories. Second, a precedence system is used for

different levels of the nonexclusive qualifier and object dimensions, many of which can occur simultaneously. For example, physical, oral, and physical + oral qualifiers are scored whether or not they include a visual looking component. Visual behavior, however, is scored only when a physical-oral component is not present. Thus, physical-oral takes precedence over visual activity. This ordering introduces a potential negative bias into visual score totals. If this is not tolerable, the nonexclusive qualifier dimension can be composed of all combinations of visual, oral, and physical activity; but this method will usually result in a need for a two-digit sequence to code the dimension. The same type of precedence scheme is used for the object-direction dimension, with self-directed behaviors scored in precedence to "security" objects (e.g., diapers, surrogates, nonnutritive feeding) and security objects scored to give precedence to simultaneously occurring reactions with other objects. If it is important to code all instances of all object directions, then codes for all combinations can be constructed; but this increased complexity will again result in increase in the number of digits needed to code the dimension and will increase the O's burden and potentially decrease O reliability.

Nested Coding Systems

It is possible, and sometimes desirable, to code special behaviors outside of the main scoring system by building a coding scheme within the main system. In our three-digit example, this method was used to code a vocalization dimension. Scoring vocalization codes always starts with a zero (0) as the first digit (note in Table 1 that none of the exclusive categories are coded by this digit). The three types of vocalization are then coded by the second digit, and whether the vocalization was a single sound or a repetitive bout of sound is scored by the third digit. The presence or absence of the nested vocalization code for each observed behavior thus qualifies the main scoring system behavior occurring as being one of two categories, with or without vocalization, and when present, the nested code allows the total number of vocalizations of each type to be measured.

Table 2 gives a complete breakdown of our three-digit, three-dimension scoring system. Each three-digit code can be read from left to right in terms of exclusive category - nonexclusive qualifier - object. These three-digit sequences would be entered, in order, into the keyboard whenever an instance of each behavior occurs.

A Four-Digit Code for Social Interaction Data

Table 3 presents a four-digit coding scheme for studying interactions of monkeys in small groups. This *focal animal* system scores the behavior of a single arbitrarily chosen focal monkey during a standard 5-min trial. Responses by other monkeys are scored only when

they involve interactions with the focal monkey. Entries are made whenever a behavior change occurs on any aspect of the four scoring dimensions.

Three types of *roles* coded by the first digit include nonsocial responses and social responses initiated or received-reciprocated by the focal S. A fourth pseudorole includes ignored behaviors scored when an interactor initiates a response toward the focal monkey who does not change its behavior from what it was before the initiation. Each social role is further qualified by the presence or absence of physical contact. The second and third digits each designate the occurrence of nine mutually exclusive behavior classes for the *focal S* and for the interactor. In addition, a 9 code entered in Digit 3 position designates "no response" by an interactor following a behavioral initiation of the focal monkey. The fourth code digit designates IDs of particular interactors in the group for social behaviors and specific objects or self-directed activities for nonsocial behaviors. When multiple interactors are involved in a behavior, we score only the first individual or the primary interacting animal, rather than attempt to score all interactors. Because we have stipulated a small group size and a large number of trials, this procedure provides a good estimate of interactor frequencies for each individual monkey. If it were necessary to code all interactors, the ID dimension could be expanded to two digits, with separate codes for all possible combinations of interacting monkeys; or interactor IDs could be nested as a separate coding type within the main scoring system. For example, a 9 as the first digit entry could mean that subsequent nonzero digits in the four-digit code represented interactor ID numbers for the individuals involved in the preceding behavior.

STRENGTHS AND WEAKNESSES OF AUTOMATED DIGITAL SYSTEMS Devising Coding Systems

There are as many potential approaches to designing coding schemes as there are behavioral problems and investigators studying them. However, our experience indicates that every unique scoring situation can be digitally coded. The first step seems to be dimensionalization of the particular universe of behaviors of interest to the investigator for the problem at hand. This exercise has the side effect of forcing a better understanding of the structural nature of the behaviors being measured. Whether it, and the use of digital coding, is worth the effort depends on at least two major factors: (1) whether or not real time durations are necessary information for the problem under study; and (2) whether the greater costs in time, money, and probable loss of numerical information incurred by the use of paper-and-pencil or voice-recording techniques are offset by the advantages of digital techniques. A general principle is that if simpler techniques work (i.e., generate the information needed within affordable cost limits), it is better not to

Table 2

Complete Listing of All Events Coded in the Three-Dimensional Scoring System Presented in Table 1*

Category 1: Sleep-Passive	
1 0 0	Sleep, not contacting any scorable objects
1 1 0	Passive (i.e., awake but inactive), not contacting any object
1 2 0	Passive, with minimal nondirected movements of eyes or body
1 3 0	Sleep, with thumb sucking or mouthing body part
1 0 1	Sleep, with self-clasping
1 1 1	Passive, with self-clasping
1 3 1	Sleep, with oral activity and self-clasping
1 4 1	Passive, with oral activity and self-clasping
1 0 2-8	Sleep, in contact with any object coded 2-8
1 1 2-8	Passive, in contact with any object coded 2-8
1 3 2-8	Sleep, with oral activity and contacting an object coded 2-8
1 4 2-8	Passive, with oral activity and contacting an object coded 2-8
Category 2: Motor-Stereotypy	
2 0 0	Stereotyped limb movements with no locomotion
2 1 0	Visual attention to stereotyped limb movement and no locomotion
2 0-4 1-8	Repetitive body movements such as rocking in a huddled position, not involving any locomotion. Scoring of qualifiers 0-4 designates whether the repetitive body movement is the only behavior occurring (Code 0) or is accompanied by visual (1), physical (2), oral (3), or physical + oral (4) activities. The scoring of an object 1-8 designates where the stereotyped activity is occurring. Code 1 indicates occurrence with self-clasping of a body part other than genitals, Codes 2-6 indicate stereotypy while in contact with various parts of the environment, Code 7 indicates stereotypy with genital involvement.
2 0 9	Use of the special 9 code as the third digit in Category 2 indicates stereotypy with locomotion, including pacing, repetitive climbing, and back-flipping movements.
Category 3: Exploration	
3 0 0	Locomotion, walking about the cage
3 1-3 1	Self-directed visual, manipulative, or oral activities
3 3 0	Locomotion, with oral activities directed to parts of the body
3 1 3	Looking at the cage or at the observer
3 1-4 2, 4-8	Any attentional or exploratory manipulative behaviors toward the objects Code 2 or 4-8
3 2-4 9	In this category use of the 9 code as the third digit designates <i>manipulation</i> of the anal or genital body parts (i.e., "autoerotic" behaviors); the manipulative mode is expressed by the entry in the second digit position.
Category 4: Play	
4 0 0	Active running, jumping, or leaping about the cage
4 3 0	Active running, jumping, or leaping while thumb sucking
4 2 1-8	Locomotor play involving a manipulative component (e.g., swatting, touching, pushing, pulling) directed toward the objects coded 1-8.

4 3-4 1-8

Locomotor play involving oral or physical + oral activity directed toward objects coded 1-8.

5 0 1

Category 5: Disturbance-Fear

Convulsive jerking

5 2 1-8

Withdrawal behavior involving locomotion taking the subject away from the object coded 1-8. An object code 2 (here, *self-withdrawal*) indicates startle reactions to such behaviors as stereotyped limb movements or shows an aversive reaction to parts of the body after a bout of self-aggression.

5 1 1-8

Fear behaviors such as grimacing, rigid body postures, and reactions accompanied by screeches or coo-screeches.

6 1 0-8

Category 6: Aggress-Threat

Threat behaviors directed toward any of the coded objects or not apparently directed toward any specific object (Code 0).

6 2 0-8

Physical, but not oral, aggression toward any object 0-8

6 3 0-8

Aggression with biting toward any object 0-8

*Note that all numerically or logically possible combinations of the 6 by 5 by 9 code would not actually occur.

change to automated digital data collection. The reasons for this advice follow.

Some Disadvantages

Voice tape or pencil scoring methods have the distinct advantage of immediate visual or aural access. Digital magnetic tape data, on the other hand, are available only after processing by machines; and these machines cannot readily check and correct all error sources and have the problem of periodically breaking down. A major source of "waste" effort and unnecessary expense in automated data involves improper indexing, filing, and sorting of data, which occur because of errors in entering trial ID information. In our laboratory, even well-trained, intelligent Os, coupled with a small percentage of machine errors, yield up to 5% ID information inaccuracy. This means that the ID information from all trials must be screened and edited for accuracy before the data can be properly indexed, filed, and summarized for trials, Ss, or conditions. Editing may involve only matching a printout of ID information with a well-kept log of all trials and inserting line entry corrections into a computer or other device. If the error rate is high, however, this process will be tedious and may make the whole effort of dubious value.

A second disadvantage of magnetic tape data is that undetected recorder failures can result in irreparable loss of data. A related disadvantage of tape data is that electronic and programming expertise is required to retrieve information: the human eye or ear is not sufficient. In principle, tape data should not have to be touched by human hands from keyboard entry until a data summary is produced. In actual fact, ID errors must be corrected, and programs must be written for input of data to a computer and to perform summaries and analyses. Such programs have been written, however, for

Table 3
Four-Digit Four-Dimension Coding System for Studying Social Interactions of a Focal
Individual Tested in a Four-Monkey Group (5-Min Trials)

Code	Digit Position			
	1 Role of Focal Individual	2 Focal Individual Behavior	3 Interactor Behavior	4 S ID-Direction
0	Nonsocial	Passive	Passive	Nonsocial
1	Initiate—With Physical Contact	Explore	Explore	Monkey 1*
2	Initiate—No Physical Contact	Withdraw	Withdraw	Monkey 2
3	Reciprocate—With Physical Contact	Disturbance-Fear	Disturbance-Fear	Monkey 3
4	Reciprocate—No Physical Contact	Rock-Huddle-Self-Clasp	Rock-Huddle-Self-Clasp	Monkey 4
5	Ignore—With Physical Contact	Stereotypy	Stereotypy	Self
6	Ignore—No Contact	Play	Play	Toy
7		Sex	Sex	Ladder-Shelf
8		Threat-Aggression	Threat-Aggression	Window
9			No Response†	

*The four monkeys in the group are arbitrarily labeled from 1 to 4 as subject ID codes.

†The no response category for the third-digit interactor behavior Code 9 refers to social interactions initiated by the focal subject that produce no change in behavior of the potential interactor from that occurring before the initiation.

the BOSS system by Jim Hinkhouse of the University of Washington Child Development Center and can be made available to off-campus users with similar computing facilities.

Data Errors

Three types of errors can occur in data collection during a trial: (1) those recognized by the O before entering all digits of a code, (2) those recognized after a full code has been entered, and (3) errors that are not recognized (nothing can be done about the latter). For Error Types 1 and 2, the scoring system must contain a unique error-designating code, e.g., depressing an enter button twice in succession. If the error code occurs before a full code has been entered, the computer simply discards the data line. If it follows a fully entered, valid code, the computer discards that code and adjusts durations accordingly.

Probability of Occurrence Measurements

Probability measures are meaningful when actual events form a mutually exclusive set from a well-defined universe of potential events. In many observational scoring schemes, some, or all, events are not defined in a manner even approaching a mutually exclusive set. For this reason, we have made every effort to dimensionalize our scoring categories and to define behaviors in a mutually exclusive fashion. Probabilities extracted from the type of scoring schemes outlined in this paper (probability of occurrence of code $i = F_i/TF$) therefore approach the mathematical and logical criteria for defining valid relative frequencies. One major strength of digital systems is that they lend themselves to proper coding of dimensionalized, mutually exclusive, code

categories; in addition, they make scoring relatively simple for trained Os, who can easily score the required dimensions by depressing keyboard buttons without looking away from the Ss—an extremely difficult task for Os using paper-pencil methods. As a result, the reliability of observations is higher.

ELECTRONIC PRINCIPLES OF DIGITAL DATA SYSTEMS

It is beyond the scope of this paper to present in detail the electronic principles and circuits needed for constructing digital systems. Although information on coding principles and transmitting circuits is available for system construction (such details can be obtained by writing to Edward Stephenson, Chief Electronics Engineer, University of Washington Child Development Center, Seattle), we believe an investigator will not be successful unless he has access to professional engineering advice and professional electronic technicians for apparatus construction. It would be wiser to purchase the equipment, since it will be guaranteed and service will be available for maintenance and repair.

NOTE

1. Modified frequency scores, used primarily with paper-and-pencil methods, represent the number of X-sec time intervals during a trial in which a behavior occurred one or more times. The X-sec sampling rate is fixed for a given experiment; rates of 3, 10, 15, or 60 sec are common. These MF scores are numerically unitless, since they provide neither unambiguous frequency of occurrence nor duration data, and are therefore unnecessary as basic data where digital systems record actual event frequencies and durations. Because investigators working with digital systems may wish to compare their data with studies using MF information, however, MF scores can be recovered from these digital trial records.

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