ROBERT L. SOLSO

COGNITIVE PSYCHOLOGY

COGNITIVE PSYCHOLOGY

ROBERT L. SOLSO
University of Idaho

Under the general editorship of
Jerome Kagan, Harvard University

Harcourt Brace Jovanovich, Inc.
New York/San Diego/Chicago/San Francisco/Atlanta

ISBN: 0-15-507870-4
Library of Congress Catalog Card Number: 79-65964

Printed in the United States of America

Cover Illustration by Gene Szafran
Technical Illustrations by Vantage Art
Original Cartoons by Sidney Harris

ILLUSTRATION CREDITS

Page 10 By permission of the British Library/28 Escher Foundation, Haage Gemeentemuseum, The Hague/149 The Bettmann Archive/150 Culver Pictures/177 From "Information and Memory" by George A. Miller. Copyright © 1956 by Scientific American, Inc. All rights reserved.

Figures 1.5, 3.2, 14.13, 14.14, 14.15 From *Explorations in Cognition* by Donald A. Norman, David E. Rumelhart, and the LNR Research Group. W. H. Freeman and Company. Copyright © 1975.
Figures 15.1, 15.2, 15.17 From *Computer Models of Thought and Language* edited by Roger C. Schank and Kenneth Mark Colby. W. H. Freeman and Company. Copyright © 1973.
Figures 15.4, 15.7, 15.9, 15.10, 15.11 From *The Thinking Computer: Mind Inside Matter* by Bertram Raphael. W. H. Freeman and Company. Copyright © 1976.
Figures 4.15, 15.12, 15.13, 15.14, 15.15 From *The Structure of Human Memory* edited by Charles N. Cofer. W. H. Freeman and Company. Copyright © 1976.

COPYRIGHTS AND ACKNOWLEDGMENTS

For permission to reprint copyrighted material, grateful acknowledgment is made to the University of Illinois Press for a selection from *The Mathematical Theory of Communication* by C. E. Shannon and W. Weaver, copyright © 1949 by the University of Illinois Press; to Harlin Quist Books for *Story Number 2* by Eugene Ionesco; to Cambridge University Press for "The War of the Ghosts" from *Remembering: A Study in Experimental and Social Psychology* by F. C. Bartlett; to Basic Books for a selection from *Artificial Intelligence and Natural Man* by Margaret Boden, copyright © 1977 by Margaret Boden, Basic Books Inc., Publishers, New York; to Basil Blackwell Publishers Ltd., Oxford, for a selection from *Computing Machinery and Intelligence* by A. M. Turing; and to the North-Holland Publishing Company, Amsterdam, for a selection from "Turing-like Indistinguishability Tests for the Validation of a Computer Simulation of Paranoid Processes" by K. M. Colby, F. D. Hilf, S. Weber, and H. C. Kreamer.

Preface

That psychology has a long past but a short history is an observation particularly applicable to cognitive psychology. The questions of main interest to the contemporary cognitive psychologist—how we perceive, how we acquire knowledge, understand the world and each other, solve problems, how we store information in memory—all these are questions people have puzzled over for centuries. But it is only recently that these questions have been examined from the perspective of a scientific discipline. This examination began in the nineteenth century, when psychology gradually emerged from philosophy with the insistence that observations concerning the mind had to be quantified. Although contemporary cognitive psychology, about twenty years old, has its roots in such traditional experimental psychology, it differs from it in both method and interpretation of data, and has a view of human behavior broader than the one of the early experimentalists. This book aims to describe and summarize the developments that have derived from this new orientation and, in so doing, to give a comprehensive and unified picture of contemporary cognitive psychology.

The number of articles and research reports reviewed in preparation of the manuscript was many times that now presented in the completed book. Many worthwhile reports, then, have been omitted simply because their inclusion would have made for an unmanageably long volume. Those chosen were selected, first, according to whether they represented the mainstream of cognitive psychology. Of those satisfying the first requirement, studies that changed the course of cognitive psychology, added a new dimension, or opened a new area to research were given preference over those that amplified or validated results of earlier studies. Final winnowing was on the basis of the interest inherent in the experimental design or the manner of presentation; of course, no significant source was discarded simply because it was not readily accessible or was inelegantly presented.

The book is meant primarily for use at the undergraduate level, though, of course, the line between undergraduate and graduate education is no more fixed than is the curriculum of a given institution or the backgrounds of its students. I have avoided jargon and technical terms wherever possible. The book progresses, in general, from sensation to thinking. The first part—the detection and initial processing of information—encompasses perception, pattern recognition, word and letter processing, and attention. The second part, on memory, devotes separate chapters to memory models, short-term memory, long-term memory, semantic memory, and mnemonics. The last part, which deals

with "higher-order" cognitive functions, includes chapters on imagery, language, developmental cognition, thinking, and computer simulation of cognition.

Each chapter should require about a week of classroom time. In some cases it will be useful to exclude some chapters and concentrate on others. For example, a course emphasizing memory might concentrate on Chapter 1 and Chapters 5–11, while one emphasizing the sensory-perceptual side of cognitive psychology could concentrate on Chapters 1–5 and perhaps 13 and 15.

Two experiences greatly influenced my decision to attempt a comprehensive book on cognitive psychology. The first was serving as coordinator of the Loyola Symposium on Cognitive Psychology between 1972 and 1974 and my subsequent editing of the three volumes based on it. This put me in direct contact with many of the theorists in the field and with their writings, providing me with a corpus of information. The second was a year spent at Stanford University, where Professor Edward E. Smith's lucid exposition of courses in human memory shaped my orientation toward cognitive psychology.

Deserving of particular acknowledgment for their contribution to the making of this book are the hundreds of previous writers and researchers whose work is its basis. I have made every effort to report accurately each author's results and interpretations—even where I differed with him or her. Acknowledged with thanks, too, are the comments (and patience) of undergraduate and graduate students from the University of Idaho, Stanford University, and Washington State University who used this book in manuscript form.

I wish also to express my appreciation to the many colleagues and friends listed below who read and criticized parts of this manuscript. Each provided expert advice that greatly enhanced the final product.

Charles Clifton, University of Massachusetts
Fergus Craik, University of Toronto
A. Brady Farrand, Stanford University
Robert Gregory, University of Idaho
Robert Haygood, Arizona State University
Keith Holyoak, University of Michigan
Ronald Hopkins, Washington State University
Earl Hunt, University of Washington
Connie Juel, University of Texas
Jerome Kagan, Harvard University
Judith Kroll, Rutgers University
Carol Krumhansl, Rockefeller University
Dominic Massaro, University of Wisconsin
Mark Mayzner, Loyola University
Douglas Medin, University of Illinois
David Meyer, Bell Laboratories
Philip Mohan, University of Idaho
Gary Olson, University of Michigan
Dorothy Piontkowski, Stanford University
David A. Rosenbaum, Bell Laboratories

Professor Fred Morrison of the University of Minnesota wrote most of Chapter 13; his skillful contribution is deeply appreciated. I wish also to express particular appreciation to Professors Earl Hunt and Mark Mayzner, whose expert advice significantly affected the content and organization of the book. Professor

Charles Clifton of the University of Massachusetts labored over each revision of the manuscript and deserves special thanks and praise. The highly skilled and professional staff at Harcourt Brace Jovanovich has my sincere thanks—especially Judith Greissman and Phil Ressner. Barbara Scrivner typed the manuscript from my handwritten notes, and her skill and patience are gratefully acknowledged.

In a discipline like cognitive psychology, in which new research is the keynote, a book can never be said to be truly completed; nevertheless, I can now genuinely appreciate fellow Nebraskan Willa Cather's comment that "there are few experiences more delicious than the completion of a book."

ROBERT L. SOLSO

CONTENTS

PART 2 MEMORY: STRUCTURE AND PROCESS

PART 3 HIGHER-ORDER COGNITION

The most fundamental problem confronting cognitive psychology today is how to represent theoretically the knowledge that a person has; what are the primitive symbols or concepts, how are they related, how are they to be concatenated and constructed into larger knowledge-structures, and how is this "information file" to be accessed, searched, and utilized in solving the mundane problems of daily living.

—John R. Anderson and Gordon H. Bower

1 INTRODUCTION

Cognitive psychology deals with how we gain information of the world, how such information is represented and transformed as knowledge, how it is stored, and how that knowledge is used to direct our attention and behavior. It involves the total range of psychological processes—from sensation to perception, pattern recognition, attention, learning, memory, concept formation, thinking, imaging, remembering, language, emotions, and developmental processes—and cuts across all of the diverse fields of behavior.

Although this chapter is called an "introduction," in a sense the topic of the entire book is an introduction to cognitive psychology. This chapter, however, in contradistinction to the remainder of the book, offers a general picture of cognitive psychology and reviews its history and the question of how knowledge is represented in the human mind.

We begin with an example of a common event; a motorist asking a policeman for directions. Though the cognitive process involved would seem to be simple, it is not.

Motorist: Say, I'm new in this town; can you tell me how to get to Pay-n-Pak?

Policeman: Well, did you want the sporting goods or hardware, because they have two different stores.

M: Oh. Well . . .

P: I guess it doesn't make any difference because they're across the street from each other.

M: I'm looking for plumbing actually; a novelty toilet seat.

P: Well, they've got that in hardware.

M: In the hardware.

P: Yes, in the plumbing area. So . . . do you know where the coliseum is?

M: Is that the building with the kind of cone-shape or is that the one that . . .

P: No, but you know where that is—that's the Expo site; remember, they had the Expo in 1974.

M: Oh yes, I know where the Expo is.

P: Okay, that's the Expo site. Well, it's kind of hard to get there from there, but if you go down from where you are now, if you go down this street one stop-light and then to the flagpole, turn right one block to another light, and then make a left, go over the train tracks past the lake to the next stop-light near the old mill . . . Do you know where the old mill is?

M: Is that the street on the bridge that says one-way street up to the old mill?

P: No, it's two-way.

M: Oh, it must be the other bridge. Okay, I know which street . . .

P: Okay, you go up past the old mill—that's where Klinkerdagger's is—and you turn left—no, right—then one block turn left and that's Boone. On Boone Street you can't miss it. It's on the right-hand side of the street.

M: You're kidding. I'm staying in a motel on Boone Street.

P: Yeh?

M: I was going the wrong direction. Here I am in the other end of town. Two blocks from my motel room! I could've walked there.

P: What motel are you in?

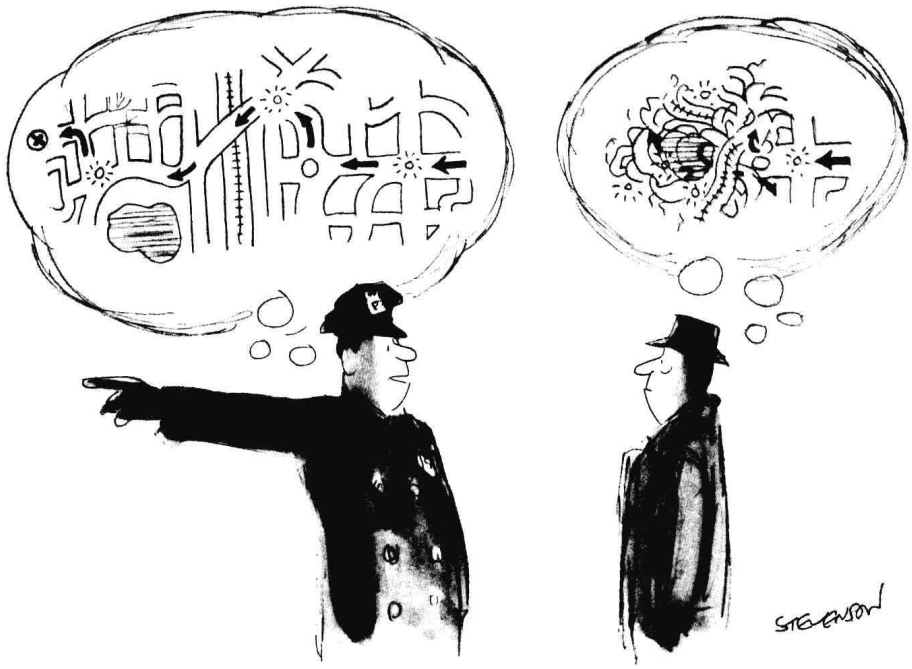
M: The Oxford Motel.

P: Oh, the Oxford. Couldn't you get a better room?

M: No, but they have a pretty good library.

P: Huh?

The episode described took less than two minutes, yet the amount of information perceived and analyzed by the two people is staggering. How might a psychologist view the process? One way is in simple stimulus-response (S-R) terms: for example, a stop-light (stimulus) and a left turn (response). Some psychologists, especially those representing a traditional behavioristic approach to psychology, feel that the entire sequence of events can be adequately de-



Drawing by Stevenson; © 1976 The New Yorker Magazine, Inc.

scribed (in a much more detailed way) in these terms. This position, however, although it has certain appeal in its simplicity, cannot adequately describe the cognitive systems involved in the exchange. In order to do so it is necessary to define and analyze specific components and then integrate them into a larger cognitive model. Cognitive psychologists examine the complex phenomena of human behavior from just such a standpoint.

In the example cited above, what are the specific components and how might a cognitive psychologist view the episode? We can begin by making certain assumptions about the cognitive characteristics possessed by the policeman and the motorist, which include:

- The ability to detect and interpret sensory stimuli and meaningful events
- The tendency to focus on certain sensory stimuli and to disregard others
- A detailed knowledge of the physical characteristics of the environment
- The ability to abstract certain parts of the event and integrate those parts into a well-structured schema that gives meaning to the total episode
- The capacity to retain immediate events and to integrate those events into an ongoing sequence
- The ability to form an image of a "cognitive map"
- An understanding on the part of each of the role of the other
- An inference that the directions can accurately be translated into a complex motor response (driving an automobile)
- The ability to quickly recall from long-term memory specific information that is immediately applicable to the present situation
- The ability to translate visual events into spoken language
- The inability to perform perfectly

These assumptions can be integrated into a larger system, or cognitive model. One model commonly embraced by cognitive psychologists is an *information-processing model,* the historical development of which is discussed in some detail in Chapter 4.

An information-processing model assumes that cognition can be analyzed into a series of stages, each represented as a hypothetical entity during which certain unique operations are performed on incoming information. The eventual response (for example, saying "Oh yes, I know where the Expo is.") is assumed to be the outcome of this series of stages and operations: (for example, perception, coding of information, recall of information from memory, concept formation, judgment, and language production). Each stage receives information from preceding stages and then performs its unique function. Since all components of the information-processing system are in some way related to other components, it is difficult to identify an initial stage, but for convenience we can think of the sequence as starting with incoming stimuli.*

These stimuli—the environmental cues in our example—are not directly represented in the policeman's brain, but are transformed to meaningful symbols, what some cognitive psychologists have labeled "internal representations." On the most fundamental level, light (or sound) energy emanating from the perceived stimulus is *transduced* (converted) to neural energy, which in turn is processed through the abovementioned hypothetical stages to form the "internal representation" of the perceived object. This internal representation is understood by the policeman and, when combined with other contextual information, provides the basis for his answering of the question.

Two important questions raised by the information-processing model are the subject of considerable debate among cognitive psychologists: *What are the stages through which information is processed?* and *In what form is information represented in the human mind?* Although there are no easy answers to these questions, a major portion of this book will deal with both issues, and it will be useful to keep these questions in mind. One way cognitive psychologists have attempted to answer them is by incorporating into their research the techniques and theories of specific psychological disciplines, of which several are described below.

the domain of cognitive psychology

Modern cognitive psychology freely draws theories and techniques from eight principal areas of research (Figure 1.1)—perception, attention, memory, imagery, language functions, developmental psychology, thinking and problem solving, and artificial intelligence—each of which will be covered in its own chapter.

* It can be argued that the sequence of events starts with the subject's knowledge of the world, which allows him to selectively attend to certain aspects of the visual stimuli, while disregarding other aspects. For example, the policeman's description generally focused on where the driver would go; he did not (at least actively) attend to other cues: the buildings, pedestrians, the sun, other landmarks.

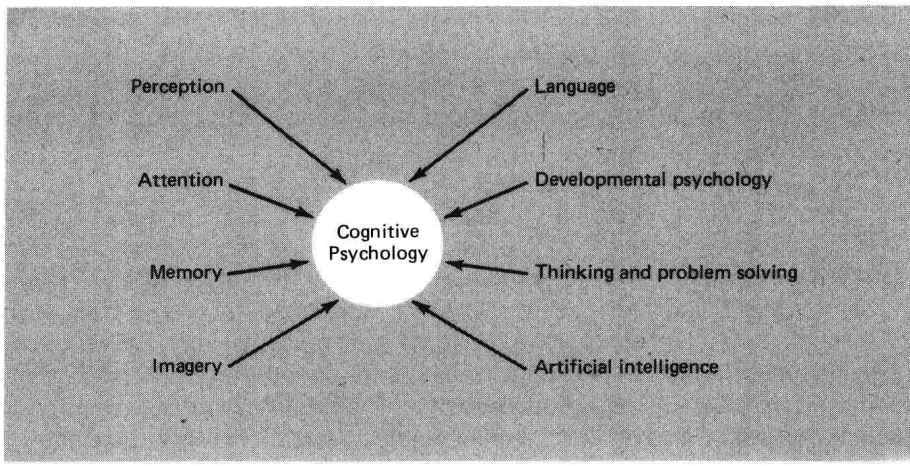


Figure 1.1 Principal research areas of cognitive psychology.

PERCEPTION

The branch of psychology directly involved with the detection and interpretation of sensory stimuli is *perception*. From experiments in perception we have a good understanding of the sensitivity of the human organism to sensory signals and—more important to cognitive psychology—of the way we interpret sensory signals.

The policeman's description of the street scene is essentially dependent upon his ability to "see" the pertinent environmental cues. "Seeing," however, is not a simple matter. The sensory stimuli—in this case, largely visual stimuli—must be of a certain magnitude in order to be perceived: if the motorist is to execute the described maneuvers, the cues must be of a certain strength. In addition, the scene is an ever-changing one. As the motorist's location changes, new cues emerge. Several cues become more important than others in the perceptual process. Signposts are distinguishable by their color, location, shape, etc. Many of these images are in constant flux, and in order to translate the directions into performance the motorist must make rapid adjustment in his behavior.

The experimental study of perception has helped identify many of the parts of this process, and we shall encounter some of these in the next chapter. But the study of perception alone does not adequately account for the expected performance; other cognitive systems are involved, including attention.

ATTENTION

The number of environmental cues available to the policeman and motorist is overwhelming. If the motorist attended to all of them or even a sizeable number he would never find the hardware store. Although we are information-gathering creatures it is evident that, under normal circumstances, we are also highly selective in the amount and type of information we attend to. Our capacity to process information seems to be limited on two levels—sensory and cognitive. If too many sensory cues are imposed upon us at any given time we can become "overloaded"; or if we try to process too many events in memory we also can become overloaded. The consequences of this may be a breakdown in performance.

In our example, the policeman, intuitively inferring that if he overloaded the system, performance would suffer, disregarded many cues the motorist undoubtedly would perceive. And, if the cartoon shown here is an accurate representation of the motorist's cognitive map, he is indeed, hopelessly confused.

MEMORY

Could the policeman describe the scene without memory? Certainly not anymore than he could function without perception—and, in fact, memory and perception work together. In the example, two types of memory seem to be contributing to the policeman's answer. The first type seems to retain information for a limited time—long enough for him to carry on a conversation. This memory system seems to hold information for only a brief period, when new information seems to displace it. The entire exchange would have taken only about 120 seconds, and it is unlikely that all of the details were permanently retained by either the policeman or the motorist. However, these details *were* stored in memory long enough for both of them to keep track of the sequence of elements making up the dialogue,* and *some* of the information may have found its way into their permanent memory. This first memory stage is called short-term memory (STM) or, in this case, a specialized form of memory called *working memory*.

On the other hand, a great amount of the answer is drawn from the policeman's long-term memory (LTM). Most obvious is his knowledge of the language. He didn't refer to the lake as a kumquat, or the Expo site as a rubber tire, or a street as a basketball; he drew words from his LTM and, more or less, used them correctly. There are additional cues that indicate LTM is involved in his description: ". . . remember they had the Expo in 1974." In a fleeting second, he was able to recall information about an event of years before. That information did not come from an immediate perceptual experience; it was stored along with a vast number of other facts in his LTM.

The information available to the policeman, then, came from his perception, STM, and LTM. In addition, we can infer that he was a thinking person, that the information was conceptualized in a scheme that "made sense."

LANGUAGE

In order to answer the question successfully, the policeman had to have extensive knowledge of the language. That knowledge involves knowing the proper names for the landmarks, but, equally important, knowing the syntax—the customary arrangement and relationships of the words—of the language. It is important to recognize that the sequence of words, although it might not satisfy a fussy English professor, does communicate. In nearly every sentence, the essential grammatical rules are observed. The policeman didn't say "got well that hardware in they've"; he did say "Well, they've got that in hardware"—and we

* For example, the police officer had to retain briefly that: the motorist was looking for "Pay-n-Pak," that he knew the location of Expo; even (at least until he finished asking, "What motel are you in?") that the motorist was staying at a motel. Similarly, in the case of the motorist: He had to retain briefly that there were two Pay-n-Paks (in order to be able to reply that he wanted the one selling plumbing); that the policeman had asked if he knew the Expo site; that he had to pass the old mill, etc.

all can understand what is meant. In addition to forming grammatically correct sentences and finding the appropriate word in his lexicon, the policeman had to coordinate the complicated motor reactions necessary for the articulation of the message.

IMAGERY

In order for the policeman to answer the question, he formed a mental image of the environment. This mental image was in the form of a cognitive map: a type of internal representation of the juxtaposed buildings, streets, street signs, stop-lights, etc. From the cognitive map he was able to draw out the significant cues, order them in a meaningful sequence, and transform those images into language which, it is hoped, would allow the motorist to construct a similar cognitive map. That re-formed cognitive map would then provide the motorist with a reasonable picture of the city, which could be later transformed into the act of driving an automobile along a certain route.

Although the experimental study of mental imagery is relatively new to psychology, some significant research has recently been reported; it is discussed in Chapter 11.

DEVELOPMENTAL PSYCHOLOGY

This is another important area of cognitive psychology that has been intensely studied. Recent experiments and theories in developmental cognitive psychology have greatly expanded our understanding of how cognitive structures develop. In the case of the present example we can only infer that the speakers share developmental experiences that allow them to (more or less) understand each other. Chapter 13 deals with cognitive development.

THINKING AND CONCEPT FORMATION

Throughout this episode the policeman and the motorist exhibit an ability to think and to form concepts. When asked how to get to Pay-n-Pak the policeman replied, after some intermediate steps, "Do you know where the coliseum is?", indicating that, if the motorist knew this landmark, he could be easily directed to Pay-n-Pak. When he didn't, he developed another plan for answering the question. In addition, the policeman seems baffled when the motorist told him that the Oxford Motel had a pretty good library. Motels and libraries are generally incongruous categories and knowing this the policeman, as well as you, might ask, "What kind of motel is that!" Finally, his use of some words (for example, train tracks, old mill, "Klinkerdagger's") indicates that he had formed concepts that were similar to the concepts shared by the motorist.

ARTIFICIAL INTELLIGENCE

There is no direct tie between computer science and our example, but the specialty within computer science called artificial intelligence (AI), which aims at simulating human cognitive processes, has had an enormous influence on the development of cognitive science, largely since the design of such AI computer programs requires knowledge of how we process information. A related and fascinating topic (dealt with in detail in Chapter 15) concerns the matter

of whether a "perfect robot" can simulate human behavior. Imagine, for example, a super robot that has mastered all of the perceptual, memory, thinking, and language abilities of humans. How would it answer the motorist's question? If the robot were identical to a human, the results would be identical, but consider the difficulty of developing a program that would make an error, as the policeman did ("you turn left"), and then, realizing its error, correct it ("no, right").

antecedents of modern cognitive psychology

As we have learned, a great portion of cognitive psychology deals with how knowledge is represented in the mind. The very lively issue of representational knowledge—what some cognitive psychologists call "internal representation" or "codes"—has probably evoked the same fundamental questions over centuries: How is knowledge acquired, stored, transformed, and used? What is the nature of perception and memory? What is thought? and How do these abilities develop? These questions reflect the essential issue of representational knowledge—how ideas, events, things, are stored and schematized in the mind.

In pursuing this topic of the "representation of knowledge," we will trace the impressions of many scholars as they approach the question of how events outside the human subject are given internal action. A principal theme—one that spans many centuries of thought—is the structure of knowledge and the transformation or "processing" of knowledge.

THE REPRESENTATION OF KNOWLEDGE: THE EARLY PERIOD

The fascination with knowledge can be traced to the earliest writings. Early theories were concerned with the seat of thought and memory. Ancient Egyptian hieroglyphics suggest that their authors believed that knowledge was localized in the heart—a view shared by the early Greek philosopher Aristotle, but not by Plato, who held that the brain was the locus of the mind.

The issue of mental representation was also discussed by the Greek philosophers within the context of what we now identify as structure and process. Discussion of structure and of process was largely dormant until the seventeenth century, and the focus of interest has passed continually from one to the other over the years. Although modern psychologists still tend to emphasize one or the other, there is an increased awareness that a definitive psychology of thought embraces both working together. The dichotomy and interaction are something like the structure of a bee's honeycomb and the processes that operate within the comb. The structure or architecture of the honeycomb is formed by the bees and is generally fixed (for example, its size, shape, position, and capacity are relatively stable), while the activity or processes—such as the gathering, transformation, and storage of honey—are constantly in flux, though acting in conjunction with the structure. Much of the current excitement in cognitive psychology is generated by the discovery of new structures and the processes