The DCR-II event recorder: A portable high-speed digital cassette system with direct computer access

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The DCR-II is a portable digital cassette system for recording single or simultaneous events. Information is entered via keyboards which are internally scanned every 10 msec for switch state changes (events). The device can accommodate up to 64 event channels and record 100 events per second without data loss. Complete data integrity is preserved by encoding each event as two 16-bit words containing key and state information, parity, and real-time information. One event switch can simultaneously activate an audio recorder to provide an optional supplementary verbal record. The DCR-II stores data on two alternate memory buffers and operates randomly (i.e., only during transcription onto magnetic tape), thereby providing compact record and an excellent observation-to-read time ratio. The entire record/replay unit measures $17 \times 10 \times 6$ in. and requires no special computer interfacing.

Behavioral scientists must consider several criteria in choosing a system for recording behavioral events. Ideally, such a system should allow for the accurate recording of behaviors in real time, maintain sufficient data integrity to permit all desired statistical analyses to be performed, and transcribe data in a form that facilitates rapid perusal, comparison and statistical testing. For field studies, portability is an important consideration.

Limited numbers of behaviors can be observed using time-sampled pencil-and-paper notation or chart-type event recorders. However, the former does not generally yield sequence or duration information and both methods require tedious manual evaluation for all but simple summaries of event frequencies and duration (Odom, Mitchell, & Lindburg, 1970).

Computer compatible systems reduce data processing time. Fernald and Heinecke (1974) and Tobach,

Schneirla, Aronson, and Laupheimer (1962) recorded directly onto computer-compatible paper tape or cards; but these systems produce unwieldy amounts of tapes or cards. Beauchamp and Scobie (1973) designed a high-speed event recorder utilizing magnetic tape for silent and compact information storage, but systems of this sort are too large for use in the field.

Several portable recording schemes have been developed which provide intermediate storage of data for later processing. Signals are accepted from a keyboard and encoded for storage on an ordinary one- or two-track audio tape recorder. The systems devised by Lentz and Haith (1969), Stephenson, Smith, and Roberts (1975), and White (1971) phase encode events using a square-wave reference signal or timing source. Dawkins (1971) and Fitzpatrick (Note 1) utilized a frequency coding principle, while Sackett, Stephenson, and Ruppenthal (1973) used a digital code. All of these systems require continuous tape recording.

Development of the DCR-II

The DCR-II system was designed to record the behaviors of prematurely born infants while alone and/or interacting with their caretakers, both in hospital nursery and home environments (Minde, Trehub, Boukydis, Marton, Corter, & Celhoffer, in press). The behaviors we observe could be termed primitive in the sense that they have not been interpreted for purposes of categorization. Moreover, the array of concurrent behaviors can change continuously, allowing the observer insufficient time to make grammatical entries. Thus,

Reprints may be obtained from Dr. K. Minde. The DCR-II system has been developed for the PDP-11 only and other systems will require program modification. Software for the PDP-11 system is available from the Computer Research Facility of the University of Toronto, Toronto, Ontario, Canada. This work was supported by Grant 542-75B from the Ontario Mental Health Foundation to Dr. Klaus Minde. The authors are especially grateful to Mr. A. H. Wilcox of the Hospital's Clinical Computer Department for his patience and expertise in helping us incorporate our research needs into a functional design. Charles Boukydis is presently with the Division of Individual and Family Studies, College of Human Development, The Pennsylvania State University, and is being funded by Canada Council Doctoral Fellowship W762868.

we required a variable-length digital code in which most codes had but a single digit in order that observers could record behaviors as if playing a musical instrument by depressing or releasing any combination of keys. Several observation sessions of approximately 1-h duration are completed daily and, hence, we needed a compact form of data storage to avoid amassing extensive amounts of tape and a fast replay system to reduce computer processing costs. Although this system was designed to meet our specific requirements, we believe that its simplicity of design and format make it a flexible and potentially powerful observational tool.

DESIGN CONSIDERATIONS

A flexible keyboard coding system was required to permit observations of one subject by one observer, two interacting subjects by two observers, or a single subject by two observers simultaneously when checking inter-observer reliability. We therefore chose two interchangeable keyboards that are identified solely by the socket into which each is plugged. Each permits recording of 32 events, any or all of which might occur singly or simultaneously.

In order to preserve total data integrity, the occurrence, time, duration, simultaneous nature, and/or sequence of every event must be recognized and recorded. Repetitive scanning of the keyboard(s) at regular rapid intervals for switch state changes and digital recording accomplish this. The 10-msec time interval between successive scans (time resolution) is less than the highest anticipated activity rates and/or observer reaction time. Though the clock is normally reset to zero at the start of each trial, this resolution can be maintained for up to 46 h. To prevent data loss and preserve time resolution during high-speed activity bursts, two storage buffers are provided. A switch state change cannot be missed as a $+/-$ or $-/+$ transition must pass serially through two shift registers whose outputs are continuously compared by an exclusive OR. The system-generated error rate is low. Nevertheless, 1 bit per event is provided to permit detection of most errors on recall.

As vast quantities of data are accumulated, minimization of data processing costs is an important objective. By loading keyboard signals into memory buffers and recording on tape only when each buffer is filled to capacity (32 events), a highly condensed record is produced. Approximately 31,000 events (18 h of our data) can be collected on a single cassette and replayed in 12 min. Each event is encoded as two 16-bit words to permit reading of data by any computer (we use a PDP-11) with a 16 parallel line input/output interface. All computer connections are made through one connector on the central unit.

As observations are conducted in various settings, portability and unobtrusiveness are essential. The entire unit (less optional audio recorder) shown in Figure 1

Figure 1. Front view of the DCR-II system. The central panel features a 115-V power outlet, a battery charge light, a computer outlet, MFE model 250 tape transport, switches for "alarm reset," "forward," "test," "rewind," "Read-Write," and "power ON-OFF," and a visual test display window. Beneath the panel are a 115-V, sealed, lead-acid, rechargeable battery, nine circuit boards, a crystal oscillator time clock, and the semiconductor core memory. Pockets are provided in the lid to house each of two 3 x 6 x 2 in. keyboards, the power cord, the computer connector cable, and spare cassettes. Total unit size is 10 x 17 x 6 in. and weight is less than 20 lb.

weighs less than 20 lb. The silent pushbutton keys and magnetic tape transport insure quietness, while the lightweight extendable cords permit additional observer mobility during recording sessions.

It is sometimes desirable to note additional events during an observation. For this reason, one event switch can simultaneously activate an audio cassette recorder to provide a supplementary verbal record.

A test control switch and display window in the central unit enable the user to check that all switches are connected and recognized by the system, and that there is sufficient charge in the battery for the collection of one data set.

Each observation period can be labeled by activating one toggle switch and entering identification variables on the remaining keys, using a suitable digital code. We enter only a serial number in this manner. Other contextual variables such as medical status are not always available at the time of the observation. These variables are coded for later transcription with taped data onto disk.

The audible end-of-tape warning permits recording of all accumulated information plus 256 additional events before the end of the cassette is reached. A new cassette can then be inserted with or without resetting the cumulative time count.

Figure 2. The pathway for information transfer.

Encoding and Decoding Scheme

The pathway for information transfer from keyboard to computer is illustrated in Figure 2. The chosen event-encoding scheme involves continuous interrogation of the keyboards at a rate of 6,400 steps (keys) per second. Thus, up to 64 keys may be interrogated within the prescribed 10-msec time slot. Only changes of state are encoded and transmitted from the keyboards to the recorder (see Figure 3). This is achieved by parallel loading key states (in groups of 16) into 16-bit shift registers. This information is then clocked through other 16-bit shift registers. An auxiliary counter, reset to zero each time a shift register is loaded (i.e., every 10 msec), is advanced by a count of one on each clock pulse. The serial outputs of both shift registers are continuously compared by an exclusive OR gate. Should a difference be detected, it indicates that a button state change occurred. The output of the first shift register at such a time indicates the most recent state of the button, while the contents of the auxiliary counter correspond to the number of the button. All this information is parallel loaded into an 8-bit shift register which is continuously clocked at a rate of 102,400 bits/sec. This

register serializes the encoded state change information and transmits it via a thin four-cored extensible cable to the main unit, where it is assembled, along with time and parity, into a 32-bit serial word (see Figure 4). The 1 bit allotted for parity insures that the number of ones in each 32-bit word is odd; thus a word which appeared later with an even number of ones would be described as an error.

A complete description of one event is contained in each 32-bit serial word. These words are assembled within 10 msec of the occurrence of each random event. This is the last operation performed in real time.

Groups of 32 such words are clocked alternately into one of two 1,024-bit buffer stores (P channel silicon gate MOS static shift registers) at a bit rate of 409,600/sec. As one buffer is filled, all incoming events are diverted to the other buffer while power is applied to the tape drive and motion is requested. When tape is up to speed (less than 50 msec from acceptance of motion request), data is phase encoded and written bit serially onto tape at a rate of 8,192 bits/sec in a 1,024-bit block. Tape motion then ceases and power from the tape drive is interrupted to conserve batteries.

Figure 3. A keyboard encoded event signal.

Figure 4. A 32-bit word assembly.

Button de-bounce circuitry has neither been included nor found necessary or desirable. As buttons are "point sampled" at 10-msec intervals, the worst that is likely to happen is that state change information could be delayed for a maximum of one sampling interval, given that the duration of bounce is less than 10 msec.

Playback is effected by reading from tape and decoding one data block of 1,024 bits and storing in a dedicated 1,024-bit shift register. Serial output from this P-MOS shift register is connected to the input of one of a pair of 8-bit TTL serial-in/parallel-out shift registers whose outputs appear at the input-output connector. This set of registers advances 16 bits at a time when permitted/requested by a computer or other interrogating device. Information is thus presented in 16-bit parallel form. When a complete data block has been transferred, a new one is immediately read from tape; thus a minimum of interfacing, control lines, and software intelligence is required.

DISCUSSION

Several factors must be considered when choosing or designing an event recorder to meet individual experimental requirements such as those discussed in the Design Considerations section. The present system incorporates many powerful features into a portable package for field study. As the unit also includes decoding circuitry, it can be transported to any computer equipped with an appropriate input/output interface for processing.

Using a single-digit code, the present system permits observation of a maximum of 64 behaviors. However, use of a multiple-digit code or use of some keys as shift keys could significantly increase the number of observable events. Subdivision of these events in blocks of 16 on two or four keyboards facilitates observation of multiple subjects and measures of interobserver reliability on a single unit. While we have chosen to use a combination of single-action pushbuttons and toggle switches on our keyboards, alternate-action or alpha-numeric keys could be used.

Stephenson et al. (1975) pointed out the advantages of recording a supplementary voice record in parallel with a keyboard output. We allot one key per keyboard which, while depressed, serves as a time marker on the digital cassette record, and simultaneously activates a small audio cassette recorder for verbal entries. In this way voice notes are collected in condensed fashion and transcripts can later be typed rapidly.

We chose digital saturation recording as opposed to audio phase encoding for several reasons. The MFE 250 digital cassette tape transport has a total size of 4.5 x 5.5 x 2.5 in. (slightly smaller than an audio cassette recorder). The transport serves both as recorder and replay deck. In addition, less circuitry is required both for pulse reshaping and noise filtering, which helps

reduce electronic failure and maintenance problems.

The system provides an excellent recording rate of 100 events per second to insure that data will not be lost during bursts of activity. The continuous recording capacity is also more than adequate for our purpose. This capacity is nevertheless subject to recording rate and battery capacity limitations. By swapping cassettes without resetting the cumulative time count and/or by using a standard 115-V power supply, one can effectively increase the continuous recording time to a maximum of 46 h before reaching time overflow on the clock.

Condensed recording on magnetic tape at a high packing density (800 bits/inch) produces a very compact data record. This condensation process combined with an excellent observation-to-read time ratio of 90:1 (assuming a recording rate of 1 e.p.s.) greatly reduces processing time and, hence, operating costs. Cost of the unit is approximately \$4,068, including design and labor.

NUMERICAL EVALUATION

Plots or charts of total frequencies and durations of events can easily be printed for immediate perusal when data is transcribed onto disk. This also provides a rapid check of interobserver reliability.

Storage on disk permits rapid replay for a wide range of statistical analyses. For example, given that one event A occurred at a particular moment, the researcher can determine which event(s) B occurred at the same moment (concurrence), or which event(s) C occurred within a preestablished time span (i.e., 1 sec, 5 sec, etc.) before or after event A (sequential analysis, such as Markov chains; see Freedle & Lewis, Note 2). One can determine also whether certain clusters of behavior can be put into a geometric representation of a few dimensions [i.e., multidimensional scaling (Tucker & Messick, 1963); INDSCAL (Carroll & Chang, 1970)]. Further, the extent to which contingent variables (e.g., physical, situational, environmental events) affect the amount of variance in frequency, duration, and concurrence of behavioral events may be assessed using multivariate analyses.

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(Received for publication July 1, 1976;
revision accepted July 19, 1977.)