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Editorial: Current thoughts on the brain-computer analogy—All metaphors are wrong, but some are useful

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Editorial on the Research Topic
Current thoughts on the brain-computer analogy—All metaphors are wrong, but some are useful

This project kicked off in the fall of 2020. There are two parts of the title of this Research Topic—Special Issue. The first one evokes the issue raised by Turing ("*Can machines think?*", Turing, 1950), a question that we, the Editors, revisit reflecting our complementary multi-disciplinary backgrounds (Evolutionary Biology, GM; Evo-Devo, PM; and Computer Science, BM) and take it up again with a fresh start; this question made us realize how ripe the Brain-Computer analogy has become for a reassessment. The complexity of the subject needed the involvement of experts from the different fields that have been concerned with many related problems, namely Natural Sciences (here Biology and Physics), Mathematics, Psychology and Philosophy. Indeed, the Topic is certainly timely for, while this Issue was going to press, a number of publications have appeared that tackle these very issues both in Sciences (Reynolds, 2022; Yang and Lu, 2022) and Humanities (Kelty-Stephen et al., 2022).

The second part of the title paraphrases a well-known aphorism in Statistics: "*Essentially, all models are wrong, but some are useful*" (George E. P. Box). This statement introduces the "philosophical" part of this topic, *viz.* the semantic issue; in Turing's words: "*Can machines think? This should begin with definitions of the meaning of the terms 'machine' and 'think'*" (Turing, 1950). Indeed, both the Authors and the Editors of this Special Issue realized that a number of other concepts, crucial to evaluate the Brain-Computer relationships, were in need of an updated definition: machine (Bongard and Levin), computer (Danchin and Fenton; Richards and Lillicrap), metaphor and analogy (Matassi and Martinez).

We started off by making a wishful list of relevant topics that would embrace a vast a spectrum of disciplines concerned. These were: Brain architecture, evolution and functioning; Neural Networks and Computational Neuroscience; *Network Science* (*network evolution*); Computer Science; Information theory; Artificial Intelligence (AI); *Game theory; Quantum* *brain—quantum computer*; *Evo-Devo*; *Neurobiology Experimental research*. In so doing, we hoped to stimulate a multi-, trans-, and inter-disciplinary authorship of the articles in this Research Topic, though we were fully aware of the controversies and debates that could arise among scientists and technologists from such diverse scientific backgrounds. Unsurprisingly, we did not fully succeed, and a number of relevant topics had to be left missing from this SI (in *Italics* in the list above).

Many other equally important disciplines were not included for they would each deserve a full Research Topic: Consciousness/Mind, Cognition, Behavior, Language, and Culture.

We have subjectively subdivided the articles in the Special Issue into five subject-wise sections, following some close relationships in their contents. Our groupings are (more details below): 1-Historical Perspectives (Cobb), 2-Philosophical Implications (Brette; Chirimuuta; Gomez-Marin), *3*-Utility and limitations of the brain-computer metaphor (Bongard and Levin; Danchin and Fenton; Davis; Fraser et al.; Richards and Lillicrap; Roli et al.), 4- Extending the concept of cognition (Gershenson), and 5-A new metaphor for the brain, the internet (Graham).

The problem area is introduced in a first paper co-authored by Matassi and Martinez (two of the three editors of this SI). The authors introduce the Research Topic and provide a detailed review of the other 12 contributions; this is complemented by a graphical summary linking articles to selected concepts. Moreover, they analyze in detail the distinction between metaphor and analogy, and offer a definition for the latter. They introduce the notion of Brain and the related evolutionary theories. The article closes with thoughts on creativity in Science, for … "if we ask "can computers think," next we ought to ask "can computers create." And the very act of creation (be it in sciences or in the arts) stems from the awareness of the aesthetic element."

Before summarizing the papers included in this SI, let us consider, briefly, what is the problem area we are trying to deal with in this issue. This introspection should provide us with a reference mark in which the discussion takes place. Obviously, we need to start by understanding what a metaphor is and what purposes it serves, with the emphasis in one of the most productive metaphors in science, the "Brain as a Computer." History tells us that the metaphor has been enriched or modified over time, incorporating new concepts arising in different disciplines, from neuronal physiology to circuit assemblies, information processing and the genesis of complex systems.

1. Historical perspectives

The revolutionary studies of Cajal and Golgi brought us a completely new view of the brain as a biological tissue. The intricate nature of its unit connections (neurons and substructures) suggested the possibility that the brain is actually a connected set of wires, with complex architectures. Moreover, the discovery of chemical and electrical connections between neurons reinforced the image of a giant electrical device with multiple, complex, switching mechanisms. The emergence of the information age, with the first devices able to "compute" operations, was instrumental in bringing a new model of the brain, understood as a complex computing device able to perform logical functions. The history of some old and new metaphors for the brain are nicely exposed by Cobb. This article introduces, from a historical perspective, the current debates in the field, as reflected in the next series of articles in this SI.

2. Philosophical implications

Metaphors are considered either as linguistic (semantic) or cognitive devices, rooted in concrete brain structures, that help us navigate the world. More than this, they help translate complex descriptions into less cognitively demanding ones. Much research is being conducted into the neurobiological basis of metaphoric thinking, but this is a problem we will not touch on in this introduction (see Gomez-Marin's paper for further commentary). As in other complex systems (e.g., the structure of the universe, the prediction of weather or the behavior of large social groups), the study of the brain has been subject to a series of reductionist descriptions.

In a suggestive paper, Chirimuuta comments on the assertion by different authors that have hypothesized the brain and computers (or any other complex artifact) as tractable using multi-level approaches. However, as appealing the simile can be, Chirimuuta thinks that there are several limitations that need to be accounted for, and she provides us with a careful discussion of all of those. In a similar line, a major concern of Brette's is "*What is a computer*?" This is followed by a reappraisal of the concept of "*program*." In this context he discusses the notions of algorithm and computation in the brain, and from a philosophical perspective he asks: "what is a *brain program*"? and, if true, "*who gets to 'program' the brain?*". All those papers bring us to the fundamental role of introducing concepts in our discussions, to make them meaningful. From the very concept of a metaphor to what actually would do a "computerized" brain, all contribute to clarify the terms of discussion.

3. Utility and limitations of the brain-computer metaphor

Whether a metaphor has a practical utility depends very much on what predictions it makes and how valid are the assumptions that underlie the use of these metaphors. In a series of papers, we are confronted with the idea of how computers (or its derivative AI technologies) can imitate humans, or certain human capacities. While the Bongard and Levin view is certainly optimistic, assuming that modern/future machines can actually imitate humans, Danchin and Fenton; Fraser et al.; Roli et al. point to some irreducible properties that make the human mind, essentially, inimitable, thus stating in different ways that brains are not digital computers. Davis takes a more neutral position and just ask himself whether this is a realizable possibility or not.

4. Extending the concept of cognition

When discussing the human mind, two concepts are normally mentioned, that of "intelligence" and "cognition." In an interesting article Gershenson revisits the concept of intelligence as the result of brain information processing. He suggests to use measures of information as a tool to study cognitive systems, including brains and computers. In addition, suggests looking at cognition beyond the individual, and analyze cognition in collectives such as insects' swarms.

5. A new metaphor for the brain, the internet

More recently, some authors have pointed out the need to incorporate the problematics of information flow and storage in the brain within our models. Others have pointed to the idea that our brains might be using quantum processes in cognition and consciousness (Kerskens and López-Pérez, 2022). This has prompted the incorporation of other, recent, models of the brain such as the internet (Graham, this issue).

6. General conclusion

The use of metaphors has helped both scientists and lay men to understand the brain functions in history. Whether they have been accurate or misleading, they have provided us with tools to interrogate the brain. Every period has had their favorite metaphor to explain how this organ performs functions that allow us to both comprehend and navigate the world. These metaphors have an intricate relationship with current ideas of the matter and the living, in most cases suggesting different mechanical similes for our organs (i.e., the brain). Among the mechanical metaphors, arguably, a very productive one has been that of equating brain with a computer device. In recent decades this very last image has changed (as always did), in parallel with our refinement of computing technologies. The arrival of AI, with the possibilities (sometimes overblown) for imitating humans, has generated a heated debate on whether machines can imitate, and perhaps substitute, humans in all endeavors, including those that rely on creativity. We should expect that in the next few years, our view of the brain as a computer will be completely transformed, perhaps entering into an era in which brain and computer performances will be indistinguishable. We asked ChatGPT (a natural language processing tool driven by AI technology) for an opinion: It agreed imitatively and wrote: "*The brain-computer analogy is a metaphor that has been used extensively in the field of artificial intelligence and cognitive science to describe the relationship between the human brain and computers. The metaphor suggests that the brain can be thought of as a computer, and that the way in which it processes information and solves problems can be understood in terms of computer algorithms and hardware, Etc.*" Clearly, a rather cheap imitation of this Special Issue's esteemed editors!

Author contributions

All authors contributed to the writing of this Editorial.

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