FUTURE OF THE BRAIN: ESSAYS BY THE WORLD'S LEADING NEUROSCIENTISTS

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One of *Times Higher Education*'s Best Books of 2015, *Future of the Brain* offers a compilation of original essays by leading brain researchers. The book is divided into seven sections, and the range and disparities of the authors' views underscore the lack of an overarching theory for researchers to apply to studies in this area. Cross-references among chapters do, however, remind us that science itself succeeds through communication among scientists about what their data says. Also noteworthy is that, even given the spectrum of views, most of the authors share a "we can do this" attitude: They are confident that scientists can and will eventually understand the brain. Suffice it to say, as Gary Marcus, one of the book's two editors, notes, "Neuroscience today is a collection of facts, rather than ideas; what is missing is connective tissue. We know (or think we know) roughly what neurons do, and that they communicate with one another, but not what they are communicating" (p. 205).

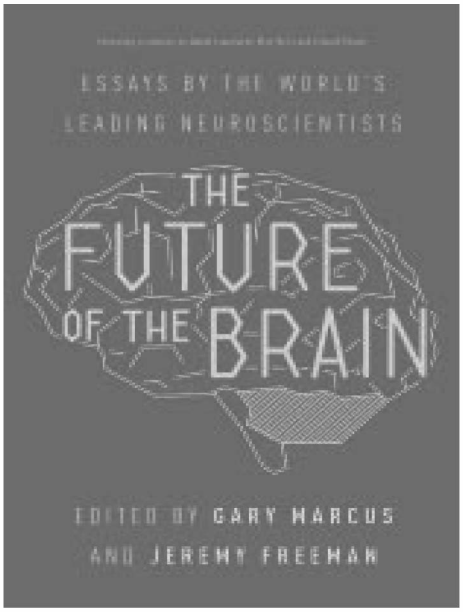
The first section, on mapping the brain, presents connectome projects. This idea (along with computation, the subject of the second section) is the primary research paradigm presented in the book. Essays by Mike Hawrylycz, Misha Ahrens, Christof Koch, Anthony Zador and George Church set the stage for this book's survey of current efforts to understand brain connectivity through mapping and imaging neural activities of mice, strategies for reverse engineering and so forth. The second section, on computation, includes essays by May-Britt and Edvard Moser, Krishna Shenoy, Olaf Sporns and Jeremy Freeman. Together the two sections argue that the brain is an organ of computation and that scientists need to figure out what the brain is computing.

The emphasis on connectivity within these two sections brought to mind that one of the most extraordinary controversies in Nobel Prize history involved moving the emphasis away from brain connectivity. In 1906, Camillo Golgi (1844–1926) and Santiago Ramon y Cajal (1852–1934) jointly shared the Nobel Prize for Physiology and Medicine despite their philosophical differences. This pairing was logical because Golgi had developed the staining method used by Cajal to advance his neuron doctrine, the prevailing paradigm for research on the basic structure of the nervous system in the twentieth century. In other words, *both* men had pioneered the procedure used in the new era, even as the two fiercely differed on how to ultimately characterize their findings about overall brain operations. The depth of their disagreement was on full display during the ceremony when, to the surprise of many, Golgi used this platform to argue against Cajal's "neuron doctrine" in a speech titled "The Neuron Doctrine—Theory and Facts." Defying the growing evidence that supported Cajal's view that the nervous system is made up of *discrete* individual cells, Golgi argued for reticular theory, a nineteenth-century scientific theory that surmised that everything in the nervous system is a part of a single continuous *network*. Moreover, his Nobel speech argued, the nervous network concept he defended was needed:

> What I have just said of the network, on its structure and, above all, on the fact that all the parts of the central nervous system make up a part of it, proves the anatomical and functional continuity between nerve cells. And that is the reason why I have not been able to accept the idea of this independence of each nerve cell which is the essential basis of the neuron theory. [1]

Whether the worm has turned is a question that is unfortunately outside of this book's scope. Instead, after establishing the value of studying connectivity and computation, Sean Hill and Chris Eliasmith introduce brain simulation efforts in the third section, while David Poeppel and Simon E. Fisher outline human language projects in the fourth. The fifth section, titled "Skeptics," is the strongest in the book. Contributors to this section include Ned Block, Matteo Carandini, Leah Krubitzer, Arthur Caplan and Nathan Kunzler and Gary Marcus. (I discuss this potpourri in more detail below.)

The sixth section, on "implications," is said to look at what happens when we understand the brain. I wish it had, because the book suffered from its lack of a broadening perspective. Instead of expanding on the previous chapters and connecting brain research with human society, the authors in this section instead touch on a few areas narrowly. Two of the chapters, by John Donoghue and Michel Maharbiz, were more about possible applications: the prospects and challenges that emerge with the blurring human-machine boundaries. The third chapter, by Kevin Mitchell, expressed concern about how research is used in treating psychiatric disorders, since experiments



rely on the diagnostic categories they hope to validate.

The book ends with a science fiction–type story—an afterword—by Christof Koch and Gary Marcus. On the one hand, their fantasy is largely unrelated to policy and humanistic realities, so elements like funding and ethical concerns are largely unaddressed even in terms of future prospects. On the other hand, the historical notations they include to buttress their narrative show an amazing unawareness of the history of the neurosciences.

Taken as a whole, the presentations remind us of the importance of communicating about evidence (data) in scientific research, which is unlike metaphysical argumentation in which evidence takes second place to ideas. Yet this collection also suffers from the lack of focus common to all anthologies. In addition, it fails to grapple with problems that many authors mention in passing. For example, an ever-increasing accumulation of data exists in parallel to a reality in which we all interpret the devilish details differently. Since figuring out what the data implies is no easy task, I found the lack of a humanistic dimension to the publication a bit disheartening. Restricting science to "just the facts, ma'am" is comparable to assuming studies on networking will now sufficiently address the limitations within localization even knowing that historically trends have swung back and forth. This pendulum seems like an ill-conceived part of scientific theorizing and is particularly disheartening when looked at comprehensively given that science provides only one avenue of inquiry in our world.

Those seeking to learn more about particular areas of current research may find the volume's limited terrain helpful. It does cover some specific projects, including new efforts to map the brain. The chapters' authors declare that better atlases will aid research, but, as several note, this can only really be the case if we ask the right questions. Many spoke of the need for and value of large observatories like those that are used in physics (e.g. CERN) and research initiatives (such as the Obama administration's BRAIN Initiative and the European Union's Human Brain Project). The papers that come closest to adding a social dimension are in the "Skeptics" section, one by Leah Krubizer and the second co-authored by Arthur Caplan and Nathan Kunzler. Caplan and Kunzler raise several good points under the header "Are We There Yet? What Counts as Progress?" As they point out, key considerations are often skirted in "progress" discussions, particularly now that genetic analogies have entered the picture. The question of whose brain to map, for example, is centrally important. Will we include data from the mentally ill? Will those who have brain diseases be a part of what is brought forth as normal? Even if these were answerable questions, additional considerations include that we don't know how different the connectome of each human brain is or what sort of variability to expect in a dynamic brain image. Caplan and Kunzler also explain that "if the genome has taught us anything, it's that those working to map out biology, be it genome or brain, have a huge social responsibility" (p. 204).

Variability is also evident in how we interpret the details, particularly within popular approaches like computation and reverse engineering. Zador argues that a connectome may allow us to reverse-engineer the brain: "To reverse engineer biological intelligence we must understand how specific neural circuits solve well-defined problems" (p. 44). According to Eliasmith:

> In short, reverse engineering the brain will allow us to: (1) understand the healthy and unhealthy brain and develop new medical interventions, (2) develop new kinds of algorithms to improve existing machine intelligence, and (3) develop new technologies that exploit the physical principles exhibited by neural computation (p. 125).

But, also, in the "Skeptics" section, we find two radically different positions being aired about computational analogies. On the one hand, Matteo Carandin expresses some concerns about interpretations that draw conclusions using an intermediate-level computer analogy. Marcus, by contrast, claims that the field needs to break free from the idea that the brain is not a computer.

If these views offer a taste of the range at play in the book, the sum total reminded me that scientific conclusions are, at best, provisional, because the methodology is also designed to probe limitations within current work. This probing mechanism is key despite the way scientists often act as if there is a destination we will reach, where we will get to the "irreducible" essence of a form or process. Unfortunately, this urge toward the irreducible seems, at least to me, to assume more of a metaphysical completeness rather than an evolutionary option, with concepts like "irreducible components" negating that the brain is a part of a living, growing and mutating reality. "Connectivity" may add a theoretical sense of a holistic process, but it is mostly framed as if there is a final place we will reach or will define. For example, according to Olaf Sporns, one of authors of the term *connectome*, who also penned a chapter for this book, "neuroscience will also need to shift perspective toward embracing a view that squarely acknowledges the brain as a complex networked system, with many levels of organization, from cells to cognition, that are individually irreducible and mutually interconnected" (p. 90). I find this idea somewhat ambiguous in light of brain plasticity. It also raises the question of what he thinks is irreducible; is he arguing that it is the levels of organization?

On finishing the book I found myself trying to reconcile its omission of culture and society. To be sure, one cannot deny that modern science and technology have added remarkably to our world. Yet the lack of consensus among researchers in all periods, and the segregation of science from culture, always seem to raise the question of whether there are other ways of looking at the brain. Given this, I'm glad the editors included a few skeptical voices in the volume to serve as a reminder that perhaps the lack of an all-encompassing theory is not a problem so much as an incentive to think about other ways of framing the "brain project." Or, as noted in the best essay in the book, by evolutionary neurobiologist Leah Krubitzer, "Context . . . can alter neocortical connectivity, functional organization, and the resultant behavior of an individual. Remarkably, it is possible to dramatically alter 'normal' brain connectivity and function by altering the patterns of stimuli experienced during development and over a lifetime" (p. 190). Krubitzer goes on to say:

> Given the enormous role of social and cultural context in human brain organization and function, to predict the future evolution of the brain—where our own brains might be a hundred or thousand or a million years from now—would require us to predict the direction of social, economic, and technological changes to our current culture. We also need to consider the physical changes in the environment like global temperature, the types of food we eat, the chemical treatment of our water, alterations in our form of locomotion, and our movement away from traditional tool use to automation and skills that require more unique movements of our digits all of which may shape our future body, morphology, physiology, and metabolism. In short, you can't predict future brain organization in isolation, but must consider the multilayered context in which the brain develops (p. 192).

In summary, although the essays are well written and enjoyable, they are rather limited in scope and may prove too technical for readers looking for a popular overview of where brain research is today and what the future holds for it. The skeptical views, however, remind us that a healthy skepticism forces us to continually examine all claims, including our own, as new information enters the arena. Critically evaluating data and seeking to keep "conclusions" open to reevaluation speak to a skeptical attitude that is neither a denial of science's value nor an elevation of mysticism. Rather it is saying that learning is a lifelong and intergenerational process. It involves the brain and extends to include society, individual traits that change throughout our lives and even nature. More broadly, in terms of science and, in this case, neuroscience, it seems that, with so much unknown, a skeptical attitude—defined as an act of suspending judgment (in other words, the opposite of jumping to conclusions)—should be the optimal approach when so much is unknown: an element of the research that all of the authors note). If science is by definition a communal exercise in evaluating explanations and claims, then skepticism is a key component of the methodology, one that encourages scientists to systematically question all information in the course of all investigations.

Let me note that readers who bring some background to the research will no doubt find the array more accessible than those less familiar with the field. *Leonardo* readers with a fascination for the brain may want to complement this volume with a title like *Experience: Culture, Cognition, and the Common Sense,* a compilation from a symposium that brought artists, musicians, philosophers, anthropologists, historians and neuroscientists together. The *Experience* anthology has a wider sweep and has much to say about the interplay of sensorial and cultural realms of experience [2].

References

1 The full lecture is available at <www.systems.neurosci.info/Cortex/golginp.pdf>.

2 Caroline A. Jones et al., eds., *Experience: Culture, Cognition, and the Common Sense* (Cambridge, MA: MIT Press, 2016).