This exciting textbook introduces students to the dynamic vibrant area of cognitive science – the scientific study of the mind and cognition. Cognitive science draws upon many academic disciplines, including psychology, computer science, philosophy, linguistics, and neuroscience. This is the first textbook to present a unified view of cognitive science as a discipline in its own right, with a distinctive approach to studying the mind. Students are introduced to the cognitive scientist’s "toolkit" – the vast range of techniques and tools that cognitive scientists can use to study the mind. The book presents the main theoretical models that cognitive scientists are currently using, and shows how those models are being applied to unlock the mysteries of the human mind. Cognitive Science is replete with examples, illustrations, and applications and draws on cutting-edge research and new developments to explore both the achievements that cognitive scientists have made, and the challenges that lie ahead.

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An Introduction to the Science of the Mind

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There are few things more fascinating to study than the human mind. And few things that are more difficult to understand. Cognitive science is the enterprise of trying to make sense of this most complex and baffling natural phenomenon.

The very things that make cognitive science so fascinating make it very difficult to study and to teach. Many different disciplines study the mind. Neuroscientists study the mind’s biological machinery. Psychologists directly study mental processes such as perception and decision-making. Computer scientists explore how those processes can be simulated and modeled in computers. Evolutionary biologists and anthropologists speculate about how the mind evolved. In fact, there are very few academic areas that are not relevant to the study of the mind in some way. The job of cognitive science is to provide a framework for bringing all these different perspectives together.

This enormous range of information out there about the mind can be overwhelming, both for students and for instructors. I have had direct experience of how challenging this can be, as Director of the Philosophy-Neuroscience-Psychology program at Washington University in St. Louis. The challenge is to give students a broad enough base while at the same time bringing home that cognitive science is a field in its own right, separate and distinct from the disciplines on which it draws. I set out to write this book because my colleagues and I have not yet found a book that really succeeds in doing this.

Different textbooks have approached this challenge in different ways. Some have concentrated on being as comprehensive as possible, with a chapter covering key ideas in each of the relevant disciplines – a chapter on psychology, a chapter on neuroscience, and so on. These books are often written by committee – with each chapter written by an expert in the relevant field. These books can be very valuable, but they
really give an introduction to the cognitive sciences (in the plural), rather than to cognitive science as an interdisciplinary enterprise.

Other textbook writers take a much more selective approach, introducing cognitive science from the perspective of the disciplines that they know best – from the perspective of philosophy, for example, or of computer science. Again, I have learnt much from these books and they can be very helpful. But I often have the feeling that students need something more general.

This book aims for a balance between these two extremes. Cognitive science has its own problems and its own theories. The book is organized around these. They are all ways of working out the fundamental idea at the heart of cognitive science – which is that the mind is an information processor. What makes cognitive science so rich is that this single basic idea can be (and has been) worked out in many different ways. In presenting these different models of the mind as an information processor I have tried to select as wide a range of examples as possible, in order to give students a sense of cognitive science’s breadth and range.

Cognitive science has only been with us for forty or so years. But in that time it has changed a lot. At one time cognitive science was associated with the idea that we can understand the mind without worrying about its biological machinery – we can understand the software without understanding the hardware, to use a popular image. But this is now really a minority view. Neuroscience is now an absolutely fundamental part of cognitive science. Unfortunately this has not really been reflected in textbooks on cognitive science. This book presents a more accurate picture of how central neuroscience is to cognitive science.

How the book is organized

This book is organized into five parts.

Part I: Historical overview

Cognitive science has evolved considerably in its short life. Priorities have changed as new methods have emerged – and some fundamental theoretical assumptions have changed with them. The three chapters in Part I introduce students to some of the highlights in the history of cognitive science. Each chapter is organized around key discoveries and/or theoretical advances.

Part II: The integration challenge

The two chapters in Part II bring out what is distinctive about cognitive science. They do this in terms of what I call the integration challenge. This is the challenge of
developing a unified framework that makes explicit the relations between the different disciplines on which cognitive science draws and the different levels of organization that it studies. In Chapter 4 we look at two examples of local integration. The first example explores how evolutionary psychology has been used to explain puzzling data from human decision-making, while the second focuses on what exactly it is that is being studied by techniques of neuro-imaging such as functional magnetic resonance imaging (fMRI).

In Chapter 5 I propose that one way of answering the integration challenge is through developing models of mental architecture. A model of mental architecture includes

1. an account of how the mind is organized into different cognitive systems, and
2. an account of how information is processed in individual cognitive systems.

This approach to mental architecture sets the agenda for the rest of the book.

**Part III: Information-processing models of the mind**

The four chapters in Part III explore the two dominant models of information processing in contemporary cognitive science. The first model is associated with the physical symbol system hypothesis originally developed by the computer scientists Allen Newell and Herbert Simon. According to the physical symbol system hypothesis, all information processing involves the manipulation of physical structures that function as symbols. The theoretical case for the physical symbol system hypothesis is discussed in Chapter 6, while Chapter 7 gives three very different examples of research within that paradigm – from data mining, artificial vision, and robotics.

The second model of information processing derives from models of artificial neurons in computational neuroscience and connectionist artificial intelligence. Chapter 8 explores the motivation for this approach and introduces some of the key concepts, while Chapter 9 shows how it can be used to model aspects of language learning and object perception.

**Part IV: How is the mind organized?**

A mental architecture includes a model both of information processing and of how the mind is organized. The three chapters in Part IV look at different ways of tackling this second problem. Chapter 10 examines the idea that some forms of information processing are carried out by dedicated cognitive modules. It looks also at the radical claim, proposed by evolutionary psychologists, that the mind is simply a collection of specialized modules. In Chapter 11 we look at how some recently developed techniques such as functional neuroimaging can be used to study the organization of the mind. Chapter 12 shows how the theoretical and methodological issues come together by working through an issue that has received much attention in contemporary
cognitive science – the issue of whether there is a dedicated cognitive system response for our understanding of other people (the so-called mindreading system).

**Part V: New horizons**

As emerges very clearly in the first four parts of the book, cognitive science is built around some very basic theoretical assumptions – and in particular around the assumption that the mind is an information-processing system. In Chapter 13 we look at two ways in which cognitive scientists have proposed extending and moving beyond this basic assumption. One of these research programs is associated with the dynamical systems hypothesis in cognitive science. The second is opened up by the situated/embodied cognition movement.

**Using this book in courses**

This book has been designed to serve as a self-contained text for a single semester (12–15 weeks) introductory course on cognitive science. Students taking this course may have taken introductory courses in psychology and/or philosophy, but no particular prerequisites are assumed. All the necessary background is provided for a course at the freshman or sophomore level (first or second year). The book could also be used for a more advanced introductory course at the junior or senior level (third or fourth year). In this case the instructor would most likely want to supplement the book with additional readings. There are suggestions on the instructor website (see below).

**Text features**

I have tried to make this book as user-friendly as possible. Key text features include:

- **Part-openers and chapter overviews**

  The book is divided into five parts, as described above. Each part begins with a short introduction to give the reader a broad picture of what lies ahead. Each chapter begins with an overview to orient the reader.
INTRODUCTION

Here is a crucial example of how different cognitive science is becoming science.
In the early 1960s, when the term “cognitive science” was first used, it referred to a new
way of thinking about how the mind works. This new way of thinking was inspired by
advances in psychology, neuroscience, linguistics, and computer science.

The early flourishing of cognitive science in the 1960s and 1970s was marked by a series of
・Exercises

These have been inserted at various points within each chapter. They are placed in the
flow of the text to encourage the reader to take a break from reading and engage with
the material. They are typically straightforward, but for a few I have placed suggested
solutions on the instructor website (see below).

SHRDLU is capable of running in a virtual environment, in which it can see and
hear through first-person asymmetrical experiences. It can also interact with
other systems by speaking and understanding natural language. The program
supports a variety of tasks and can be trained on a wide range of
problems.

SHRDLU is a key example of the interdisciplinary nature of cognitive science. It
combines elements from linguistics, artificial intelligence, and computer science
to create a system that can understand and interact with the world.
Preface

Boxes and optional material

Boxes have been included to provide further information about the theories and research discussed in the text. Some of the more technical material has been placed in boxes that are marked optional. Readers are encouraged to work through these, but the material is not essential to flow of the text.

Example: Entropy

The entropy of a set of examples is given by the following equation:

\[ H(S) = -\sum_{i=1}^{N} P(S_i) \log_2(P(S_i)) \]

where:
- \( H(S) \) is the entropy of the set \( S \)
- \( P(S_i) \) is the proportion of examples in \( S \) that belong to class \( i \)
- \( \log_2 \) is the base-2 logarithm

In this equation, \( P(S_i) \) is the proportion of total examples that belong to class \( i \). For a balanced dataset, where each class has an equal number of examples, the entropy would be highest and equal to \( \log_2(2) = 1 \). If all the examples belong to the same class, the entropy would be 0, indicating no uncertainty.

Summaries, checklists, and further reading

These can be found at the end of each chapter. The summary shows how the chapter relates to the other chapters in the book. The checklist allows students to review the key points of the chapter, and also serves as a reference point for instructors. Suggestions of additional books and articles are provided to guide students' further reading on the topics covered in the chapter.

Figure: Decision tree example

- **Entropy (S/A)**: This is given by the formula in Box 7.1 and gives the baseline entropy of the set \( S \) with respect to the target attribute – i.e. the subset of \( S \) that does not have attribute A. This gives a value to compare the entropy of \( S \) with respect to the target attribute.
- **Entropy (S*/A)**: This is given by the following formula:

\[ \text{Entropy (S*/A)} = -\sum_{i=1}^{N} P(S_i) \log_2(P(S_i)) \]

where:
- \( P(S_i) \) is the proportion of examples in \( S \) that belong to class \( i \)
- \( \log_2 \) is the base-2 logarithm

This formula gives the entropy of \( S \) relative to attribute A, and it helps in determining the information gain.

Information gain (IG)

The information gain of attribute A is calculated as follows:

\[ \text{Information gain (A)} = \text{Entropy (S)} - \sum_{i=1}^{N} \left( \frac{|S_i|}{|S|} \right) \text{Entropy (S_i/A)} \]

where:
- \( |S_i| \) is the number of examples in subset \( S_i \)
- \( |S| \) is the total number of examples in \( S \)

The attribute with the highest information gain is selected and assigned to the node. The algorithm repeats the procedure, starting at the leftmost node. The leftmost node splits the examples using the attribute that minimizes the entropy. This process is repeated until each branch of the tree ends in a value for the target attribute.
Course website

There is a course website accompanying the book. It can be found at www.cambridge.org/bermudez. This website contains:

- links to useful learning resources, videos, and experimental demonstrations
- links to online versions of relevant papers and online discussions for each chapter
- study questions for each chapter that students can use to structure their reading and that instructors can use for class discussion topics

Instructors can access a password-protected section of the website. This contains:

- sample syllabi for courses of different lengths and different level
- PowerPoint slides
- electronic versions of figures from the text
- suggested solutions for the more challenging exercises and problems

The website is a work in progress. Students and instructors are welcome to contact me with suggestions, revisions, and comments. Contact details are on the website.
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