minicomputer system consisting of one or two heavily implemented computers will provide services that are impossible to obtain from time-sharing terminals. It may be true that for a few specific applications, the number-crunching capabilities of large systems may be essential; but, for almost all applications of computers in the laboratory, it now seems that minicomputers can serve our needs at a low cost.

In summary, I would like to repeat my request for a standardized notational language for process control. I also believe that the state graph system can fulfill this function. It is already being taught to many students of psychology as a communication aid. It could also serve as a general computer programming language.

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Discussion of "On-line computers in the animal laboratory"

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There is very little of a substantive nature that I can add to the excellent presentations made by Johnson, Anger, Church, and Snapper, and so I shall not try to amplify on their contributions. Instead, I shall offer some comments addressed to the general topic of this symposium, namely, the on-line use of computers in the animal laboratory. I shall do so with the following key questions in mind: (1) What are the principle objectives of animal research? (2) In what major ways has the on-line use of the computer assisted in achieving these objectives? (3) What is the character of some of the work that remains to be done?

PRINCIPLE OBJECTIVES OF ANIMAL RESEARCH

We all know the answer to the question of why psychologists initially became involved with animal research, but a brief restatement may help to sharpen these remarks.

Watson, in his famous manifesto, indicated the following: First, the use of animals permits us to avoid the perils of mentalistic explanations of human behavior. Second, working with animals in psychological research extends the implications of Darwin's theory of evolution. And third, by experimenting with animals in the laboratory, we are better able to control environmental variables and thereby to satisfy more fully the demands of natural science (Watson, 1913).

These are worthy objectives, but I cannot permit the opportunity to slip by without observing that animal psychology has not done too well by them.

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Some of us have been unable to resist the tendency to endow animals with the same mentalistic homunculi that Watson, Skinner, and others were, and still are, trying to avoid in the analysis of human behavior. This serves not only to confound us further, but does violence to a violence.

We do not yet have a broadly conceived animal psychology; the adjective is altogether too often employed as a euphemism for rat psychology.

Lastly, the need to specify carefully environmental variables has led to an overly restrictive view of the ways in which an organism is capable of interacting with the environment. We tend to ignore the rich variety of options available to the animal.

ACHIEVEMENT OF ANIMAL RESEARCH OBJECTIVES THROUGH USE OF THE ON-LINE COMPUTER

However, to the extent that the objectives of animal research have been attained, and by means of on-line computers, the following favorable appraisal may be made: First, the use of computer-programmed reinforcement contingencies assists the scientist in describing complex forms of behavior. Second, the time-sharing feature of the digital computer makes it easier to gather data from several experiments simultaneously, and consequently to decrease the burden of routine laboratory chores. Third, the data storage and retrieval functions of the on-line computer enable the scientist to make informed decisions rapidly, and this is especially important when the outcome of one phase of an experiment influences the procedure selected for the ensuing phase. And fourth, the on-line computer delivers information both to itself and to the scientist with speed and accuracy unmatched by that of the human operator.

But the very same features often are abused and,

instead of facilitating attainment of the objectives of animal research, actually retard progress toward them. And this is not the fault of the computer, but of the person using it.

I am sure that we are all familiar with the following symptoms of the computeritis disease: (1) *The diarrhea symptom*—this is manifested in the researcher's assumption that the more data, the better the experiment. (2) *The displacement symptom*—the more time spent in manipulating the computer, the more incisive the psychological research. (3) *The Lorenzian-territorial symptom*—the more expensive the computer, and the larger the laboratory in which it is housed, the greater the personal authority exerted either in the academic or in the institutional setting.

CHARACTER OF REMAINING WORK

I want to return to a theme struck earlier in discussing the objectives of animal research. One of them, you will recall, dealt with the need for a fuller description of the ways in which an organism interacts with its environment. Three points need to be made by way of elucidation. First is that there are various modes of such interaction (cf. Kornilov, 1930). Second is that the on-line computer is practically essential for coping with the many variables that are demanded by description of these interactions. And third is that I placed the psychological considerations before that of computer utility. It would be idle, if not ridiculous, to pose mainly those experimental problems which the computer can answer merely because it is peculiarly capable of answering them.

There are various behavioral ways in which a biological creature can relate to its environment. In this country, and mainly in this country, experimental psychologists have emphasized yes-no responding taken as a joint function of occurrence in time and of reinforcement contingencies. In contrast, but still within the realm of what we would call "operant behavior," Soviet scientists have been studying the discriminable content of the organism's movements, emission of forces, and the importance that these stimuli have for higher-order conditioning, as well as for response differentiation (cf. Ladygina-Kots & Dembovskii, 1969; Luria, 1969; Bernshtein, 1969; Zaporozhets, 1960). The phrase "discriminable content" is meant to emphasize the importance of feedback cues from kinesthesia and proprioception. Perhaps it is no exaggeration to say that in the American behaviorist's zeal to do away with nonoperational explanations of behavior, he has often neglected to take into account those advances in technology that sometimes render operational the previously nonoperational. For example, the characteristics of the biophysical cues of on-going movement may have been difficult to specify 15 years ago, but with the advent of transducers and of on-line computers, they are now not only measurable, but rigorously so.

The secondary reinforcing properties of food and of tokens rest upon their concurrent function as discriminative stimuli (Notterman, 1951). The same is true of discriminative stimuli that develop their cueing properties from the feedback stimuli accompanying the neuromuscular behavior of choice and of action. One need not reify the learning and performance processes involved. Since the researcher can now actually identify and measure different classes of these stimuli, he can experimentally manipulate the underlying processes and not take appeal to mythical entities.

As scientists, we are sometimes too loathe to accept the challenges of innovative methodology:

Shall we, in our fear of a return to the sterile aspects of past structuralism, stand aloof from the contributions of modern science that have rendered less mentalistic the facts of inner discrimination?

Shall we, in our fear of the teleological undertones to the words "purposivism" and "functionalism," ignore the evidence that lower forms of life (let alone man himself) can extrapolate in time from the immediate present, based upon cueing information provided by the momentarily changing values of current discriminative stimuli (Rosenbluth, Wiener, & Bigelow, 1943; Bernshtein, 1969; Notterman, Fillion, & Mandriota, 1971)?

Shall we, in our fear of being called mystics, consider as permissible evidence only those sources of information which bear the stamp of approval of Western science and continue to deny the existence of possibly important sources of peripheral and somatosensory stimulation? It is good that Harlow was not so prejudiced (Harlow, Harlow, & Suomi, 1971).

Shall we, in our fear of coming to view ourselves as merely robots, minimize the fact that, in important perceptual-motor types of behavior, we do indeed act as if we were on-line computers, programmed to function as error detectors and error correctors (Notterman, 1970; Fowler, Morgenstern, & Notterman, 1972)?

In summary, I have tried to face some of the broader implications of the main theme of this symposium. After quickly reviewing why it is that behavioral scientists first became involved with animal research, I went on to evaluate some of the contributions made to date by means of the on-line computer. Finally, I attempted to suggest certain additional ways in which creative use of the on-line computer can reach out and contribute even further to the excitement of research in the animal laboratory.

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Choosing a programming system for on-line control of research

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The papers presented at this symposium illustrate very nicely the problem that psychologists using small computers face today: What language should we use for software development? Johnson and Anger (1973) prefer to write programs to run their experiments in Assembly language, while they use either a floating-point interpreter or a FORTRAN compiler for data analysis. Church (1973), together with Howard Dyckman, has developed THICIE, a special-purpose operating system, which may be used for time-shared control of several concurrent experiments. For data analysis, Church uses a version of FOCAL that he has modified somewhat for his own needs. Snapper (1973), on the other hand, uses his SKED compiler for a variety of applications, including the control of operant experiments, monitoring of bioelectric signals, and data analysis.

To the novice, this plethora of programming systems and lack of standardization may be confusing, but in fact it represents a healthy development in the use of minicomputers in research. Until recently, the user had only one viable option open to him—do everything in Assembly language. There are still a number of individuals who masochistically adhere to this approach, but for someone who prefers to devote his time to psychology rather than to obsolescent computer technology, the advantages of high-level software are obvious.

If written properly, Assembly language programs make efficient use of core memory, but they are wasteful in terms of the programmer's time. The ratio of software/hardware costs is bound to increase dramatically if, as seems inevitable, the price of labor goes up while the price of computers comes down. For example, the staff of the Arthur D. Little Company has projected a cost of about \$400 for a basic minicomputer in 1980. The price of mass storage is expected to decline even more drastically during this decade as new technologies based on laser, magnetic bubble, or holographic approaches replace magnetic tape and rotating disk systems. These technological advances should have a major effect on the behavior of

psychologists who use real-time computers, for, as the average system becomes larger, it will become more feasible to program research using powerful and sophisticated languages. One consequence is that anyone with a modicum of programming experience on a large computer will be able to write software quickly and easily on the small-scale system of the future. As laboratory computers become more accessible to the masses, we, the devoted few who dedicated ourselves to the cult of Assembly language, will unfortunately, but inevitably, lose our status as resident gurus.

Fortunately, as this symposium has demonstrated, there is no need to wait until 1980 in order to use high-level languages on small computers; rather the problem is to decide which type of system best fits your current needs. One approach is to use a special-purpose operating system that is tailor-made for your particular research application, and Church's THICIE system illustrates this approach quite nicely. A number of other operating systems have been written for operant conditioning, psychoacoustic, reaction-time, and signal-averaging applications, etc. If they have been well designed, specialized operating systems can be extremely useful. Because they are restricted to a small number of jobs, they tend to be undemanding of core memory and they may allow fast execution of instructions, a factor which is important in paradigms where critical timing is required.

The main disadvantage of specialized operating systems is that they usually can run only on one computer—that of the individual(s) who wrote the system. That is, they are usually written with one laboratory in mind, and they are therefore tied down to particular configuration of computer, peripherals, interface, and apparatus that happen to be present in that laboratory. This usually means that if you want a special-purpose system to run on *your* computer, you will have to write it yourself, a process that may take several years. The resulting development costs may be justifiable if you are sure that you will still be running the same type of experiments in 2 or 3 years. Otherwise, special-purpose systems are probably useful only if you can find one that runs more or less as is on your configuration.