Cognitive Dynamic Systems

The principles of cognition are becoming increasingly important in the areas of signal processing, communications, and control. In this ground-breaking book, Simon Haykin, a pioneer in the field and an award-winning researcher, educator, and author, sets out the fundamental ideas of cognitive dynamic systems. Weaving together the various branches of study involved, he demonstrates the power of cognitive information processing and highlights a range of future research directions.

The book begins with a discussion of the core topic, cognition, dealing in particular with the perception–action cycle. Then, the foundational topics, power spectrum estimation for sensing the environment, Bayesian filtering for environmental state estimation, and dynamic programming for action in the environment, are discussed. Building on these foundations, detailed coverage of two important applications of cognition, cognitive radar and cognitive radio, is presented.

Blending theory and practice, this insightful book is aimed at all graduate students and researchers looking for a thorough grounding in this fascinating field.

Simon Haykin is the Director of the Cognitive Systems Laboratory at McMaster University, Canada. He is a pioneer in adaptive signal processing theory and applications in radar and communications, areas of research that have occupied much of his professional life. For the past 10 years he has focused his entire research interests on cognitive dynamic systems: cognitive radar, cognitive radio, cognitive control, and cognition applied to the cocktail party processor for the hearing impaired. He is a Fellow of the IEEE and the Royal Society of Canada, and is the recipient of the Henry Booker Gold Medal from URSI (2002), the Honorary Degree of Doctor of Technical Sciences from ETH Zentrum, Zurich (1999), and many other medals and prizes. In addition to the seminal journal papers "Cognitive radio" and "Cognitive radar," he has also written or co-written nearly 50 books including a number of best-selling textbooks in the fields of signal processing, communications, and neural networks and learning machines.

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Perception–Action Cycle, Radar, and Radio

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Preface

In my Point-of-View article, entitled "Cognitive dynamic systems," *Proceedings of the IEEE*, November 2006, I included a footnote stating that a new book on this very topic was under preparation. At long last, here is the book that I promised then, over four years later.

Just as adaptive filtering, going back to the pioneering work done by Professor Bernard Widrow and his research associates at Stanford University, represents one of the hallmarks of the twentieth century in signal processing and control, I see cognitive dynamic systems, exemplified by cognitive radar, cognitive control, and cognitive radio and other engineering systems, as one of the hallmarks of the twenty-first century.

The key question is: How do we define cognition? In this book of mine, I look to the human brain as the framework for cognition. As such, cognition embodies four basic processes:

- perception–action cycle,
- memory,
- attention, and
- intelligence,

each of which has a specific function of its own. In identifying this list of four processes. I have left out language, the fifth distinctive characteristic of human cognition, as it is outside the scope of this book. Simply put, there is no better framework than human cognition, embodying the above four processes, for the study of cognitive dynamic systems, irrespective of application.

Putting aside the introductory and epilogue chapters, the remaining six chapters of the book are organized in three main parts as follows:

- Chapter 2, entitled the "Perception–action cycle," provides an introductory treatment of the four basic processes of cognition identified above. Moreover, the latter part of the chapter presents highlights of neural networks needed for the implementation of memory.
- Chapters 3, 4, and 5 provide the fundamentals of cognitive dynamic systems, viewed from an engineering perspective. Specifically, Chapter 3 discusses power spectrum estimation as a basic tool for sensing the environment. Chapter 4 discusses the Bayesian filter as the optimal framework for estimating the state of the environment when it is hidden. In effect, Chapters 3 and 4 are devoted to how the environment is perceived

by dynamic systems, viewed in two different ways. Chapter 5 deals with dynamic programming as the mathematical framework for how the system takes action on the environment.

- Chapters 6 and 7 are devoted to two important applications of cognitive dynamic systems: cognitive radar and cognitive radio respectively; both of them are fast becoming well understood, paving the way for their practical implementation.

To conclude this Preface, it is my conviction that cognition will play the role of a software-centric information-processing mechanism that will make a difference to the theory and design of a new generation of engineering systems aimed at various applications, not just radar control, and radio.

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Acknowledgments

In the course of writing this book, I learned a great deal about human cognition from the book *Cortex and Mind: Unifying Cognition* by Professor J. M. Fuster, University of California at Los Angeles. Just as importantly, I learned a great deal from the many lectures on cognitive dynamic systems, cognitive radio, and cognitive radar, which I had the privilege of presenting in different parts of the world.

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(1) The notion of "fore-active radar" as the first step towards radar cognition, which was made by Professor Christopher Baker, Australian National University, Canberra.
(2) The analogy between feedback information in cognitive radar and saccade in vision, which was made by Professor José Principe, University of Florida.

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The writing of this book has taken me close to four years, in the course of which I must have gone through 20 revisions of the manuscript. I am truly grateful to my Administrative Coordinator, Lola Brooks, for typing those many versions. Without her patience and dedication, completion of the manuscript would not have been possible.

Last but by no means least, I thank my wife, Nancy, for allowing me the time I needed to write this book.

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