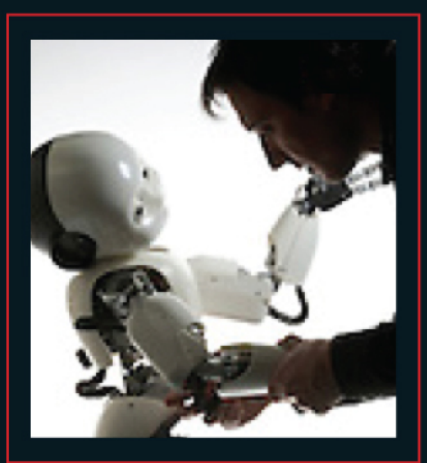
ARTIFICIAL COGNITIVE SYSTEMS

A PRIMER



DAVID VERNON

Artificial Cognitive Systems
A Primer

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David Vernon

The MIT Press
Cambridge, Massachusetts
London, England

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This book was set in Palatino by the author and was printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Vernon, David, 1958–
Artificial cognitive systems : a primer / David Vernon.
p. cm
Includes bibliographical references and index.
ISBN 978-0-262-02838-7 (hardcover : alk. paper)
1. Cognition. 2. Brain. 3. Development psychology. 4. Artificial intelligence. I. Title.
BF311.V447 2014
153—dc23

2014013208

10 9 8 7 6 5 4 3 2 1

To Keelin, Ciana, and Georgina —
for never giving up on your dreams

“It’s a poor sort of memory that only works backwards.”

Lewis Carroll — *Through the Looking Glass*

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Preface

This primer introduces you to the emerging field of artificial cognitive systems. Inspired by artificial intelligence, developmental psychology, and cognitive neuroscience, the aim is to build systems that can act on their own to achieve goals: perceiving their environment, anticipating the need to act, learning from experience, and adapting to changing circumstances.

It is an exciting and challenging area. The excitement stems from the possibility of designing intelligent adaptive systems that can serve society in a host of ways. The challenge is the breadth of the field and the need to bring together an intimidating spectrum of disciplines. Add to this the fact that there is no universal agreement on what exactly it means to be cognitive in the first place and the stage is set for an interesting journey. Think of this primer as a guidebook to help you on that journey, pointing out the main features of the landscape, the principal routes, and the most important landmarks.

To get started, we develop a working definition of cognitive systems, one that strikes a balance between being broad enough to do service to the many views that people have on cognition and deep enough to help in the formulation of theories and models. We then survey the different paradigms of cognitive science to establish the full scope of the subject and sketch the main geography of the area. We follow that with a discussion of cognitive architectures — effectively the blueprints for implementing cognitive systems — before tackling the key issues, one by one, in the remaining chapters: autonomy, embodiment, learning & development, memory & prospection, knowledge & representation, and social cognition.

By the time you have finished reading this primer, you will have a clear understanding of the scope of the domain, the different perspectives, and their underlying differences. You will have a solid grasp of the issues that need to be addressed when attempting to design an artificial cognitive system. Perhaps most important of all, you will know where to go next to deepen your understanding of the area and its constituent disciplines.

Like all guidebooks, this primer tells a story about the land it surveys. In fact, it tells two stories in parallel, one in the main narrative and another through a sequence of sidenotes. The main text is kept as short and simple as possible, focussing on relatively straightforward descriptions of the key issues. The sidenotes highlight the finer points of the material being discussed in the main narrative, suggesting material that you can read to gain a deeper insight into the topic under discussion. New ideas are introduced in a natural intuitive order, building step-by-step to a clear overview of this remarkable and exciting field, priming you to go further and faster in your studies of cognitive systems.

Ideally, you will read the primer three times. On the first reading, you might read only the main narrative to get a feeling for the topic. You might then read through the sidenotes without reference to the main text. This will expose you to a series of interesting snapshots of key landmark topics and reinforce ideas you encountered on the first reading. Finally, you should be ready for a third, more careful reading of the book, referring to each sidenote as it is referenced in the main narrative.

A primer, by its very nature, is a short book. Consequently, there are many omissions in this text, some intentional, others less so. By far, the topic that is most noticable by its absence is language. While providing an overview of areas such as embodiment and autonomy is a challenge because of their diverse meanings, the task of doing the same for language is far greater. So, rather than attempt it and almost inevitably fall short, I have omitted it. If there is ever a second edition, the inclusion of language will be the top priority.

Other omissions are more methodological. This primer focusses almost exclusively on the "What?" and "Why?" questions in cognitive systems, to the exclusion of the "How?" In

other words, it does everything except tell you how you can go about building a cognitive system. There is an unfortunate, but inevitable, lack of formal theory and algorithmic practice in this book. This doesn't mean that this theory doesn't exist — it certainly does, as a quick scan of the literature on, e.g., machine learning and computer vision will demonstrate — but the breadth of cognitive systems is so great that to address the computational and mathematical theories as well as the algorithmic and representational details of cognition would require a book of far greater scope than this one. Perhaps, some day, a companion volume might be appropriate.

Skövde, Sweden *David Vernon*
May 2014

Acknowledgements

My interest in cognitive systems was ignited in 1984 by Dermot Furlong, Trinity College, Dublin, who introduced me to the seminal work of Humberto Maturana and Francisco Varela. In the intervening 30 years, he has continued to prompt, question, and debate, and his insights have helped greatly in putting the many different aspects of cognition in perspective.

Giulio Sandini, Istituto Italiano di Tecnologia (IIT), played a pivotal role in the writing of this book. Twenty years after we first worked together on an image understanding project, we collaborated again in 2004 on his brainchild, the iCub, the open-source 53 degree-of-freedom cognitive humanoid robot featured on the front cover. In this 5-year research project, funded by the European Commission, we investigated many aspects of artificial cognitive systems, and I would like to thank him sincerely for involving me in the project and for his insights and inspiration.

In 2003, Henrik Christensen, then at KTH in Sweden and now at Georgia Tech in the USA, and Hans-Hellmut Nagel, University of Karlsruhe (now Karlsruhe Institute of Technology), organized a lively workshop on cognitive vision systems at Schloss Dagstuhl. The discussions at this workshop had a strong influence in determining the content of the book and in achieving, I hope, a balanced perspective. I would like to pay a special tribute to Hans-Hellmut for his remarkable attention to detail and passion for clarity of expression. I learned much from him and I have tried to put it into practice when writing this book.

From 2002 to 2005, I coordinated *ECVision*, the EU-funded European research network for cognitive vision systems. Many of the ideas discussed at the brainstorming sessions conducted in

the development of the *ECVision* research roadmap were crucial in developing my ideas on cognitive systems.

Beginning in 2006, I coordinated *euCognition*, the European Network for the Advancement of Artificial Cognitive Systems, for three years. The members — then numbering 300 or so, now over 800 — are drawn from many disciplines, including neuroscience, psychology, computer science, control, cognitive science, linguistics, cybernetics, dynamical and self-organizing systems, computer vision, and robotics. I have benefitted enormously from being exposed to their thoughts and insights, and those of our guest speakers at network meetings.

In the context of my work in European projects, I would like to say a special thank you to Horst Forster, Colette Maloney, Hans-Georg Stork, Cécile Huet, Juha Heikkilä, Franco Mastroddi, and their colleagues in the European Commission for their unstinting support. Europe's vibrant cognitive systems community is due in no small part to their foresight and leadership.

I wish to thank Gordon Cheng and Uwe Haass for giving me the opportunity to work at the Institute for Cognitive Systems (ICS), Technical University of Munich, in 2011 and 2012. My work at ICS provided the initial impetus to turn my lecture notes into a textbook and the time to do it.

Marcia Riley, a researcher at ICS, provided the intellectual flint that is essential for sparking new ideas and better ways of communicating them. I am grateful for her time, knowledge, and willingness to debate the finer points of robotics and cognition.

During my time in Munich, I had many fruitful conversations with Michael Beetz, University of Bremen. His insights gave me a fresh appreciation of the importance of new AI in cognitive systems and a much better understanding of the ways knowledge can be shared between people and robots.

If my time at the Technical University of Munich provided the impetus, my move to the University of Skövde, Sweden, in early 2013 provided the ideal environment to write the bulk of the book. Here I have the pleasure of working with great people — Tom Ziemke, Serge Thill, Paul Hemeren, Erik Billing, Rob Lowe, Jessica Lindblom, and many others — all of whom contributed directly and indirectly to the throughts expressed in the chapters

that follow. Heartfelt thanks to each and every one of you.

The insights of Claes von Hoftsten, University of Uppsala, and Luciano Fadiga, University of Ferrara and Istituto Italiano di Tecnologia, contributed greatly to the material in Chapter 6. I am obliged to them both for taking the time to explain the basis of human development to me when we collaborated on the design of the iCub cognitive humanoid robot.

During my time working on the iCub, I gave several short courses on cognitive systems at the University of Genoa and the Istituto Italiano di Tecnologia. The notes for these courses formed the original basis of this book while a paper co-authored by Giulio Sandini, IIT, and Giorgio Metta, IIT, in 2007 provided the foundations for Chapter 2.

I am grateful to Alessandra Sciutti, Istituto Italiano di Tecnologia, for allowing me to use her survey data on milestones in the development of human infants in Table 6.1, Chapter 6.

The material in Chapter 9 on joint action, shared intention, and collaborative behaviour derives in part from the contributions made by Harold Bekkering, Radboud University Nijmegen, Yiannis Demiris, Imperial College, London, Giulio Sandini, Istituto Italiano di Tecnologia, and Claes von Hofsten, University of Uppsala, to a research proposal we worked on in 2012.

Thanks go to Alan Bushnell, Phoenix Technical Co. L.L.C., for taking the time to cast a cold eye on the manuscript and for his many helpful suggestions.

Books need publishers and editors, and it is a pleasure to acknowledge the part played by Philip Laughlin, Senior Acquisitions Editor at MIT Press, in bringing this particular book to completion. Without his patience and support, I wouldn't be writing these acknowledgements. Thanks too to Virginia Crossman, Christopher Eyer, Susan Clark, and Erin Hasley at MIT Press for all their help in transforming my initial draft into the finished product.

The front cover picture — featuring the iCub cognitive humanoid robot and Lorenzo Natale, IIT — is used with the kind permission of the Department of Robotics, Brain and Cognitive Sciences, Istituto Italiano di Tecnologia. The photograph was taken by Massimo Brega.

The final word of appreciation goes most especially to my wonderful wife Keelin, for patiently putting up with me working on the book during goodness-knows how many evenings, weekends, and holidays and for painstakingly proof-reading every page. Such love and understanding is exceedingly rare and I will be forever grateful.

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