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Introduction

Computation, or information processing, can be defined as that which describes the changes which occur in the natural world. Typically an algorithm or equation, such as the ones used in neural modeling, are employed for such processing due to their ability to describe the behavior of a system according to certain dependent and independent conditions. Due to the recent increase in processing capacity of modern computers, neuroscientists and computer scientists have attempted to model large scale brain architectures that include entire populations of neurons, or in the case of a team of Swiss researchers, the entire human brain, in hopes of simulating the processes in the brain to a point that higher cognitive functions would arise from the models. While this is an exciting prospect, it is unclear whether running the "Brain Program", would actually yield genuine cognitive processes, simply because the brain is not necessarily a digital computer, and its functions not necessarily computational. In this paper, I pose the question: Does the brain run algorithms? I will argue that this question stems from a deeper uncertainty of whether cognitive processes are computational, and explore the implications that this may have on our ability to model the mind with computers.

What is an algorithm?

For the purpose of this article, it is appropriate to use a general purpose definition with a few clarifications. First, an algorithm must consist of precise, unambiguous steps which require no subjective interpretation, and, resultantly, the execution of the algorithm must always yield the same outcome given a particular set of inputs.

Intentional Use of Algorithms

While executing even the simplest tasks such as brushing one's teeth, or navigating to a desired, familiar destination, application of an algorithm is essential for successful completion of the task. More complex tasks, such as using the quadratic formula, require similar use of step-by-step processes. However the algorithms we draw on to accomplish such everyday tasks are learned through many experiences of trial and error; each algorithm was developed indirectly through intentional, goal-driven behavior, and so is not inherent to the architecture of the brain. In other words, the processes which govern the underlying functions of the brain, i.e. protein synthesis and the physical and chemical basis for generating action potentials are neither learned, nor controllable through intentional behavior. Such processes are inherent in the physics of the system.

Computer algorithms

Though a general purpose dictionary will explain that an algorithm consists of a step-by-step problem solving procedure, the computational meaning of the word has not yet been agreed upon. Computation, in its most basic definition, occurs in a system which is designed to process information in the form of simple symbol exchange, as in the 0-1 coding paradigm used in digital computers. A certain combination of such formally defined symbols correlates to certain commands, which can take the form of stepwise algorithmic functions.

In most modern computers, this symbol exchange corresponds to the presence or absence of electrical current. Hardware is designed so that input generates current fluctuations in a vast array of transistors, which eventually leads to some output mechanism. This output can be expressed, for example, through a mechanical device that takes the current fluctuations and converts them to light on a monitor. It can also be converted into signals that direct the motion of the mechanical arm that writes on the hard disc. Note, however, that transistors are not strictly necessary for a formal symbol exchange. Theoretically, any system upon which a formal symbol definition can be imposed can be a computer.

What is the difference between human and computer algorithms?

The human method of following an algorithm requires consciousness. Humans are consciously aware of the task that they are supposed to complete, and use the meaning of their instructions to drive their behavior. Computers run algorithms in a completely different manner due to their lack of consciousness. The computer "performs" algorithms simply through following a formal symbol definition that precipitates changes in the hardware and software. Though both humans and computers can use the same exact algorithm to find the value of variables in a quadratic equation, the processes which underlie their behavior are radically different. But the question still remains: Are there any nonconscious algorithms (i.e. computational processes) in the brain?

What things in nature are potentially capable of algorithmic behavior?

In the post-Newtonian era, all of us can observe a natural process, such as a rock falling from a cliff overhang, and can imagine a basic set of laws or equations which could accurately model the rock's motion. It is also clear to us that the rock is not following an algorithm, which could look something like this:

```
Detach oneself from cliff face
While(collision with
ground=FALSE)
{
            Do{
Move towards the center of the
earth, increasing velocity by interval determined by force of gravity
and mass of rock }
Until(terminal_velocity ==velocity)
Move towards center of the earth
at terminal_velocity
}
```

Why is it clear to us that the rock is not following this algorithm? For one, we know that a rock does not have an input/output system. It neither has way of measuring its own velocity, nor a way to alter its velocity, and so could not follow the do… until instruction, or any of the others. Additionally, a rock does not propel itself; rather, gravity exerts a force on the rock that causes it to move in a particular direction at a particular speed. In other words, we know that a rock cannot detect its progress, and aside from not having a propulsion system, it wouldn't be able to execute commands if it did have a propulsion system.

But does there exist anything in nature that does follow algorithms? Immediately, it should occur to us that there is one prime candidate: Life. Even the most basic life forms have organization which functions as an input/output system. Paramecia have the ability to sense changes internally and in the environment, and thus can perform certain behaviors, e.g. food acquiring. Yet this by itself does not indicate that any algorithm is being followed. Biological processes are unique in their input/output organization, but this does not contradict the fact that all things that occur are still based on chemical and physical processes. A cell membrane is not selectively permeable because it detects each substance on its exterior and passes judgment on whether or not to let it through, but because the substances that make it through are small enough to pass, and do so because of a chemical gradient, or because they are chemically suited to pass through a specific channel. Similarly, a cell membrane is not round because the cell actively maintains its shape due to the fact that this enables higher internal organization, but rather because it is the lowest energy configuration of the hydrophilic heads and hydrophobic tails of each phospholipid molecule in the membrane. In other words, there are no instructions written somewhere to govern these behaviors; they are results of physical and chemical processes.

Unfortunately, accepting that all things are results of physical and chemical processes does not by itself refute the proposal that the brain is computational. Indeed, it is still possible to assert that all things in nature are intrinsically computational.

Is everything intrinsically computational?

This viewpoint has been furthered by such prominent philosophers as Daniel Dennett, who proposed that evolution was an algorithmic process. Others debate this claim, however. John Searle, an opponent of this type of thinking stated in his book The Rediscovery of the Mind, "…notions such as computation, algorithm, and program do not name intrinsic physical features of a system. Computational states are not discovered within physics, they are assigned to the physics".

In order to understand this, let us remember that computation can be defined as a system of information processing that relies on the mindless exchange of symbols, i.e. the use of syntax. In much of his work, Searle vehemently points to the fact that syntax is a formally defined system which is imposed upon a natural system. By this he means that the voltage levels of a computer which we encode as 0's and 1's, and in fact all state changes in any natural system, are not in themselves indicative of anything. Rather, we as observers assign symbolic meanings to each state. In this sense, nothing is intrinsically computational.

Considering any given pattern found in the brain, we could readily ascribe a computational interpretation. But this does not mean that the brain is a digital computer, or that it has a separate "program level", as has been the assumption since Marr proposed a model of the brain that separated the neurobiology from the other "higher" functions. As Searle said, "You don't need to suppose that there are any rules on top of the neurophysiologic structures."

What does it mean for computer science models of the brain if the brain isn't algorithmic?

If the brain lacks any intrinsic algorithmic processes, then there is no algorithm we'll invent that will recreate any fundamental processes in the brain. Computational models that emphasize a top-down approach may be valuable for academic fields that wish to use brain-like behavior for the purpose of improving mechanical and computational systems. But the top-down method of devising a computational model that represents the relationship between higher level brain architectures and behaviors will fail to provide an ultimate explanation of how the brain works. Methods that operate under the mistaken assumption that the brain contains "programs" of behavior which are somehow distinct from neurobiology will never offer explanations of how behaviors actually arise from the neurobiology, and so are limited in their ability to realistically portray what the brain actually does.

Could a network of Ordinary Differential Equations constitute real consciousness?

Top-down approach aside, there are those whose efforts revolve around reconstructing the brain from the bottom-up using computers to simulate its most basic components. Networks of ordinary differential equations have been used to mimic the changes in individual neurons as they fire. But even this only provides a simulation of the processes that occur in the brain. There is still this assumption that the physiology that causes the brain to function is somehow incidental. On the contrary, the physicality of any system is what causes it to behave as it does. To suppose otherwise is unscientific. Thus efforts like Tom Markram's Blue Brain project may succeed in simulating all processes in the brain perfectly, but such a feat would not amount to creating a mind any more than simulating a tornado will amount to creating a tornado[1].

Conclusion

With a certain degree of complexity, it is often difficult or impossible to decipher the processes of a system. Because the human brain is radically more complex than most natural phenomena, attempts to explain the operations and physical processes which cause a brain to function fall victim to these difficulties. Often times when such a system is encountered, descriptions which focus on behavior, that is, on the input-output relationship displayed by the system, are put forward, rather than explanations which are based purely on physical properties of the system. An indispensable tool used in nearly all math and science, the algorithm, is often used to generate similar input-output relationships in a virtual environment.

Upon first examination, it seems obvious that brains "run" algorithms, simply because a brain appears to us as a black box function, i.e. an entity which, when given specific input, produces specific output with some predictability[2]. However, the same could be said for many other natural phenomena, such as a projectile moving through the air, or the formation of phospholipid membranes. Each of these systems can be reduced to a set of inputs or initial conditions, which after a series of steps or computations that are defined by physical rules produce a predictable set of output. Indeed, one can write algorithms which describe the behavior of each of these systems. But we have seen that our unique position as observers creates the notion of a symbol, and this predisposes us towards believing that nature contains its own inherent language of computation. Were it not for the philosophical analysis of such problems, we would forever be limited in our ability to understand the universe.

Though the implications of the brain's lack of intrinsic algorithmic processes may seem inconsequential, many areas of research operate under the assumption that the brain is a computer. Of course, the majority of these projects are not concerned with creating a truly conscious mind, but rather focus on developing applications for small-scale artificial intelligence software, in which a simulation of behavior is appropriate. Projects that do aim to create a conscious mind, however, may be faced with severe difficulty unless they adapt their methods to reduce or eliminate the modeling of higher-level structures in the brain. Henry Markram's Blue Brain project, for example, is attempting to model the brain at the molecular level, and so has a much higher chance of creating a mind than if he were to model the brain at a higher-level. In addition, there may be success in attempts to build a physical recreation of the brain with synthetic materials analogous to the biological ones. This approach would excel not only because it emphasizes the importance of the brain's physicality, but also because it would enable a view into the precise relationships and connections between the parts of the brain, and possibly explain how such relationships contribute to consciousness.

Current research programs that wholly embrace the philosophical considerations related to science are rare. Even Boston University's own Cognitive and Neural Systems department barely considers the myriad philosophical problems associated with the study of the mind. Institutions that care only about the utility of the fruits of an experiment dominate the realm of scientific funding, as they should. What these institutions (and the scientists who appeal to them) tend to forget is that robust theoretical deliberation improves the chances of practical, scientific success. It should be the aim of every research effort, then, to develop a solid theoretical paradigm that places their experiments in context, and clearly defines the domain in which results may appear. Still, the scientific study of the mind is relatively young. With any luck, neuro-researchers will begin to recognize the significance of the philosophy of mind in time to guarantee the success of their scientific endeavors.

Notes:

1. That is not to say that it will not provide valuable data on how the brain works. Simulations are created and used for their ability to supply vast amounts of knowledge about a particular system, knowledge which may be otherwise inaccessible. But that is the extent of their abilities.

2. The mathematical definition of a function requires that specific input will always produce the same output, that is, the relation must be totally predictable. While it can be assumed that minute processes which occur in the brain during normal operation respond predictably to given inputs, the unpredictability of processes in the brain as a whole (due to the vast number of contingencies within the brain) causes us to view the brain's responses as probabilistic rather than deterministic. Note however that if by some terrific feat of neuroscience we could view how all of these contingencies interacted, it may be more appropriate to think of the brain as deterministic.