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ARTICLES

Why Think That the Brain Is Not a Computer?

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ABSTRACT
In this paper, I review the objections against the claim that brains are computers, or, to be precise, information-processing mechanisms. By showing that practically all the popular objections are either based on uncharitable interpretation of the claim, or simply wrong, I argue that the claim is likely to be true, relevant to contemporary cognitive (neuro)science, and non-trivial.

Computationalism is here to stay. To see why, I will review the reasons why one could think that the brain is not a computer. Although more reasons can be brought to bear on the issue, my contention is that it's less than likely that they would make any difference. The claim that the brain is a specific kind of an information-processing mechanism, and that information-processing is necessary (even if not sufficient) for cognition, is non-trivial and generally accepted in cognitive (neuro)science. I will not develop the positive view here, however, as it was already stated sufficiently clearly to my tastes in book-length accounts.[1] Instead, I will go through the objections, and show that they all fail just because they make computationalism a straw man.

SOFTWARE AND NUMBER CRUNCHING

One fairly popular objection against computationalism is that there is no simple way to understand the notions of *software* and *hardware* as applied to biological brains. But the software/hardware distinction, popular as the slogan "the mind to the brain is like the software to hardware,"[2] need not be applicable to brains at all for computationalism to be true. There are computers that are not program-controllable: they do not load programs from external memory to internal memory to execute them. The most mundane example of such a computer is a logical gate whose operation corresponds to a logical connective, e.g., disjunction or conjunction. In other words, while it may be interesting to inquire whether there is software in the brain, there may as well be none, and computationalism could still be true. Hence, the objection fails, even if it is repeatedly cited in popular press.

Another intuitive objection, already stated (and defeated) in the 1950s, is that brains are not engaged in number-crunching, while computers, well, compute over numbers. But if this is all computers do, then they don't control missiles, send documents to printers, or display pictures on computer monitors. After all, printing is not *just* number crunching. The objection rests therefore on a mistaken assumption that computers can only compute numerical functions. Computer functions can be defined not only on integer numbers but also on arbitrary symbols,[3] and as physical mechanisms, computers can also control other physical processes.

SYMBOLS AND MEANING

The notion of a symbol is sometimes interpreted to say that symbols in computers are, in some sense, abstract and formal, which would make computers strangely dis-embodied.[4] In other words, the opponents of computationalism claim that it implies some kind of dualism.[5] However, computers are physical mechanisms, and they can be broken, put on fire, and thrown out of the window. These things may be difficult to accomplish with a collection of abstract entities; the last time I tried, I was caught red-handed while committing a simple category mistake. Surely enough, computers are not *just* symbol-manipulators. They do things, and some of the things computers do are not computational. In this sense, computers are physically embodied, not unlike mammal brains. It is, however, a completely different matter whether the symbols in computers mean anything.

One of the most powerful objections formulated against the possibility of Artificial Intelligence is associated with John Searle's Chinese Room thought experiment.[6] Searle claimed to show that running of a computer program is not sufficient for semantic properties to arise, and this was in clear contradiction to what was advanced by proponents of Artificial Intelligence who assumed that it was sufficient to simulate the syntactic structure of representations for the semantic properties to appear; as John Haugeland quipped: "if you take care of syntax, the semantics will take care of itself."[7] But Searle replied: one can easily imagine a person with a special set of instructions in English who could manipulate Chinese symbols and answer questions in Chinese without understanding it at all. Hence, understanding is not reducible to syntactic manipulation. While the discussion around this thought experiment is hardly conclusive,[8] the problem was soon reformulated by Stevan Harnad as "symbol grounding problem":[9] How can symbols in computational machines mean anything?

If symbol grounding problem makes any sense, then one cannot simply assume that symbols in computers mean something just by being parts of computers, or at least they cannot mean anything *outside* the computer so easily (even if they contain instructional information[10]). This is an assumption made also by proponents of causal-mechanistic analyses of physical computation: representational properties are not assumed to necessarily exist in physical computational mechanisms.[11] So, even if Searle is right and there is no semantics in computers, the brain might still be a computer, as computers need no semantics to be computers. Maybe something additional to computation is required for semantics.

Let us make the record straight here. There *is* an important connection between the computational theory of mind and the representational account of cognition: they are more attractive when both are embraced. Cognitive science frequently explains cognitive phenomena by referring to semantic properties of mechanisms capable of information-processing.[12] Brains are assumed to model reality, and these models can be computed over. While this seems plausible to many, it's important to remember than one can remain computationalist without assuming representationalism, or the claim that cognition requires cognitive representation. At the same time, a plausible account of cognitive representation cannot be couched merely in computational terms as long as one assumes that the symbol grounding problem makes sense at least for some computers. To make the account plausible, most theorists appeal to notions of teleological function and semantic information,[13] which are not technical terms of computability theory nor can be reduced to such. So, computers need something special to operate on inherently meaningful symbols.

What made computationalism so strongly connected to cognitive representations was the fact that it offered a solution to the problem of what makes meaning causally relevant. Many theorists claim that just because the syntax in computer programs is causally relevant (or efficacious), so is the meaning. While the wholesale reduction of meaning to syntax is implausible, the computational theory of mind makes it clear that the answer to the question includes the causal role of the syntax of computational vehicles. Still, it is not an objection to computationalism itself that it does not offer a naturalistic account of meaning. That would be indeed too much.

The debate over the meaning in computers and animals abounds in red herrings, however. One recent example is Robert Epstein's essay.[14] While the essay is ridden with confusion, the most striking mistake is the assumption that computers always represent everything with arbitrary accuracy. Epstein cites the example of how people remember a dollar bill, and assumes that computers would represent it in a photographic manner with all available detail. This is an obvious mistake: representation is useful mostly when it does not convey information about all properties of the represented target (remember that the map of the empire is useful only when it is not exact?[15]). If Epstein is correct, then there are no JPEG files in computers, as they are not accurate, and they are based on lossy compression. And there are no MP3 files. And so on. No assumption of the computational theory of mind says that memory should be understood in terms of the von Neumann architecture, and only some controversial theories suggest that it should.[16]

Epstein also presses the point that people are organisms. Yes, I would also add that water is (mostly) H_2O. It's true but just as irrelevant as Epstein's claim: physical computers are, well, physical, and they may be built in various ways. It's essential that they are physical.

A related objection may be phrased in terms of James J. Gibson's ecological psychology. Ecological psychologists stress that people do not process information, they just pick it up from the environment.[17] This is an interesting idea. But one should make it more explicit what is meant by *information processing* in the computational theory of mind. What kind of information is processed? It should be clear enough that the information need not be semantic, as not all symbols in computers are *about* something. The minimal notion that should suffice for our purposes is the notion of structural information: a vehicle can bear structural information just in case it has at least one degree of freedom, that is, may vary its state.[18] The number of degrees of freedom, or yes-no questions required to exactly describe its current state, is the amount of structural information. As long as there are vehicles with multiple degrees of freedom and they are part of causal processes that cause some other vehicles just like some model of computation describes these processes,[19] there is information processing. This is a very broad notion, as all physical causation implies information transfer and processing in this sense.[20]

Right now it's important to note that the Gibsonian notion of information pickup, interesting as it is, requires vehicles of structural information as well. There needs to be some information out there to be picked up, and organisms have to be so structured to be able to change their state in response to information. Gibsonians could, however, claim that the information is not processed. Frankly, I do not know what is meant by this: for example, Chemero seems to imply that processing amounts to adding more and more layers of additional information, like in Marr's account of vision.[21] Why information processing should require multiple stages of adding more information is beyond me. Even uses of Gibsonian information in, say, simple robots, are clearly computational, and insisting otherwise seems to imply that the dispute is purely verbal. To sum up: the Gibsonian account does not invalidate computationalism at all.

CONSCIOUSNESS

Some people find (some kinds of) consciousness to be utterly incompatible with computationalism, or at least, unexplainable in purely computational terms.[22] The argument is probably due to Leibniz with his thought experiment in *Monadology*.[23] Imagine a brain as huge as a mill, and enter it. Nowhere in the interplay of gears could you find perceptions, or qualitative consciousness. Hence, you cannot explain perception mechanically. Of course, this Leibnizian argument appeals only to some physical features of mechanisms, but some still seem to think that causation has nothing to do with qualitative consciousness. Notice also that the argument, if cogent, is applicable more broadly, not just to computationalism; it is supposed to defeat reductive physicalism or materialism.

For example, David Chalmers claims that while awareness, or the contentful cognitive states and processes, can be explained reductively by appealing to physical processes, there is some qualitative, phenomenal consciousness that escapes all such attempts. But his own positive account (or one of his accounts) is panpsychism, and it states that whenever there is physical information, there is consciousness. Qualitative consciousness. So how is this incompatible with computationalism, again? According to Chalmers, qualitative consciousness supervenes on information with physical necessity (not conceptual one). So be it, but it does not invalidate computationalism, of course.

Notice also that virtually all current theories of consciousness are computational, even the ones that appeal to quantum processes.[24] For example, Bernard Baars offers a computational account in terms of the global workspace theory,[25] David Rosenthal an account in terms of higher-level states,[26] and Giulio Tononi in terms of minimal information integration.[27] Is there any theory of consciousness that is not already computational?

Let us turn to Searle. After all, he suggests that only a non-computational theory of consciousness can succeed. His claim is that consciousness is utterly biological.[28] Fine, but how does this exactly contradict computationalism? You may build a computer of DNA strands,[29] so why claim that it's metaphysically impossible to have a biological computer? Moreover, Searle fails to state which biological powers of brains specifically make them conscious. He just passes the buck to neuroscience. And neuroscience offers computational accounts. Maybe there's a revolution behind the corner, but as things stand, I would not hold my breath for a non-computational account of qualitative consciousness.

TIME AND ANALOG PROCESSING

Proponents of dynamical accounts of cognition stress that Turing machines do not operate in real time. This means that this classical model of computation does not appeal to real time; instead, it operates with the abstract notion of the computation step. There is no continuous time flow, just discrete clock ticks in a Turing Machine.[30] This is true. But is this an objection against computationalism?

First, there are models of computation that appeal to real time.[31] So one could use such a formalism. Second, the objection seems to confuse the formal model of computation with its physical realization. Physical computers operate in real time, and not all models of computation are made equal; some will be relevant to explaining cognition, and some may be only useful for computability theory. What is required for explanatory purposes is a mechanistically-adequate model of computation that describes all relevant causal processes in the mechanism.[32]

Universal Turing machines are crucial to computability theory. But one could also appeal to models of analog computation if required. These are still understood as computational in computability theory, and some theorists indeed claim that the brain is an analog computer, which is supposed to allow them to compute Turing-incomputable functions.[33] While this is controversial (others claim that brains compute in a more complex fashion[34]), it shows that one cannot dismiss computationalism by saying that the brain is not a digital computer, as Gerald Edelman did.[35] There are analog computers, and an early model of a neural network, Perceptron, was analog.[36] The contention that computers have to be digital is just dogmatic.

ARTIFICIAL INTELLIGENCE

There are a number of arguments with a form:

1. People ψ.
2. Computers will never ψ.

So, artificial intelligence is impossible (or computationalism is false).

This argument is enthymematic, but the conclusion follows with a third assumption: if artificial intelligence is possible, then computers will ψ. The plausibility of the argument varies from case to case, depending on what you fill for ψ. For years, people thought that winning in chess is ψ,[37] but it turned out to be false, which makes the argument instance unsound. So, unless there is a formal proof, it's difficult to treat premise 2 seriously.

So what could be plausibly substituted for ψ? Obviously, not sexual reproduction, even if it is humanly possible. There are many properties of biological organisms that simply seem irrelevant to this argument, including exactly the same energy consumption, having proper names, spatiotemporal location, and so on. The plausible candidate for substitution is some capacity for information-processing. If there is such capacity that humans have but computers cannot, then the argument is indeed cogent.

So what could be the candidate capacity? The classical argument pointed to the human ability to recognize the truth of logical statements that cannot be proven by a computer.[38] It is based on the alleged ability of human beings to understand that some statements are true, which is purportedly impossible only for machines (this argument is based on the Gödel proof of incompleteness of the first-order predicate calculus with basic arithmetic). The problem is that this human understanding has to be non-contradictory and certain. But Gödel has shown that it's undecidable in general whether a given system is contradictory or not; so either the argument states that it's mathematically certain that human understanding of mathematics is non-contradictory, which makes the argument inconsistent (it cannot be mathematically certain because it's undecidable); or it just dogmatically assumes consistency, which means that the argument is implausible, and even unsound because we know that people commit contradictions unknowingly.[39]

Another argument points to common sense. Common sense is a particularly difficult capacity, and the trouble with implementing common sense on machines is sometimes called (somewhat misleadingly) *the frame problem*.[40] Inferential capacities of standard AI programs do not seem to follow the practices known to humans, and that was supposed to hinder progress in such fields as high-quality machine translation,[41] speech recognition (held to be immoral to fund by Weizenbaum[42]), and so on. Even if IBM Watson wins in *Jeopardy!*, one may still think it's not enough. Admittedly, common sense is a plausible candidate in this argument. Notice that even if the proponent of the computational theory of cognition could reject the necessity of building genuine AI that is not based on a computer simulation of human cognitive processes, he or she still has the burden of showing that human common sense can be simulated on a computer. Whether it can or not is still a matter of debate.

COMPUTERS ARE EVERYWHERE (OR DON'T REALLY EXIST)

Still another argument against computationalism brings pretty heavy artillery. The argument has two versions. The first version is the following: at least some plausible theories of physical implementation of computation lead to the conclusion that all physical entities are computational. This stance is called *pancomputationalism*. If this is the case, then the computational theory of mind is indeed trivial, as not only brains are computational, but also cows, black holes, cheese sandwiches, and what not, are computers. However, a pancomputationalist may reply by saying that there are various kinds (and levels) of computation, and brains do not execute all kinds of computation at the same time.[43] So it's not just computation that is specific to brains, but there is some non-trivial kind of computation specific to brains. Only the kind of pancomputationalism that assumes that everything computes all kinds of functions at the same time is catastrophic, as it makes physical computation indeed trivial. But this is what Hilary Putnam claims—he even offered a proof that one can ascribe arbitrary kinds of computation to any open physical system.[44]

Another move is to say that computers do not really exist; they are just in the eyes of beholder. John Searle has made both moves: the beholder decides whether a given physical system is computational, and therefore may make this decision for virtually everything. But the body of work on physical computation in the last decade or so has been focused on showing why Putnam and Searle were wrong.[45] The contemporary consensus is that computational models can adequately describe causal connections in physical systems, and that these models can be also ascribed wrongly. In other words, computational models are not different in kind from any mathematical model used in science. If they are mere subjective metaphors and don't describe reality, then mathematical models in physics are subjective as well.[46]

Intuitively, arguments presented by Searle and Putnam are wrong for a very simple reason: nobody would buy a new computer if it was just easier to think that an old computer simply implemented new software. I could stare at my old laptop and think that it's a brand new smartphone. It's obvious that it doesn't work this way. Therefore, there must be a flaw in these arguments somewhere, and even if the technicalities involved are indeed interesting, they fail to establish the conclusion.

A popular strategy to defeat triviality arguments is to show that it is *ad hoc*: the ascriptions of computational states to physical systems wouldn't support relevant counterfactuals.[47] In other words, they couldn't, for example, accurately predict what kind of computation would run on a physical system, were things slightly different. While this is intuitive, I have argued that one can strengthen the triviality strategies to deal with counterfactuals.[48] As long as one is poised to predict the evolution of a physical process, one can invent a computational ascription. Thus, instead, one should look for a systematic solution that presupposes that computational models are not different in kind from other causal models in science. This is the move recommended by David Chalmers, who has stressed that computational models should be understood causally.[49] However, his strategy requires all computational models to be rephrased to use his favorite mathematical model of computation, combinatorially structured finite-state machine (CFSA), and then matched to a causal structure of a physical system. But rephrasing has an important disadvantage: the states of an original model of computation may turn out to be causally inefficacious. This is why, in reply to Chalmers, I suggested that computation should be modeled *directly* in a mechanistically-adequate model of computation whose causal organization matches the organization of a physical mechanism, and appeal to standard explanatory norms.[50] The norms of mechanistic explanation, which should be followed when explaining a computational system causally, are sufficient to block triviality arguments. (For example, ascriptions will turn out to be extremely non-parsimonious, and will not offer any new predictions except the ones already known from a physical description of a system, which suggests that the model is based on so-called over-fitting.)

All in all, triviality arguments required theorists to spell out the account of physical computation much more clearly but are not a real danger to computationalism. This is not to say that more often than not, empirical evidence is insufficient to decide between vastly different hypotheses about the computational organization of a given mechanism. But again, this is not in any way special for computational hypotheses, since theories are generally underdetermined by evidence.

CONCLUSION

Let me wrap up. In this paper, I have listed and summarized a number of arguments against computationalism. The only objection that does not seem to be implausible at the first glance is the one that states that common sense is impossible or extremely difficult to implement on a machine. However, more and more commonsensical capacities are being implemented on machines. For example, in the 1990s and early 2000s, I used to work as a technical translator for software companies. We used to laugh at machine translation, and nobody would use it professionally. But it's the machine that translates the Microsoft Knowledge Base, which was extremely difficult for professionals to deal with. While the quality of machine translation is still behind the best human beings for complex literary translations, it is no longer something that translators laugh at. We use machine translation at work and merely post-edit it.

The point is that there's no good reason to think that the brain is not a computer. But it's not just a computer. It is, of course, physically embedded in its environment and interacts physically with it with its body, and for that, it also needs a peripheral nervous system[51] and cognitive representations. But there's nothing that denies computationalism here. Most criticisms of computationalism therefore fail, and sticking to them is probably a matter of ideology rather than rational debate.

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NOTES

1. Piccinini, *Physical Computation: A Mechanistic Account*; Miłkowski, *Explaining the Computational Mind*.
2. Block, "The Mind as the Software of the Brain"; Piccinini, "The Mind as Neural Software?"
3. Newell, "Physical Symbol Systems."
4. Lakoff, *Women, Fire, and Dangerous Things*; Barrett, "Why Brains Are Not Computers, Why Behaviorism Is Not Satanism, and Why Dolphins Are Not Aquatic Apes"; Barrett, Pollet, and Stulp, "From Computers to Cultivation: Reconceptualizing Evolutionary Psychology."
5. Searle, "Is the Brain's Mind a Computer Program?"
6. Searle, "Minds, Brains, and Programs."
7. Haugeland, *Artificial Intelligence: The Very Idea*, 106.
8. Preston and Bishop, *Views into the Chinese Room: New Essays on Searle and Artificial Intelligence*.
9. Harnad, "The Symbol Grounding Problem."
10. Fresco and Wolf, "The Instructional Information Processing Account of Digital Computation."
11. Fresco, "Explaining Computation Without Semantics: Keeping It Simple"; Piccinini, "Computation without Representation"; Miłkowski, *Explaining the Computational Mind*.

12. Shagrir, "Brains as Analog-Model Computers."
13. Millikan, *Language, Thought, and Other Biological Categories: New Foundations for Realism*; Dretske, "Misrepresentation"; Bickhard, "The Interactivist Model"; Cummins and Roth, "Meaning and Content in Cognitive Science."
14. Epstein, "The Empty Brain."
15. Borges, *A Universal History of Infamy*.
16. Gallistel and King, *Memory and the Computational Brain*.
17. Gibson, *The Ecological Approach to Visual Perception*; cf. Chemero, "Information for Perception and Information Processing."
18. MacKay, *Information, Mechanism, and Meaning*.
19. Miłkowski, "Computational Mechanisms and Models of Computation."
20. Collier, "Causation Is the Transfer of Information."
21. Chemero, "Information for Perception and Information Processing," 584; cf. Marr, *Vision. A Computational Investigation into the Human Representation and Processing of Visual Information*.
22. Chalmers, *The Conscious Mind: In Search of a Fundamental Theory*.
23. Leibniz, *The Monadology*.
24. Hameroff, "The Brain Is Both Neurocomputer and Quantum Computer."
25. Baars, *A Cognitive Theory of Consciousness*; cf. also Dennett, *Sweet Dreams. Philosophical Obstacles to a Science of Consciousness*.
26. Rosenthal, *Consciousness and Mind*; cf. Cleeremans, "Computational Correlates of Consciousness."
27. Tononi, "An Information Integration Theory of Consciousness."
28. Searle, *The Rediscovery of the Mind*.
29. Zauner and Conrad, "Parallel Computing with DNA: Toward the Anti-Universal Machine."
30. Bickhard and Terveen, *Foundational Issues in Artificial Intelligence and Cognitive Science: Impasse and Solution*; Wheeler, *Reconstructing the Cognitive World*.
31. Nagy and Akl, "Computations with Uncertain Time Constraints: Effects on Parallelism and Universality."
32. Miłkowski, "Computational Mechanisms and Models of Computation."
33. Siegelmann, "Analog Computation via Neural Networks."
34. Piccinini and Bahar, "Neural Computation and the Computational Theory of Cognition."
35. Edelman, *Bright Air, Brilliant Fire*.
36. Rosenblatt, "The Perceptron: A Probabilistic Model for Information Storage and Organization in the Brain."
37. Dreyfus, *What Computers Still Can't Do: A Critique of Artificial Reason*.
38. Lucas, "Minds, Machines and Gödel"; Penrose, *The Emperor's New Mind*.
39. Krajewski, "On Gödel's Theorem and Mechanism: Inconsistency or Unsoundness Is Unavoidable in Any Attempt to 'Out-Gödel' the Mechanist"; Putnam, "Minds and Machines."
40. Dreyfus, *What Computers Can't Do: A Critique of Artificial Reason*; Wheeler, *Reconstructing the Cognitive World*.
41. Bar-Hillel, "A Demonstration of the Nonfeasibility of Fully Automatic High Quality Translation."
42. Weizenbaum, *Computer Power and Human Reason: From Judgment to Calculation*.
43. Miłkowski, "Is Computationalism Trivial?"
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