

Preface

We must know. We will know.

Epitaph on the gravestone of David Hilbert, German mathematician

I had already taken an aspirin, but the toothache persisted. Lying in bed, I couldn't sleep because of the pounding in my lower molar. Trying to distract myself from this painful sensation, I pondered why it hurt. I knew that an inflammation of the tooth pulp sent electrical activity up one of the branches of the trigeminal nerve that ends in the brainstem. After passing through further switching stages, pain was ultimately generated by activity of nerve cells deep inside the forebrain. But none of this explained why it felt like anything! How was it that sodium, potassium, calcium, and other ions sloshing around my brain caused this awful feeling? This mundane manifestation of the venerable mind-body problem, back in the summer of 1988, has occupied me to the present day.

The mind-body dilemma can be expressed succinctly by the question, "How can a physical system, such as the brain, experience anything?" If, for example, a temperature sensor coupled to a computer becomes really hot, the processor may turn on a red alarm light. Nobody would claim, however, that the flow of electrons onto the gate of the transistor that closes the light switch causes the machine to have a bad day. How is it, then, that neural activity can give rise to the sensation of a burning pain? Is there something magical about the brain? Does it have to do with its architecture, with the type of neurons involved, or with its associated electro-chemical activity patterns?

The matter becomes even more mysterious with the realization that much, if not most, of what happens inside my skull isn't accessible to introspection. Indeed, most of my daily actions—tying my shoes, driving, running, climbing, simple conversation—work on autopilot, while my mind is busy dealing with more important things. How do these behaviors differ neurologically from those that give rise to conscious sensations?

In this book, I seek answers to these questions within a neuroscientific framework. I argue for a research program whose supreme aim is to discover the neuronal correlates of consciousness, the NCC. These are the smallest set

of brain mechanisms and events sufficient for some specific conscious feeling, as elemental as the color red or as complex as the sensual, mysterious, and primeval sensation evoked when looking at the jungle scene on the book jacket. Characterizing the NCC is one of the ultimate scientific challenges of our times.

To get to the heart of the matter, I need to be as close as I can to where the rubber meets the road, in the interstitial spaces between phenomenal experience and corporeal brain matter. These regions have been best explored in visual perception, which is why this book focuses on seeing, though not exclusively. I survey the relevant anatomical, neurophysiological, psychological, and clinical data and weave these into a larger tapestry that constitutes a novel framework for thinking about the neuronal basis of consciousness.

This book is intended for anybody curious about an ancient debate that has recaptured the imagination of today's philosophers, scientists, engineers, doctors, and thinking people in general. What is consciousness? How does it fit into the natural order of things? What is it good for? Is it unique to humans? Why do so many of our actions bypass consciousness? Answers to these questions will determine a new image of what it is to be human. This image, which is slowly emerging even now, contradicts many of the traditional images of which we have grown fond. Who knows where this quest will take us? As Lord Dunsany wrote, "Man is a small thing and the night is large and full of wonder."

The ideas expressed in these pages are the fruits of an intensive collaboration with Francis Crick at the Salk Institute in La Jolla, California, just north of San Diego. We first met in 1981 in Tübingen, Germany, while debating with Tomaso Poggio over the function of dendritic spines. When I subsequently moved to the Massachusetts Institute of Technology in Cambridge and devised, with Shimon Ullman, ways to explain visual attention on the basis of artificial neural networks, Shimon and I visited Francis for a stimulating and vigorous week-long exchange of ideas. The pace of our interaction intensified when I became a professor at the California Institute of Technology in Pasadena, a two-hour drive from La Jolla.

Francis's interest in the biological basis of consciousness, which he traces back to the days after the Second World War, converged with my unbridled enthusiasm for thinking about visual attention and awareness within a computational framework and mapping that onto neurobiological circuits. Our joint speculations took on concrete form with the rediscovery of oscillatory and synchronized spiking activity in the cat visual cortex in the late 1980s. Francis and I published our first paper, "Towards a neurobiological theory of consciousness," in 1990. As new data became available and our point of view evolved to encompass multiple aspects of consciousness, we kept up a steady pace of publications. Over the last five years, I spent two to three days each month in

Francis's home. For reasons of his own, Francis chose not to be a co-author of this book. Nevertheless, to emphasize the joint ownership of the main ideas expressed herein, I frequently write "we" or "us" to mean "Francis and I." I know this is somewhat unusual, but ours is an unusual collaboration.

Although I have retained my enthusiasm, acquired in youth, for certain Greek and Germanic philosophers—Plato, Schopenhauer, Nietzsche, and the young Wittgenstein—my writing style strives to follow the Anglo-Saxon tradition of clarity. *The Economist's* guide to writing summarizes it as, "say it as simply as possible." I try to be unambiguous in distinguishing what is known from what is mere speculation. I provide references to the literature in ample footnotes. These also allude to complexities that may not be of interest to the general reader. The first time a technical term is mentioned, it is italicized, and further explained in the glossary.

If you are new to these questions, I suggest you begin by reading the introductory chapter and the interview at the very end, which summarizes in an informal manner my thinking on a range of topics. The novel technical material is contained in Chapters 2, 9, 11, 13, and 15, while Chapters 14 and 18 are in a more speculative vein.

I use this book for an introductory class on the neurobiology of consciousness. Teaching material, including homework and streaming media versions of all of my lectures, can be found at www.klab.caltech.edu/cns120.

I would here like to acknowledge everybody who made this book possible.

Foremost, of course, is Francis Crick. Without his constant guidance, insight, and creativity, this book simply would not have happened. All the basic ideas found here have been published over the years with Francis. He read and commented upon numerous versions of the manuscript. I dedicate the book to Francis and his searing, uncompromising search for the truth, no matter where it takes him, and to his wisdom and his ability to gracefully accept the unavoidable. I do not know anybody else like him.

Over the years, I have benefited, again and again, from the gracious hospitality and wonderful cooking of Odile Crick, Francis's wife, and have had too few occasions to reciprocate. It was she who suggested the title of the book during one of our frequent lunches on their sun-drenched patio in La Jolla.

The research program carried out in my laboratory is intense, time-consuming, and deeply satisfying. It is also quite expensive. Over the years, I have enjoyed the unstinting support of a number of institutions. First and foremost is the California Institute of Technology, under the leadership of David Baltimore. What an oasis—an ivory tower—perfectly suited to the search for the truth with a capital 'T.' External funding has been provided by the National Science Foundation, the National Institute of Health, the National Institute of

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I have been blessed by nine enthusiastic readers of the entire manuscript: John Murdrek, a professional developmental editor, and eight consciousness aficionados—Tim Bayne, Joseph Bogen, Constanze Hofstötter, Oliver Landolt, Ernst Niebur, Parashkev Nachev, Javier Perez-Orive, and Rufin Van Rullen. Three colleagues, Bruce Bridgeman, McKell Carter, and Ilya Farber, took the time and the immense effort to carefully proofread the entire manuscript. The perseverance and never-ending stream of suggestions of all these readers eliminated many infelicities, both small and large, and immensely improved the readability of the book. Thank you very much. My editor, Ben Roberts, masterfully steered the entire process from raw manuscript to the final tome you hold in your hands. A true bibliophile, he insisted at all times on the highest standards for both form and content. The art, from the gorgeous cover to the endpages, the figures in the text, and the font and overall layout of the book were designed by Emiko-Rose Paul and her team at Echo Medical Media and by Mark Stuart Ong. Leslie Galen from Integre Technical Publishing proofread every single character between the two bookends and oversaw the entire production process. I could not have asked for a better team of professionals.

When all is said and done, there remains my immediate family, without whom I am lost: Edith, Alexander, Gabriele, and our canine companions, Trixie, Nosy, and Bella. I have no idea why I am so lucky as to be with all of you.

And now, esteemed reader, I invite you to enjoy the book.

Pasadena, August 2003