Control of Contingencies of Reinforcement in the Laboratory

Arthur G. Snapper
State Systems Inc.

I am truly humbled by this opportunity to honor Fred Keller on his 90th birthday. My career was heavily influenced by exposure to K & S in several different undergraduate courses at Harvard. These courses included learning and motivation, conditioning and learning, and even a course on instinctive behavior all taught by William S. Verplanck. Soon I began to recognize that K & S seemed to be relevant to many areas of psychology, and this recognition led me to apply to Columbia University to study under Fred Keller and Nat Schoenfeld.

My role is to serve as yet another example of one with a non-traditional career that stems from the influence of Keller and Schoenfeld (K & S). What I do is to sell a computerized system for conducting research in the area of the experimental analysis of behavior. Most of my customers at drug houses, federal research laboratories, or medical schools conduct animal research using the techniques of the experimental analysis of behavior. The system consists of hardware (a computer and interfacing connecting the computer to the experimental chambers) and more importantly the software that simplifies programming the desired contingent relations between responses, stimuli, and reinforcers. For example, a drug house planning to test a new compound might want to use a battery of test procedures including drug discrimination, fixed interval, avoidance, etc. They would buy test chambers and then connect them to my system to control these procedures and collect data from them.

The SKED computer system is based on the state notation language which I originally developed to promote precise descriptions of behavioral contingencies. I still feel today that verbal descriptions of complex reinforcement schedules are often imprecise and unclear. It has been my experience that a typical experiment reported in *JEAB* is impossible to rep-

licate without extensive communication with the author. I shall come back to state notation later.

I shall attempt to describe the real world contingencies that led me to devote myself to instrumentation leading to the automated behavioral lab. To preview these contingencies briefly I should point out that because of career moves I helped design and build at least 10 different laboratories. I am a slow learner, but I eventually began to recognize a pattern that led me to deliberately spend my time on instrumentation rather than research.

I first became attracted to the instrumentation used in animal experimentation as an undergraduate. In our introductory laboratory course the text was K & S and we were each assigned a white rat, living in a cage that could be converted into a test apparatus. Our advanced equipment consisted of a lever constructed by each student and made from the end of a clothes hanger contributed by the student. On the end of the lever extending through the cage to the outside wall we glued a small trough cut from a tin can which was large enough to contain a food pellet. The lever was made to pivot on the cage wall so that if the rat pressed hard enough, the pellet would be flung into the center of the cage. This automatic apparatus permitted us to observe not only the operant lever press, but also response chaining, since the rat would gradually learn to snag the pellets. I now realize that this may have been the first experiment in sport behavior analysis.

The apparatus for controlling reinforcement contingencies and recording resultant data consisted of the student experimenter. The only automation consisted of the reinforcement delivery device which did provide a timely delivery of the scheduled pellet. With this apparatus, depending upon the ability of the student to count responses and to switch

between taking records and providing pellets at the appropriate time, one could apply various intermittent reinforcement schedules, and if one owned a flashlight it was even possible to conduct a test of discrimination. The amount of effort expended by the researcher in terms of time and concentration subtracted from the reinforcement arising from investigating behavior scientifically.

At Columbia I first discovered automated laboratories. I was hired by Dr. Helmut Adler to work in a lab in the American Museum of Natural History to help on a project investigating the vision of starlings and other migratory birds. We used the Blough technique for testing threshold vision using relay equipment for control of the complex contingencies used in this elegant procedure (Blough, 1955). Data were recorded on chart recorders, cumulative recorders, and electro-mechanical counters.

Our major problem in this laboratory consisted of bugs that affected both the relay equipment and the feeding regimen of the birds. The research labs were infested with *Americanus Giganticus*, a very large cockroach. If they strayed too near the food deprived birds, the subjects would snatch the bugs and refuse to work for food for two or three days. If the bugs explored the relay circuitry they often would short out the equipment and themselves.

This laboratory was state of the art at the time, but data analysis required the full time of the laboratory personnel in measuring graphs with rulers and recording visual thresholds by hand. Relay control was also too complicated to change easily.

On the Columbia campus I had the unique experience of working for Nat Schoenfeld in a pigeon lab that used vacuum tube equipment for control and a high-fidelity tape system for data recording. This research used the temporal reinforcement schedules of the T-tau system that had been invented by Schoenfeld, Cumming, and Hearst (1956). That system permitted us to build a simple switching circuit to investigate a wide range of behavioral performances simply by selecting from a finite set of

parameters before each session. The student technician who ran each experiment had only to set some switches and dials that would select the basic parameters of the study. This lab was a successful dissertation factory in which many students earned their degrees.

In those days of yore, it was very difficult to use microanalysis to examine the fine grained temporal details of operant behavior. Relay equipment was incapable of operating at the speed necessary to measure the duration of a pigeon peck (between 2 and 10 milliseconds). Doug Anger in his elegant study of interresponse times (IRTs) used extremely sophisticated techniques to gather his data. He employed a double buffer method with stepping counters so that one could record an IRT while the other reset after the previous response. Even using these methods it was difficult to measure an IRT with a precision finer than 25 ms.

Nat Schoenfeld's pigeon lab recorded a base frequency of .001 s on a stereo tape recorder at high speed. The frequency would change during a key closure by the pigeon and a third frequency marked reinforcements. The tape could be replayed after the session at an eight times slower speed so that the frequencies could be recorded, responses and reinforcements could be detected, and the resulting times could be printed on an electro-magnetic printing counter. Each session could be analyzed in this fashion with .001 s precision for IRTs or durations in just eight hours. Of course the result of this analysis was a paper roll of several thousand consecutive time printouts. Further data reduction was required to make sense of this mess. A computer of that era, the IBM 650, could be programmed to produce distributions, take means and variance, etc. in a relatively short time (for example a week of full time programming). However, the data then needed to be entered by hand on a card punch (a device resembling a typewriter that produced punched cards), which could take months for a slow typist.

I next had the good fortune to be hired by Francis Mechner to work in the most advanced behavioral research laboratory

for both human and animal subjects that existed at that time. This laboratory at Schering Corporation (now Schering-Plough) had been constructed to examine the effects of a variety of drugs on the behavior of rats, monkeys, and people. Mechner anticipated future developments in the late 1950s by designing a laboratory that could test the behavioral repertoire of over 100 rats per day using only two technicians who actually interacted with the subjects.

The basic scheme of the laboratory was the rat rotor designed by Mechner and others following a scheme for testing pigeons designed by Charley Ferster at Harvard (Ferster & Aprison, 1960). This device held eight subjects in pie shaped divisions of a circular test chamber. The center of the circle contained a motor that could move one cage into the testing position. A second motor system could move an intelligence panel consisting of stimulus lights, two levers, and a liquid reinforcement delivery system into the test cage. All of this could be controlled by one of the largest relay laboratories used for the study of operant behavior. The central control room was approximately 150 feet long, with a two-sided relay rack running from floor to ceiling, 20 feet above. Access to the rack was provided by a pair of ladders that were attached by wheels to a rail that ran the entire length of the room. With a total of 13 rat rotors each holding 8 rats we could run 104 rats a day on as many as 13 different procedures.

To record the volume of data produced every day in these test chambers was a problem given the technology of the 1950s. To begin with we had a bank of 400 electro-mechanical counters that also could be electrically reset. We partitioned these counters between the 12 or 13 experiments running concurrently, and recorded the results at the end of each of the three daily one hour sessions by photographing the bank of counters with two electrically operated German cameras. We used one main camera and the second served as a backup in case the first failed.

Of course there were several drawbacks to this system. First, the volume

of data required a full time technician to develop the films and to project the results onto a screen, from which the data would be transcribed onto forms on a daily basis. Second, figuring on 200 responses per hour from ratio type reinforcement schedules we could get 600 IRTs per day from 3 sessions per subject leading to 62,400 responses per day from our rat lab. That's a lot of numbers. We predistributed our data into IRT bins which reduced our data to 9,600 data points per day. Of course we used the ubiquitous and revered cumulative recorders as well to monitor ongoing performance and to provide some data analysis.

Francis Mechner devised a solution to these problems. Our laboratory had the first on line transistorized digital computer used in behavioral psychology. In 1958 transistorized computers differed greatly from the mini and micro computers of the present time. It was again necessary to record interresponse times on a magnetic tape for later analysis. The computer was capable of analyzing only one performance at a time. However, technology had advanced enough so that the tape could be run more slowly during the experiment and faster during analysis. Since it was a multi-channel tape with 100 channels, it could keep a record of the temporal characteristics of one lever on each channel. Data were recorded 24 hours per day except for a 5 minute period in the morning when the tape reel was removed and replaced with a fresh tape.

The computer had a memory of 140 cells and each cell could hold a four digit decimal count. However, compared to the multi mega bytes of modern computers, this small memory posed some problems in analyzing the massive amounts of data our laboratory produced. Moreover this computer was programmed by means of patch cords using one or more patch cord panels for each program. The elements that were programmed were individual logic modules consisting of Flip-Flops, AND gates, OR gates, inverters, etc. We would sort the coded data coming from the tape recorder, channel them into the 140 cell mem-

ory and then dump the resulting distributed data onto fourteen punch cards per session.

We then proceeded to carry these cards to a Burroughs clone of the IBM 650 for further analysis and graphs. At least this computer could be programmed in Fortran using a paper tape punch. It usually took only four hours per day to run the cards into this computer and to produce the reams of graphs that we desired by the end of each day.

The major drawbacks of this system were many, but were due to the limited technology of the time. First, it was horrendously expensive. The computer cost 150,000 1958 dollars, which in constant terms still exceeds the equipment budgets of even the best funded research labs in our poorly funded field. Second, the system was difficult to use, and really required a trained expert to do the programming. Each data analysis program could require many days to develop with the patch cord system. Because of the involved wiring, it could take many days to debug even simple problems with the programs. Also each panel would have to be torn down to change a program for a new procedure. Panels were too expensive to store in a library of programs, but had to be reused. Third, the system still required a full time technician to monitor and manipulate the tape and data acquisition system and now that position required the title and salary of a computer operator. Finally, the main frame time used to process this volume of data was very expensive and the main frame also required programmers and operators.

My next experience in instrumenting a behavioral research laboratory came in 1963, after I joined Nat Schoenfeld as co-principal investigator on a research project housed in a VA hospital in Montrose, NY. The project employed from two to seven graduate students and most of them did their doctoral research in these facilities. The Digital Equipment Corporation had just announced their revolutionary PDP-8 computer priced low enough for scientific research projects. For an initial price of \$18,000 one could obtain a computer with 4k of mem-

ory and an ASR33 teletype that served not only as a terminal and printer, but also had a 10 byte per second paper tape reader and punch for program storage. Best of all it had provision for interfacing the electrical connections between computer registers and high amperage external devices such as feeders, stimulus projectors, lights, and tone generators.

The major drawback of this system was the effort involved in programming it to provide for control of contingencies and for data acquisition. The computer had to be programmed in machine language with arcane instructions such as load the accumulator, add the contents of memory location 30 to the accumulator, etc. If one could not afford the expense of an optional hardware arithmetic unit, the use of subroutines of several hundred machine language instructions was required just to multiply two numbers. Very little software was provided with the computer. All you could get in those days was a crude editor and a compiler for translating mnemonics into computer instructions. Programming this machine to handle even one operant reinforcement schedule could literally take months.

However, while we were awaiting delivery of this computer (which actually took 12 months after it was ordered) I conceived of the idea of writing software that would translate state notation into computer code. Let me mention that state notation was based both on the earlier Mechner notation (Mechner, 1959) and on state graphs used by electrical engineers to design computer hardware. Mechner notation had been developed to explain the intricate features of the two lever reinforcement schedules in a graphical fashion. I adapted state notation to improve various features of the notation and to include notation of data acquisition as well. One day while driving to work the notion of writing a compiler to translate state notation of reinforcement schedules to machine language occurred to me. (By the way, I got a speeding ticket that day because I became so excited with the idea I forgot to watch the speedometer—or look out the rear view mirror.)

It would have several advantages. One

could expect that even graduate students could learn state notation. It would be unreasonable to expect all of them to learn machine language computer programming. If they learned state notation, I would not have to code their experiments myself. It seemed that a few months of effort could produce a compiler and run-time-system that would allow the computer to run more than one experiment at a time with associated data collection. Since the programming would use state notation, which is more natural for behavioral scientists than computer machine language, the scientist's time could be devoted to reading the literature, writing papers, comparing different techniques of data analysis, and generally becoming more productive. It would no longer be necessary to spend enormous amounts of time on instrumentation and data acquisition.

Living through the computer revolution was an exciting event. In a few years mass storage devices became available that speeded the process of loading programs, so that developing a program became a much more rapid process. However, it was still necessary in the early days of disk drives, to use the computer for only one task at a time. It could run up to 12 individual experiments, or it could be used for program development, or it could analyze data captured in the experiments, but it could not do all of these jobs at the same time. This led, of course, to getting a second computer that was to be dedicated to programming and data analysis. The price of the second computer had fallen to one half of the first PDP-8 through the yearly advances in technology that have become commonplace in electronics. Of course, having a second computer was a temptation. One could simply interface it and then more experiments could be conducted daily. However, once again, midnight programming sessions were necessary to analyze the data.

At about the time it seemed necessary to get a third computer, I moved to WMU. In the middle 70s, computer software also started to advance, providing us with a multi-tasking operating system.

This meant that the computer could be used to develop programs and to analyze data while controlling the experiments and capturing the data.

During these years the power of the equipment kept increasing while the cost kept decreasing. One technical advance that occurred was the beginning of computer networks. One or more laboratory computers could be linked to the larger university time sharing computer so that data could be easily transmitted to the central computer for archiving and data analysis. The central computer had expensive peripheral equipment such as plotters, high speed printers, magnetic tape data archiving, and expensive general purpose data analysis routines that were too powerful to be run on the smaller laboratory systems.

More recently, modern lab computers also gained the capacity of time sharing so that several people could work on different terminals while the computer was controlling experiments. Data could be examined while they were being generated, and networks began to provide transparent connections, so that users could work on more than one computer at a time. The fully automated laboratory had really arrived.

In summary, when using computers in behavioral research:

1. The scientist must decide upon the specific details of the operant procedure to be investigated using state graphs to spell out those details.

2. Once the procedures have been designed, the state graphs can be typed and translated into a working program in a matter of minutes.

3. A standard procedure including variables that will change throughout the experiment must also be designed. Then the scientist can write a job control program that will ask the technician questions including subject identification and weight, identification of variables such as drug dosage, etc., and specification of experimental variables such as ratio size, interval length, etc. If the scientist plans ahead, the job control program can be easily modified for a new experiment. Ninety percent of the job control can be

reused for any experiment. Only the details need to be changed across procedures.

4. A data analysis strategy needs to be designed as well and data analysis programs need to be written. A general spread sheet type of program such as RS1 or Minitab can be used to analyze the data captured in the experiment.

Daily conduct of the experiment can proceed almost automatically. The technician can log into the computer using his/her password. Messages left on the system by the scientist in charge can be printed at this point to alert the technician to special conditions for this session. The technician can then be presented with a menu that will lead him/her through testing the experimental apparatus and ask questions with prompts to obtain the identification of the subject and specification of the experimental variables. The session will then begin and data collected can be displayed on one or more video terminals so that progress can be monitored. At the end of the session the data can be sent to another computer for archiving or they can be automatically processed on the same computer while further experiments are being conducted.

This is the automated research laboratory of today.

Finally, I would like to mention the most elegant automated experiment in our field. When I was an undergraduate at Harvard, I was impressed by B. F. Skinner, and I looked up all of his publications at that time. I discovered a very early article on geotropism in ants in which he dipped ants in ink and then let them produce his graphs by tracking across graph paper arranged at various angles. This is the perfect example of automation in that the subjects of the experiment do all of the work!

REFERENCES

- Blough, D. S. (1955). Method for tracing dark adaptation in the pigeon. *Science*, 121, 703-704.
- Ferster, C. B., & Aprison, M. H. (1960). A multiple-unit pigeon apparatus. *Journal of the Experimental Analysis of Behavior*, 3, 165-166.
- Mechner, F. (1959). A notation system for the description of behavioral procedures. *Journal of the Experimental Analysis of Behavior*, 2, 133-160.
- Schoenfeld, W. N., Cumming, W. W., & Hearst, E. (1956). On the classification of reinforcement schedules. *Proceedings of the National Academy of Sciences*, 42, 563-570.