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A REVIEW OF ‘BRAIN COMPUTATION AS HIERARCHICAL ABSTRACTION’

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Abstract: *This article is a review of the book ‘Brain Computation As Hierarchical Abstraction’ by Dana H. Ballard published by MIT press in 2015. The book series computational neuroscience familiarizes the reader with the computational aspects of brain functions based on neuroscientific evidence. It provides an excellent introduction of the functioning, i.e. the structure, the network and the routines of the brain in our daily life. The final chapters even discuss behavioral elements such as decision-making, emotions and consciousness. These topics are of high relevance in other sciences such as economics and philosophy. Overall, Ballard’s book stimulates a scientifically well-founded debate and, more importantly, reveals the need of an interdisciplinary dialogue towards social sciences.*

Keywords: *computational neuroscience, book review, link to social sciences*

JEL Classification: *D87, D70, D80, C70, M20,*

1. INTRODUCTION

The book ‘Brain Computation As Hierarchical Abstraction’ by Dana H. Ballard has certainly not been recognized as one of the big surprises in the recent book market. Of course, it is rather an academic book than a novel for ordinary people, containing aspects that require more visibility especially in social sciences because it may be able to shape future theory. The book has nearly 400 pages, but despite its length and bulky topic, it is discussed in a lively and interesting manner. It contains good illustrations and, thus, makes it accessible for academics of all scientific fields. So far, the book is most likely sold to experts in the field, but I will argue that it is as important to social scientists as it is to neuroscientists.

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2. BRAIN COMPUTATION: RESULTS

The main theme of the book is about computational neuroscience. It is not easy to measure the relevance of research publications across scientific disciplines. Usually, measures include impact factors, number of citations or journal rankings, however, such standards have limitations, especially for books. In fact, measuring the overall attention of a book from a different discipline requires a more comprehensive approach. One unique measure of attention is Google search data (Da et al. 2011). Figure 1 denotes the public attention of three major fields in neuroscience: behavioral, cognitive and computational neuroscience.

Generally, computational neuroscience has the lowest public attention in comparison to other subfields. The public's attention on behavioral and cognitive neuroscience is not just higher, but also displays interesting cyclical patterns. This pattern does not appear in the Google data. Of course, the different cyclical patterns are interesting, but this is itself a topic of research and remains to be further studied. One hypothesis might be that computational neuroscience is a more recent subfield than the others. Another conjuncture is that computational neuroscience requires more interdisciplinary skills and dialogues. Thus, the book under review tends to belongto a rather closed niche in neuroscience and social sciences.

In fact, computational neuroscience literature goes almost unnoticed in social sciences despite its groundbreaking developments and new contributions on modeling behavioral aspects of humans. However, there is a subfield called neuro-economics which focuses on these issues, yet despite the fundamental insights of neuroscientific discoveries, mainstream economists, sociologists or political scientist do not have sufficient knowledge. Undoubtedly, this is one of many books with potentially major implications for social sciences.

Certain chapters, especially 9-11, provide explicit information on important phenomena for social scientists such as the modelling of brain processes during decision-making. This aspect is a major research field in economic and business theory as well. For the last half a century, the role of emotions in decision-making has been applied in behavioral economics. Consequently, the volume is more than a book on brain computation, it is an interdisciplinary volume for scientists in other fields such as social sciences too.

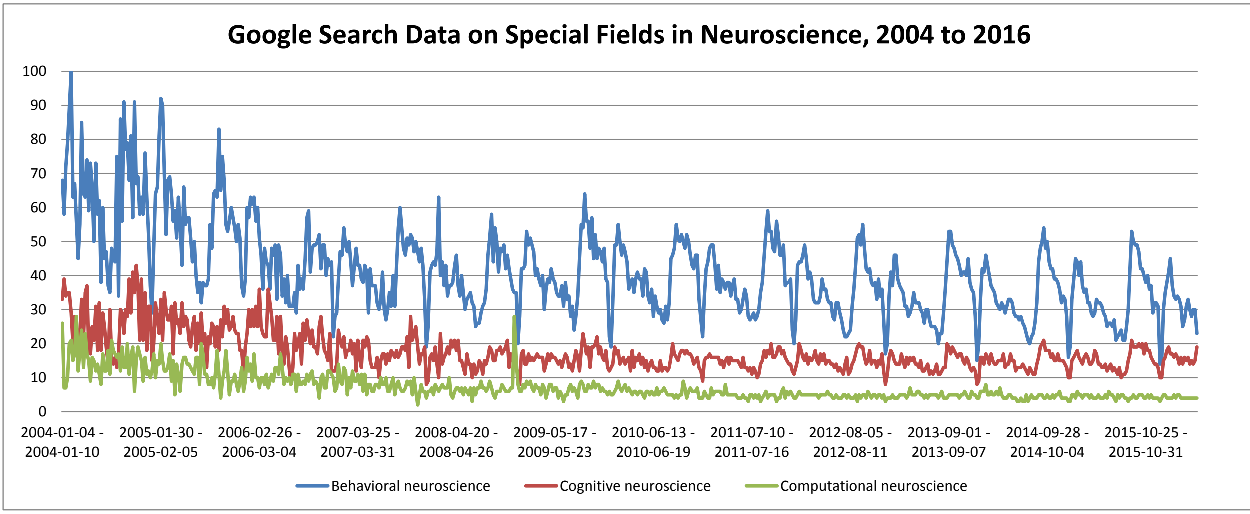

Figure 1 *Google Trends Statistics, 2004-2016*

Source: Google Data, own computations.

2.1. What can be learned from the book?

Ballard's book has a logical structure and it is accessible to readers with no knowledge of neuroscience. The book consists of four parts.

Part I is about the structure and function of the brain, as well as its relationship (i.e. similarities and differences) to silicon computers of today. The reader has the opportunity to learn about the main brain parts and operations, processes and networks.

So far, brain computation 'was thought that a [neuron] spike was a binary pulse, but recent experiments suggest' that it is in the order of a byte' (p. 21). However, the major evidence is that 'nerve cells communicate 10 million times slower than silicon transistors' (p. 22). This detail is interesting because, so far, economists believed in the concept of rational humans, yet rationality assumes that our brain processes all information in a fast manner. Consequently, the challenge is not the understanding of speed, but rather the brain code. Economists probably have to learn that rationality is more than maximizing utility subject to constraints under complete information.

What makes the brain so efficient despite its inherent slowness? The book discusses this issue in more detail. Still it is questionable whether the brain is more powerful than a computer. Chapter 2 elaborates the neuroscientific underpinning of the human brain. The author provides an excellent introduction of the brain functions. In addition, the author is clearly stating when it is a scientific fact or speculation. On brain memory, he stated that ‘the exact limits of cortical memory are completely unknown’ (p. 54).

Rather interesting features tend to be hidden in particular issues of interest for social scientists. In fact, economists model decision-making within a rigorous utility framework. This modelling is somehow analogous to the reward-error-prediction model in neuroscience. The author describes that our brain is ‘never creating brand new programs’ but, according to the situation, it is ‘modifying existing programs’ (p. 57). Hence, a rigorous mathematical model, such as utility maximization, is most likely not flexible enough according to recent neuroscientific evidence.

On p. 58, he refers to a well-known discovery in philosophy. Already I. Kant (1781) stated that ‘…”you see what you want to see.”, however this statement was not based on neuroscientific evidence (Allais, (2004). The interpretation of the outside world is based on a program’s internal expectations’. The neuroscientific evidence of brain processes confirms that ‘expectations almost always get the upper hand’ (p. 58 & p. 378, Baum 2004, Hawkins 2004). Even this insight is not completely new in psychology. For the last four decades, psychologists have studied topics such as framing, biases, and heuristics (Tversky and Kahneman 1973). Similar examples are discussed in the book (e.g.: Rubins Vase on p. 149, the Blue Disk illusion on p. 147). The neuroscientific underpinning of brain processes is quite striking and certainly has a major impact of modelling human behavior in the future. In my opinion, these aspects have been, up until today, underestimated in mainstream economics, business and social sciences.

Modern neuroscience also reveals lessons for philosophical debates. One is about whether our world is discrete or continuous (VanRullen and Koch (2003), Hintikka (1966)). According to the author, ‘our continuous perception of the visual world is somehow created from the series of discrete instants lasting about 300 milliseconds’ (p. 62, p. 128). This would be evidence that the perceived continuous world is rather discrete. Therefore, modeling human behavior by using continuous mathematical tools has its own limitations. Another debate is the neuroscientific underpinning of learning. Learning ‘cannot be complete done without sleep’ and it requires that the new things are ‘filed near similar experiences’ in our brain (p. 73).

Karni et al. (1994) find that the sleep cycle is essential for the hippocampus to do its encoding and downloading work.

Part II is about neurons, circuits and systems; in short, the brain structures. These structures make us special in comparison to silicon computers. Here, for the first time, the reader gets some mathematical and computational background of the human brain. Unfortunately, the mathematical discussion is rather brief. A more comprehensive and rigorous derivation of the mathematical models would be beneficial. Indubitably, more empirical hypothesis, together with the respective testing based on neuroscientific data would enhance the computational aspects of the book. At least several case studies provide an overview about these issues. A rather good discussion in the book is about risk. It turns out that handling risk can be achieved by making it less rewarding, which has the effect of modulating serotonin levels (Doya and Kimura 2009). This insight may have an implication on financial regulation in future.

Part III is about embodiment of behavior especially the role of routines in our brain. The reader learns how expectations can be processed by computational formalism such as in optimal feedback control theory (Shadmehr and Mussa-Ivaldi 2011, Scott 2012). In fact, there is neuroscientific evidence that our brain processes information in a congruent way aligned with the reinforcement learning theory (Schulz et al. (1997)). In the end, 'the brain's dopaminergic system codes an internal reward signal in terms of deviations from expectations' (p. 255). Once again, the computational oriented reader does not get all mathematical or computational details and is looking for more real empirical testing of this neuroscientific evidence.

The final is about highly relevant notions of social and behavioral issues such as decision-making, emotions and consciousness. These topics are closely related to social sciences (i.e. psychology and economics; Tversky and Kahneman (1973)). Recent progress in neuroscience makes it possible to study in detail such topics. The separation of the brain's states with new neuroscientific techniques allows a better understanding of the brain networks, but there are still divergent views on issues such as consciousness.

Chapter 9 (on decision-making) discusses (p. 322-325) the computational aspects and coding of reward values, uncertainty and discounting. The author makes reference to game theory, commonly used in economics. This discussion reveals the need for a closer interdisciplinary dialogue. In fact, the author does not refer to recent research in economics, which has implications on the computational aspects discussed in the book. For instance, Nagel (1995) showed that humans are less rational than suggested by game theory. Hence, human decision-making is based on second- or third-degree beliefs. Nevertheless, under the assumption of infinite-order beliefs, mainstream economists still mainly focus on fully rational agents. Although Nagle's evidence (Grosskopf and Nagel 2008, Costa-Gomes and Crawford 2006) is a well-proven result in experimental game theory, it has not been included in the book.

Of course, in almost any book on neuroscience there is a chapter about conscious free will. The author elaborates on such issues and the computational aspects in Chapter 10. It turns out that a stochastic model may be a reasonable approach to model the perceived concept of free will. In addition, the different philosophical theories on this issue (p. 392) provide a rather interesting discussion. The author suggests that consciousness is likely generated by mental simulations using the same neural circuitry in everyday actions, as proposed by Merleau-Ponty (1962) and Barsalou (1999). If we obtain evidence for this hypothesis one can assume that philosophic and economic theories will have to be rewritten.

In the wake of this book, several ideas pass through the reader's mind. Although there is no concluding chapter that pools all issues in a comprehensive model, it is a stimulating reading. Of course, given the brain's complexity, to conclude such a book is almost impossible. But science is continuously progressing by trial and error, thus scientists should favor to establish a testable hypothesis rather than none at all.

How the book can be further promoted ? Firstly, it should emphasize the scientific approach (i.e. utilize the unique neuroscientific data to develop testable models). Secondly, it should include a more rigorous and comprehensive mathematical treatment of the computational aspects. Thirdly, redefining the rather unappealing title. Lastly, recommendations are highly welcomed.

3. Conclusion

In summary, the book '*Brain Computation As Hierarchical Abstraction*' is a stimulating source about the computational aspects of human brains. It is continuing the debate about the mathematical modelling of human behavior. The informed reader wants to see more hypotheses based on neuroscientific evidence. This probably requires a further closer interdisciplinary scientific dialogue. Nevertheless, the book is well structured and recommendable to researchers in other scientific fields. As a result, Ballard's work is not just a book on computational neuroscience, but rathera remarkable study on brain modelling. It sheds light on almost all aspects of human behavior and thus, provides insights for academic researchers and interested readers alike.

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