COMPUTER CONTROL OF OPERANT BEHAVIOR EXPERIMENTS VIA TELEPHONE LINES¹

DONALD C. UBER AND BERNARD WEISS

THE JOHNS HOPKINS UNIVERSITY AND
UNIVERSITY OF ROCHESTER SCHOOL OF MEDICINE AND DENTISTRY

Many operant laboratories will, in time, own a computer or have access to one on a shared-time basis. In the latter system, a central computer services concurrently a number of remote stations (Burgess, 1965). This allows individual access to the computer without having to pay its full operating cost. But even small computers may have to communicate, on occasion, with remote laboratories.

Over short distances, voltage levels and pulses may be transmitted over direct cables, either installed privately or rented from the telephone company. Signal degradation and high noise levels often make direct transmission impossible over distances of thousands of feet or more. One solution is to code information in the form of frequency-modulated tones which can be transmitted by cable and decoded at the other end. The Dataphone devices (Bell Telephone System) are well suited for on-line control of operant experiments (see Sheldon and Luzon, 1963, for a semi-technical description of Dataphone operation). Those with relatively slow input-output rates are no great handicap in most operant experiments, and their use of relays to code information meshes neatly with current operant technology.

The present article describes a system used to control experiments in a remote laboratory by means of Dataphone equipment connected to a LINC computer. Although the LINC is a small computer specifically designed for on-line use (Clark and Molnar, 1965), the princi-

ples involved are applicable to other computers as well, especially the newer types.

The system enables the LINC to monitor on-line eight response switches (either normally-open or normally-closed) in the remote laboratory. The eight switches may be operated independently of each other, and each switch is sampled 50 times per sec. In return, the LINC may control independently eight pairs of contacts in the remote laboratory for the operation of lights, feeders, stimulus and reward devices, *etc.*

DATAPHONE OPERATION

Several types of Dataphone equipment are available from Bell Telephone for transmitting data in analog or digital, serial or parallel form over telephone lines. Our system uses the Model 402A transmitter and 402B receiver (Bell System, 1963). These components can handle eight-bit parallel binary data words, *i.e.*, eight simultaneous channels, at rates up to 75 eight-bit words per sec. Each data set includes a standard dial telephone for initiating calls, and a Voice Mode/Data Mode selector switch that permits use of either conventional voice transmission or data transmission. In addition, a non-simultaneous answer-back channel permits transmission of two-bit words from receiver to transmitter at 20 words per sec. This feature is not presently being used.

These Dataphone sets operate on a simple frequency-shift basis. The transmitter contains eight frequency shift channels, each of which normally transmits its individual audio frequency "space" tone. These vary from 800 to 2160 cps. The input to each channel is provided by a pair of normally-open switch contacts. Closing the pair of contacts on any transmitting channel lowers its frequency to the "mark" frequency. The space and mark frequencies correspond to the binary 0 and 1, so

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that at every instant the data channels are transmitting an eight-bit binary "word" determined by the open or closed status of the eight input contacts. It is therefore possible to transmit simultaneously information from eight independent sources, such as response devices, and to sample each source as often as 75 times per sec. In addition, a timing signal, discussed below, must be transmitted at the start of each new word. The timing signal is transmitted over a ninth channel.

At the receiver, the frequency of each channel is decoded by filters. Upon receiving a timing signal, the receiver samples the data channels and sets eight flip-flops to 0 or 1 according to the space and mark pattern of the new word. These flip-flops drive relays whose contacts are available at the receiver's output connector. The system thus uses contact closures to convey information between stations, and could easily be used to connect remote experimental chambers to a relay rack of recording or programming equipment. No additional equipment would be needed, except to operate the timing channel as described below.

The timing requirements of the system are crucial and must be observed if it is to operate reliably. The transmitter contains a mark/space timing channel under the control of external contacts. This channel is required to

change state at the beginning of each new data word. Thus, if it is in the mark state during one word it must be in the space state during the next. After detecting a timing transition, the receiver delays about 5 msec before sampling the data channels in order to allow the frequency discriminators to stabilize. These relationships are indicated in Fig. 1. The timing transitions need not be regularly spaced, but must be at least 13.3 msec apart, corresponding to the maximum rate of 75 words per sec. These transitions actually provide the signals that activate the receiver.

The receiver contains a timing relay whose contacts are available for synchronizing external equipment to the Dataphone system. As shown in Fig. 1, the contacts close for the first 5 msec of each data word, then open for the remainder of the word.

In the present application, two-way communication between the remote laboratory and the LINC computer is provided by two Dataphone systems. One system monitors up to eight response switches and informs the LINC of responses through eight external input lines which are scanned by appropriate instructions in the program. Special timing and holding logic at the transmitter permits the switches to be operated at rapid rates without exceeding the transmission speed of the system or dis-

Fig. 1. Timing relationships at the receiver between two data channels and the timing channel. "Space" is represented by 0 and "mark" by 1. Note that the transitions of the timing channel are produced only at the changes in status of the data channels. The 5-msec delay at the receiver output allows the frequency discriminators to reach steady state.

rupting synchronization between the transmitter and receiver.

The other Dataphone system enables the LINC to operate up to eight devices (such as lights and feeders) in the remote laboratory by means of output signals from the LINC, also produced by appropriate program instructions.

Because the great majority of Dataphone applications involve transmission of data from conventional sources such as keyboards or punched paper tape readers, our special methods for using Dataphone in operant experiments conducted on-line by a digital computer are described in some detail.

INTERFACE DESIGN

Figure 2 shows that appropriate equipment is required at four separate interfaces for this application. Each will be considered in detail below.

Response Transmitter

In the present system, more than one experiment can be conducted at a time. But the use of the eight Dataphone channels to transmit the status of eight response switches simultaneously means that a new eight-bit "word" is formed whenever any response switch changes state from "open" to "closed" or vice versa. With two or more subjects responding, new words may occur more frequently than the Dataphone transmitter can accept them (a maximum rate of one word every 13.3 msec), mak-

ing it impossible to transmit a timing channel transition with every word. The alternative is to drive the timing channel with a clock, so that the receiver samples the data channels at constant intervals. A clock rate of 50 pps is high enough to give good temporal resolution (20 msec) yet still fall within the range of Dataphone capability. This rate also is high enough to detect every response. The frequency with which our pigeons peck a key is well below once every 20 msec.

Such a sampling scheme requires a holding circuit so that response switch closures shorter than the sampling interval are not lost. (Pigeon pecks may be as little as 8 msec in duration.) Exceedingly short response durations, plus the problem of contact bounce in the response switches, dictate an electronic interface between the switches and the Dataphone transmitter of the sort depicted in Fig. 3. Only one data channel is shown in detail here.

The present circuits are built around solid-state modules fabricated by DEC (Digital Equipment Corporation), but equivalent circuits can easily be built with components manufactured by others. The transistor switches that open and close the eight data channels and the timing channel are of a special design compatible with the voltage levels used by DEC logic.²

The timing channel consists of a 50 pps clock, pulse amplifier, complementing flip-flop,

²Details available from the authors.

Fig. 2. Block diagram of the complete system with one 402B Receiver and one 402A Transmitter at each end of the line.

Fig. 3. Interface circuitry at the response transmitter showing one data channel plus the timing channel. Numerals under components refer to DEC model numbers. Open arrowheads and diamonds refer to 0 volt pulses and levels, respectively. Filled arrowheads and diamonds refer to -3 v pulses and levels, respectively. Inputs to FF_b are via capacitor-diode gates. PI = pulse inverter. C = complement input. INV = inverter. FF = Flip-Flop.

and transistor switch. It presents a space/mark or mark/space timing transition to the Dataphone transmitter every 20 msec since each clock pulse complements the flip-flop and changes its output level.

Each of the eight data channels requires two flip-flops and a transistor switch. A data channel operates as follows. A response sets FF_a (FF = flip-flop) by grounding the zero output terminal through the response switch. (A modification for using normally-closed switches makes use of a separate plug-in card containing inverters.)² Switch chatter is eliminated because the flip-flop remains set even if the switch terminals bounce open. Every 20 msec a clock pulse reads the contents of FF_a into FF_b and clears FF_a . If the response switch remains closed, FF_a will be set again. In this way, response durations can be determined, if necessary, with a resolution of 20 msec. FF_b drives the transistor switches, which in turn operate the Dataphone data channels. An indicator card provides a visual monitor of the timing and data channels.

Figure 4 is a schematic diagram of the events described above. Note that if the response switch is closed at any time within a 20-msec

clock interval, the data channel will transmit "mark" during the following clock interval. Note also that the data channel transitions coincide with the timing channel transitions at the Dataphone transmitter.

Response Receiver

The response channel interface logic between the Dataphone receiver and the LINC computer is diagrammed in Fig. 5. The eight data channels use DEC modules that contain input relays. When closed by an incoming signal, the relays produce brief pulses at DEC logic levels that are suitable for setting flip-flops. Each relay circuit sets a data flip-flop whenever the corresponding relay closes in the Dataphone receiver. No pulse is produced when the relay opens; hence, the data flip-flop is set only at the beginning of a response. After a level from a set flip-flop has been sensed in the LINC program, the flip-flop is reset by a LINC output pulse produced by a programmed instruction. If desired, all the flip-flops could be cleared simultaneously with a single LINC output pulse at the end of each clock interval.

Fig. 4. Timing relationships for a single data channel and the timing channel in the response transmitter. Deflection upwards indicates the presence of a signal.

may use this as the signal to start sampling the data flip-flops. The timing flip-flop must be cleared by a LINC output pulse before the end of the interval. Since these events—the sampling and resettings—require only a few microseconds, the remaining time frees the computer

for computations or for sampling other stations if it is organized in a time-sharing mode.

Reinforcement Transmitter

A completely separate Dataphone system delivers to the remote laboratory reinforcement or other signals programmed by the computer. Figure 6 shows the "reward" transmitter, which can control up to eight devices such as lights, feeders, shock stimulators, *etc.* Each device is turned on by a programmed output pulse and held on for a duration determined by a one-shot (a flip-flop would be used instead, if a cue or house light were to be turned on and kept on for a long period). Each one-shot operates a 402A Dataphone transmitter channel by means of a transistor switch identical to those used in the response transmitter.

The operation of the timing channel is identical to that of the response transmitter.

Timing transitions cause the Dataphone receiver to sample the data channels every 40 msec. A slower rate is used here because timing is less critical than in the response channel.

Reinforcement Receiver

To within one sampling interval, the 402B Dataphone receiver holds each data relay closed as long as the corresponding transistor switch at the transmitter is on. The devices connected to the receiver are usually controlled by the relays directly, without any intervening interface logic. The Dataphone relay contacts are rated for 50 v at 100 ma, with capacitive surges to 500 ma. When devices requiring higher currents are used, intermediate, heavier-duty relays are inserted to protect the Dataphone relays.

The present system has successfully operated LINC-controlled experiments with pigeons

Fig. 6. Reinforcement transmitter interface showing one data channel plus the timing channel. Numerals under components refer to DEC model numbers.

and humans in a remote laboratory a quarter of a mile away. One pigeon experiment involved a simple fixed-interval schedule. The other involved a pair of pigeons, each with three response keys, and reinforcement was produced for both when the "follower" pecked a key corresponding to the one pecked by the "leader" (Skinner, 1962). The human experiment studied a stochastic analog of the DRL schedule (*cf.*, Weiss and Laties, 1964). Once installed, the system proved exceedingly reliable.

The cost of installing and leasing such a system varies from city to city. In Baltimore, total installation cost came to \$308, and the rent to \$265 per month. In Rochester, the total installation cost was given as \$230, and the rent was \$194. (Rochester Telephone Corporation is not affiliated with the Bell System.) In both cities, we experienced difficulties with the telephone company bureaucracy and engineering capabilities. Applications that are even slightly unconventional seem to produce extreme anxiety states, but a soothing manner and patient ex-

planation finally led to the equipment being installed. Decoding of the Bell System manuals was our responsibility. Despite the cost of the system, which seems excessive, it is more economical than a separate computer, which is still out of the question for most laboratories.

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