Preface

Since brains are not "impossibility engines," they cannot do the logically impossible. Since brains are not infinite in size or speed, they cannot do the computationally impossible. Since brains are found *in* the universe, rather than in some fantasy world, they cannot do the physically impossible. Brains have constraints. And not simply the garden variety Earthly constraints like having to work well at the human body temperature, or having some upper limit in working memory. Brains have "high level" constraints, by which I mean constraints to which nearly any other possible kind of brain will also be subject. Such constraints are typically more at a physics or mathematics level, rather than depending on the particular contingencies of the ecology encountered by any specific kind of brain.

To understand the brain one must, I believe, understand the limits and principles governing all possible brain-like things—objects that somehow instantiate minds. For example, if I tell you I want to know how this computer on which I am typing works, and you tell me about the details of just this kind of computer, you really would have missed the point. That is, unless I already knew all about how computers worked generally, and just wanted to know the specifics about this kind of computer. But if I did not understand how *any* kind of computer works, then to really explain to me how this computer works will require telling me how computers work in general. That is what is interesting about computers and computation: the fundamental questions in computer science are about how computer-like things work generally, not about how this or that computer actually happens to work. Similarly, what is most fascinating about the brain is not that it is our brain (although that helps), but that it happens to be one of presumably an infinite class of brain-like things, and I want to know how brain-like things work.

To do *this*, one must back sufficiently far away from the brains we find here on Earth so as to lose sight of these brains' distracting peculiarities, and consequently to gain a focus on what is important about these Earthly brains. That is, we must view the brain from 25,000 feet up—or, from very high up. At this height, the details of the brain are lost, whether they be ion channels, intricate neural connectivity patterns, or pharmacological effects. The background required of a researcher who wishes to study the brain from this high level is therefore not traditional neurobiology, neuroanatomy, psychology or even computational neuroscience (the latter which almost always focuses on modeling specific, relatively lower-level mechanisms thought to occur in the brain). What is needed is a training in mathematics, computer science and physics, and even an appreciation of conceptual limits from philosophy.

This book serves two purposes. One aim is to illustrate a number of high-level approaches to brain science. These range from an explanation for why natural language is vague, to a solution to the riddle of induction and applications to issues of innateness, to the use of probability and decision theory in modeling perception, to the inevitability of visual illusions for any animal with a non-instantaneous brain, and finally to the morphology, complexity and scaling behavior of many aspects of nervous systems. The second aim is to both encourage others to approach brain science from a high level and to provide, along the way, an introduction to some of the mathematical, computational and conceptual principles needed to be able to think about brains at a higher level.

For the remainder of this preface, I wish (i) to provide a preview of the topics covered throughout the book, and (ii) to communicate the overarching philosophy I take toward the brain sciences, a philosophy that is the theme connecting the diverse topics through which we traverse in this book: that philosophy is that understanding the brain will require ignoring most of the brain's peculiar details and giving greater attention to higher level principles governing the brain and brain-like machines. In an attempt to convince the reader that this philosophy is right, I put forth in this preface an extended allegory concerning futuristic cavemen attempting to reverse engineer the artifacts of a now-dead civilization. It will be rather obvious to us what the cavemen need to know in order to understand these artifacts, and I hope to convince you that in our own attempt to understand the brain, we should expect to need to know similar kinds of things. Namely, we must discover the high level principles governing the brain. The chapters of the book provide examples from my own research of such high level approaches.

Let us start by imagining an intelligent, scientifically primitive society of a post-apocalyptic future. They have no computers, no electricity, no modern architecture, and no principles of physics, mathematics and engineering. They live in caves, eating berries and raw squirrel. One day they stumble onto a magnificent thing like nothing they have seen before: a house. It seems the house had been abandoned at the beginning of the 21st century, many centuries before. Equipped with solar cells, the house and the things inside are still in working order (despite the apocalypse!). They quickly find many other houses in the area, and eventually an entire city of houses and buildings, all miraculously in working order (and also running on solar cells). Unfortunately, they find no libraries.

Always striving for a better life, the cavemen promptly leave their caves to live in the houses, where they find warmth, running water, refrigerators, ovens and video games. They thereby achieve the good life, and their children and children's children are happy. They no longer even look like cavemen, having found ample supplies of 21st century clothing and soap.

But although you can take the caveman out of the cave, it is not so easy to take the cave out of the caveman. They begin this new life in a remarkably ignorant state, very unlike the people who had created the city, namely us. The cavemen quickly guess what toilets and light switches are for, but they have no idea about how such things work. We as a 21st century society, however, *do* know all there is to know about electrical wiring and plumbing in our houses. ...and architecture in our houses and buildings, and computer engineering in our computers, and mechanical engineering in our can openers, and so on. We have entire disciplines of engineering devoted to these kinds of technologies, each one laying the groundwork for how such systems work, and how to make it work best given the circumstances. Furthermore, we grasp the more basic principles of mathematics and physics themselves: e.g., Newtonian mechanics, electricity and magnetism, fluid dynamics, computer science, geometry and calculus. We built from scratch those houses the cavemen live in; and built from scratch the things inside the houses that the cavemen are using. We did not originally build them via mimicry, but, rather, through our knowledge of all the relevant principles involved. This is what I mean when I say that we understand houses and the things inside them, but the cavemen do not.

The cavemen have high aspirations, both materially and intellectually, and are not content to merely live in the nice homes without understanding them. They begin asking how to fix them when they break down. Repairmen of their day pop up, whose aim is to fix failures in the houses. And scientists of their day arise, asking what kind of magic the builders knew, and how can they discover it. These cavemen are not content to remain cavemen on the inside, and to become more, they have a task ahead of them more daunting than they can possibly imagine: to discover all the principles the 21st century builders had discovered over the course of a couple millenia! Of course, the cavemen have a tremendous advantage in that they have countless relics of modern technology in which these principles are "embedded." But their task is nevertheless tremendous, and it should not be surprising to learn that it takes well over a century for them to catch up to where the builders (us) were when they mostly killed themselves off somehow.

What is interesting about this story of futuristic cavemen is that . . .

1. From the point of view of the cavemen, they have a scientific task of understanding the technological artifacts they encounter, and this is analogous to our own 21st century scientific task of understanding the brain and biological systems.

2. And, importantly, we 21st century "builders" are in the special position of actually completely understanding the principles behind the technological artifacts; that is, we have a God's eye view of what the cavemen need to figure out.

As we watch the cavemen begin to study the artifacts, we have the privileged position of seeing how close they are to really "getting it." And by fantasizing about what kinds of stages of discovery the cavemen will go through before achieving full understanding, we can more readily get a handle on what kinds of stages *we* will need to go through before fully understanding brains and biological systems. That is, this story, or thought experiment, is useful because we grasp the kinds of theories the cavemen must (re)discover in order to understand the artifacts, and we may use their intellectual development as a model for the kind of intellectual development we must go through before we will fully comprehend the brain and biological systems. We will further explore this analogy, running futuristic-caveman history forward, looking at the kinds of knowledge they have at each stage, asking what more they need to know, and discussing the connections to our own epistemic position in regards to the brain.

Mapping, a lower level approach

Toward understanding these new-found houses, one of the more obvious tasks the cavemen scientists and engineers think to do is to try to figure out what houses are made of, which parts are attached to which others, how they are attached, what each part in isolation seems to do, and so on. That is, they attempt to "map out" the house, in all its details, from the structural beams and girders, to the windows, doors, hinges and dry wall, to the plumbing and the electrical wiring. They even try to figure out what each part on its own seems to do.

This takes an incredible amount of work—thousands of dissertations are written and tens of thousands of papers are published in the early caveman journals. Eventually they succeed in mapping the entire builder's house, and the details are made publicly available to all the cavemen. Caveman television shows and newspapers declare that all the house repair problems are now on the verge of being solved, and that they have entered an exciting new era in caveman understanding of the technology from the past. "Houses completely understood" emanates from the cavemen, layman and many scientists alike.

And through time, maps are provided for all the different kinds of house and building, from split-level and ranch, to varieties of chapels and movie houses, and so on. With these maps in hand, cavemen scientists can begin to see similarities and differences in the maps of different building types, and can even formulate good guesses as to which kind of building is "more evolved"—i.e., rests on principles developed later in the builders' (our) time.

From the caveman point of view, they have made staggering advances in cracking the magic of the 21st century. And although it is certainly true to say that they have made a great step forward, it is not the case that they are *anywhere near* really understanding the technology.

We know this because *we* happen to entirely comprehend, as a culture, this technology—*we* built it first. And the knowledge needed for us to invent and build this technology encompassed much more than just a map of the parts, connectivity, geometry, and an understanding of what each part seems to do locally. To grasp how all these parts, when correctly assembled, work together, mechanical, electrical and civil engineering are required, each of which is really composed of many disciplines. And for the computer systems found in the homes, computer engineering is required. Principles of architecture, masonry and carpentry must also be known. These disciplines of engineering rest, in turn, upon many areas of physics and mathematics, which required hundreds of years to develop the first time.

These cavemen have just barely begun their scientific adventure—they have only made it to square one.

This is akin to the recent sequencing of entire genomes of various organisms. The analogy is by no means perfect, though, since we have been studying organisms at many different levels for years—e.g., physical chemistry, organic chemistry, genetics, protein biophysics, pharmacology, cell biology, physiol-

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