COMPUTING IN PSYCHOLOGY

AN INTRODUCTION TO PROGRAMMING METHODS AND CONCEPTS

JAMES H. REYNOLDS

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Preface

Anyone familiar with the field of psychology is well aware of the recent and substantial growth of computer usage in virtually every arena of the psychological domain, including the construction of computer models of numerous psychological processes, the use of the computer in real-time control of laboratory experiments, its use in clinical and educational assessment, as well as its use as a tool for statistical analysis. Most students who go beyond the introductory level of psychology now become familiar with the latter usage when they take courses in statistics and research design. They are much less likely, however, to study or develop programming skills in the other important types of computer usage. The aim of this text is to introduce to upper-level undergraduate and beginning graduate students in psychology the computing skills and concepts that will allow them to understand and write these several kinds of advanced computer programs. It assumes the student has already completed one semester of computer programming using Pascal, BASIC, or FORTRAN at either the high school or college level. Its emphasis is upon the development and use of intermediate programming skills using the Pascal language, and upon providing an introduction to the LISP language, which has become so important in modeling human psychological functions.

The text is divided into four major parts. Part I (Chapters 1 and 2) provides a perspective of the ways in which psychology and computing in-

teract, how the advent of computing and information-processing has influenced psychological theory and methodology, and also reviews the basic principles of structured programming. Since Chapters 2 through 8 use the Pascal language, students whose prior programming experience has been with BASIC or FORTRAN should also read Appendix A while working through Part I. This appendix shows programmers who are unfamiliar with Pascal the similarities between Pascal and other languages. It then introduces the unique features of Pascal that will be needed when reading Parts I, II, and III of this text. Appendix A may also be useful for students who have studied Pascal but wish to review it before going on to Part II of the text. (The appendix is *not* intended, however, to be used as a substitute for a beginning course in computing; it is a review for those already familiar with basic programming concepts and skills, and students with no previous programming experience should first study one of the many introductory texts in Pascal before attempting to use this book.)

Part II presents, both by descriptions and through examples, the basic principles and objectives of computer modeling of psychological processes. It distinguishes between a computer model, which is viewed as a formal theoretical statement, and computer simulation, which in this text is taken to be that aspect of a computer program which applies the theoretical model to some behavioral situation. The limitations of computer modeling, as well as its benefits, are presented in detail over the several chapters in this part.

The chapters in Part II present, in turn, a basic model of a perceptual process, a simple model of memory, and one of the first computer models of a personality process. All programs in this part are written in Pascal. The emphasis, as in all of the chapters in the text, is upon programming; but each chapter begins with a summary description of the psychological background for the model, giving a quick review of psychological terms, definitions, and experimental findings related to the topic. Following this psychological introduction, the typical chapter will present various segments of a program that models the theory or process reviewed, introducing programming methods and explanations of concepts as needed.

Since the main intent is the development of skills and concepts for students whose previous programming experience has been only at the introductory level, all of the programs presented are introductory to intermediate in difficulty, and no attempt is made to present program analyses or listings of any of the advanced models that are found in the current research literature. Students wishing to learn more about either advanced computer modeling or the general topic being covered will find additional information in materials recommended in the Suggested Readings section at the end of each chapter. After reading each chapter the student should

then write the program(s) described, including additional elaborations or variations as suggested in the exercises found at the end of the chapter.

Part III consists of two chapters that introduce the reader to other ways that psychologists make use of computers; particularly microcomputers. The programming language used for illustration in each of these chapters is Pascal. Chapter 7 describes the various ways that clinical, social/personality, and educational psychologists make use of computers to score various types of personality or other tests and questionaires, to draw test profiles, and conduct automated interviews. Chapter 8 then describes elementary programming techniques used in real-time control of laboratory experiments. Each of these topics can, of course, quickly become very technical. The intent of the chapters is not to introduce all of the technicalities needed for writing professional programs in these areas, but rather to inform the reader about the possibilities of such usages, about some of the problems that are inevitably encountered, and also to provide some basic programming examples that will get the student started. Advanced texts and articles are then recommended for those who wish to pursue these fascinating and useful topics further.

Part IV, consisting of Chapters 9 through 13, introduces the programming language LISP and shows how it can be used to model various components of such higher mental processes as concept formation, language analysis, and problem solving. A working knowledge of LISP has become increasingly important to psychologists because, as anyone who has had any contact with computer models in cognitive psychology or artificial intelligence knows, most of the sophisticated models involving higher mental processes and the use of natural language are programmed in LISP. The intent of this last part of the text is to introduce the psychology student to this important language in an illustrative and non-technical way that shows both its similarities and its differences relative to the language or languages most students learn first. The limited introduction given here will not make anyone an expert, but if the examples are studied and the exercises completed, the reader will be in a good position to understand existing models written in LISP and also to continue building his or her LISP programming competency independently.

The book can be used in any of several ways depending upon the intent of the course and the programming sophistication of the readers. Students who are already good programmers and have some background in psychology can easily complete the text in one semester. For psychology students whose programming skills are not yet strong, the first three to four weeks of a semester can be used to review a good text that is simply intended to teach Pascal, and then use the Pascal chapters 1 through 8 of this text to provide an introduction to psychological uses of computers. Finally, for those interested primarily or only in psychological theory and

computer modeling, Chapters 1 through 6 followed by Chapters 9 through 13 will give a comprehensive introduction.

I want to express thanks to a number of people for their help and guidance in the construction of this text. Students in several of the courses I have given on this topic have used various chapters in manuscript form, and have offered many helpful reviews and suggestions. The entire manuscript and most of the programs were written, tested, and printed on the computing facilities at the Colgate Computer Center, and I give sincere thanks to the Center's staff—and particularly Jeanne Kellogg—for their help, advice, and patience. Finally, thanks are due to a number of anonymous reviewers and to my production editor, Debbie Ford, for her cooperation and constructive comments.

James H. Reynolds

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Interactions Between Psychology and Computer Science: An Overview

Computer science has had a major influence upon the older discipline of psychology in two significant contexts—its *theory* and its scientific *methodology*. The impact upon psychological theory is apparent in the phrase *information-processing psychology,* which can be found nowadays in virtually any psychological text and which, indeed, is considered by many psychologists to be synonymous with *cognitive psychology,* the term given to the most influential type of current psychological theorizing. The second influence, upon methods, relates to the substantial and seemingly ever-increasing use of the computer by psychologists as a tool for such psychological chores as data handling, test scoring, statistical analysis, interviewing, and running or controlling experiments in the psychology laboratory.

This text examines in some detail both of these impacts. In the first two chapters we will review both the historical development of the interaction between computing and psychology and also the general principles of structured programming with Pascal.* Beginning with Chapter 3, the general strategy will be first to describe a given psychology topic or problem, then analyze it from an information-processing viewpoint and write one or

*If you wish to review the details of the Pascal language that are necessary for understanding the Pascal problems presented in this text, see Appendix A.

more computer programs that enhance, clarify, or solve the questions asked. Our purposes are twofold: (1) to give the reader insight into the types of aids and enrichments that computing is bringing to psychologists, and (2) to develop your programming skills to the point where you can write and understand programs and program types that are meaningful and important to the discipline of psychology.

We begin by taking a brief look at the historical development of the interaction between computing and psychological theorizing.

THE THEORETICAL INFLUENCE

Theoretical Trends in Psychology: A Brief History

Like most other disciplines, and particularly scientific disciplines, psychology has experienced a number of major theoretical changes as it has grown and developed. Until the late nineteenth century there was really not a separate discipline that could be formally called "psychology" in its modern, scientific sense. Several other disciplines had worried about the topic, of course—physiology, medicine, philosophy, for example. But around 1879 the first psychological laboratory designed strictly for the investigation of psychological functions was established by Wilhelm Wundt at the University at Leipzig, Germany. Most psychologists consider this date to mark the beginning of an independent discipline devoted specifically to the scientific study of the mind and behavior of humans and other animals.

Since 1879, the field of psychology has entertained a variety of viewpoints about how best to conceptualize human behavior and mental processes, some of which have lasted while others have not. One major viewpoint, familiar to most educated people, has been Freud's psychoanalytic orientation. He proposed that we can look upon and understand behavior as being driven by basic motives which act as energies that continually build in strength and must be released in the form of behavior. Freud's theory attempts to describe in detail these energies, how they are controlled and directed, and their behavioral consequences. This viewpoint is, of course, a long-standing one that maintains a powerful influence on psychology today.

Although it is not our purpose to explore Freudian theory in detail, it is important to analyze briefly some of the terminology of the preceding paragraph in order to clarify certain rather complex concepts that will be needed later. First, one should distinguish between "viewpoint," as used above, and "theory." Freud's *theory* consists of a detailed set of constructs and a set of postulates stating how these constructs interact with each other to determine the way a person will behave at any given moment. But more about that in a minute. For now, simply contrast the details of such a theory with Freud's *pretheoretical view* of looking at a person generally as an energy

(he called it "psychic energy") system. The philosopher of science Thomas Kuhn (1970) has referred to these pretheoretical viewpoints upon which theories eventually get built as *paradigms*. Thus using the terms of modern philosophy of science, we can say that the Freudian paradigm (viewing humans as a psychic energy system whose actions depend upon how basic energies are controlled and directed) is one influential paradigm in psychology today and it has been the basis for a number of particular theories, including those of Freud, Jung, and others.

Having gotten a feel for what paradigm means, look for a moment at the term *theory*. Different theories can vary dramatically from each other, of course; but when one must evaluate or compare them there are a few major features that appear quite generally among nearly all of them, and these commonalities can serve as focal points for analyzing and comparing theories. Probably the two most common components (mentioned above) are *constructs* and *postulates*. A construct identifies an assumed structure that the theorist uses to help explain the phenomenon in question. Most often the construct is an abstraction—that is, it is not a real or physical "thing" that can be pointed at, or felt or touched, but rather is a hypothetical construction proposed by the theorist as having explanatory importance. Freud's constructs of ego, id, and superego are good examples. He did not pretend that they were physical entities; instead, he defined them as hypothetical psychic systems, each of which has certain assumed properties and characteristics.

Sometimes constructs that have no physical identity at one time become identifiable at a later time. For example, the electron was first proposed as an explanatory construct, and only later was the technology developed that permitted physicists to identify electrons physically. But physical verification is not a necessity for a construct to be of value; "quarks" in physics, "voter appeal" in political science, and "beauty" in the arts all help us to understand some very complex phenomena, regardless of whether they may become physically identifiable at some future time. As we shall see, many of the constructs proposed by psychological theorists are of a type that will never be identified as physical entities; nevertheless, they can have powerful explanatory capabilities.

The other major component common to nearly all psychological theories, and of interest to us at the moment, is the *postulate*. A postulate is a kind of working assumption, often given without proof, which presents a description or a proposal (usually verbal) about some aspect of the theory. Postulates may refer to a number of different components of a theory. They might state how the proposed constructs interact with each other, or what the properties and processes of a construct are, or what is assumed to be the effect of nature upon a system, and so on. For example, Freud postulated that the id stores the energy of the psychic system, and that the ego and superego control and direct how the energy is used in overt behavior.

This brief discussion of paradigms and theories is, of course, grossly incomplete. The terms reviewed are themselves controversial and refer to only a small part of what philosophers of science have to say about the nature of theories and theory building. But they will suffice for the moment as an aid in putting into perspective three other paradigms that are of particular interest to us—*behaviorism, neo-behaviorism,* and *information-processing.*

In the early 1900s a group of psychologists became disenchanted with contemporary attempts to propose and validate constructs describing the structure and content of the mind. Led by the American psychologist John B. Watson, these theorists claimed that, because "mind" is itself a construct and thus not knowable as a physical entity, it is not possible to describe and explore it scientifically.

They advocated that the discipline of psychology should ignore mentalism and concentrate only upon the study of those phenomena and events that are observable, measurable, and capable of being examined empirically. For psychology, such aspects are limited to (1) the surrounding environment present at the time an organism does something (that is, the *stimulus*), and (2) how the organism behaves in, or as a consequence of, that environment (that is, the *response*). This paradigm, which became known as *behaviorism* or stimulus-response (S-R) psychology, arrived at a time when many American psychologists were looking for something new and it quickly caught on and became a dominant psychological viewpoint. In essence, behaviorism insisted that there should be no mentalistic constructs proposing how the "mind" might be structured or what its processes might be. It has at times been referred to as a "black box" paradigm, signifying the attitude that we can never come to know the workings of that mysterious box referred to as mind.

In place of mentalistic constructs, behaviorism simply postulated *conditioning* as the theory explaining how and why people behave in the ways they do. The principles of conditioning were assumed to be part of the laws of nature. These principles are known by every student who has finished an introductory psychology course and they need not be reviewed here. But it is worthwhile simply to point out that the behavioristic paradigm did indeed propose a strong and concise theory, and for a number of years it produced significant research that has led to our understanding of basic learning processes in both humans and lower animals.

Despite remarkable early gains made by advocates of the strictly antimentalistic behaviorist paradigm, many psychologists eventually became concerned with the limitations of a paradigm that permits no theoretical constructs. Although they still agreed with the basic behavioristic doctrine that the only psychological phenomena ultimately available for scientific study are physically observable stimuli and responses, these pyschologists proposed that inferences could be made in a scientific manner about possible unobservable events or states presumed to intervene be-

tween the observable stimulus and response. This emerging *neo-behavioristic* paradigm thus permitted the reinstatement of certain hypothetical constructs as explanations of behavior, provided they were defined in such a way that they could ultimately be measured in terms of stimulus-response relationships. The arguments and justifications for this emergent paradigm were complex and took place over a number of years from the early 1940s onward—often amidst a great deal of emotion and perhaps a bit of illogic—among well-meaning theorists who wanted to preserve their scientific orientation while expanding their spheres of operation beyond the limits of strictly empirical (that is, observable) data. So the black box was opened, albeit a tiny bit, to permit certain formally defined constructs—such as intelligence, drive level, habit strength, and a few selected others—into scientific psychology.

Historically, neo-behaviorism has been a very powerful and important paradigm, and it remains so today. However, although it permitted a liberalization of the use of hypothetical constructs as explanatory theoretical mechanisms, it retained another major component of the older "pure" behaviorism out of which it grew. That component was a pretheoretical assumption that the behavior of the living animal organism can always be traced back to mechanistic processes determined by natural laws; for example, classical and instrumental conditioning. Taken to its logical conclusion, this assumption predicates that the human is a *passive system* that does not act in any way to determine its next response but instead responds as a mechanism conditioned to behave in certain ways in the presence of certain stimulus situations. Experimental psychologists adhering to the neo-behavioristic paradigm had difficulty justifying, and proving experimentally, that such complex behaviors as reasoning, problem solving, and the use of language are explainable strictly within the rules of conditioning. Thus the stage gradually was set for a willingness among pyschologists to shift to a paradigm other than behaviorism; namely one that would allow for explanations of complex psychological functions yet still ensure a continuation of a scientific, experimental approach to the study of psychological phenomena.

The Shift to the Information-Processing Paradigm

A. Multiple pressures lead to a shift. The theoretical orientations of many experimental psychologists changed over the decade of the 1960s from a predominantly behavioristic paradigm to the *information-processing* paradigm. The impetus for the shift came from several sources. One, of course, was the general and increasing disenchantment with behaviorism described above. However, theoretical views tend to remain, despite their inappropriateness or inadequacy or incompleteness, until better or more fruitful directions come along. Other sources pushing toward a change in

the direction of information-processing included research in verbal learning, linguistics, human engineering, and information theory. Results obtained in all of these research areas pointed away from the passive-mechanistic view of human behavior toward the more realistic proposal that human beings—and indeed lower animal organisms as well—*actively reorganize* or *process* the stimuli impinging upon them from the outside world, and that their responses are based upon this active processing rather than, or in addition to, their history of prior conditioning.

Each of these influences has its own detailed history, which, because of the specificity of our main topic, need not be reviewed here. More pertinent for us is the fact that this theoretical unrest with behaviorism was occurring at about the same time that the development of the modern digital computer and the corresponding development of the discipline of computer science were taking place. While these latter events cannot be considered the sole basis for the resulting change in theoretical psychology, they certainly played a major role in provoking a shift away from behaviorism to a new paradigm. The basic assumption of that new paradigm is that humans are not passive mechanisms who make conditioned responses to stimuli. Rather, they are symbol-manipulating systems that can receive information and actively process and reorganize it, and use that information as a basis for their behavior.

What really was at the core of the problem and what was the proposed solution? Consider for a moment the (relatively) simple behavior of picking up a fork when one sits down at the dinner table. The strict behaviorist would explain this behavior solely in terms of conditioning; for example, the organism has been conditioned to respond to the stimuli present (the plate, table, fork-on-table, internal sensations of hunger, and so forth) with movements that result in grasping the fork in a certain way. This learned response, argues the behaviorist, results from a past history in which conditioning processes reinforced grasping the fork and extinguished alternative (incorrect or undesirable) responses. The result of this history is that the organism's present response is now highly predictable and automatic; furthermore, it is explainable in terms of the natural laws of conditioning. Thus, there is no reason to invoke mentalistic processes to account for the behavior.

Conversely, the information-processing view would include in the account of this simple behavior the proposal that the fork and plate are symbols that evoke in the organism the retrieval of memories that include such information as what these objects are called, their purpose, and the conditions under which they are used. Further, according to this theoretical viewpoint, these symbolic activities may in turn lead to an active search to determine if all of the latter conditions have been met, and perhaps to a decision by the organism (based upon the information processed) to pick up the fork. Clearly major differences exist between these two theoretical