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In Search of the Ultimate Model

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Abstract

In recent years, researchers from a variety of scientific disciplines have begun to notice surprising similarity between the network and topological features of the human brain, or brain-like systems in general, and the picture of the universe emerging out of theoretical physics. In this paper, I discuss some of these recent developments and suggest ways to further investigate structural and dynamical similarities between the human brain and universe. I discuss the impact that a close correspondence between these two systems would have on research in the fields of neuroscience and theoretical physics, and I discuss what type of fundamental underlying processes could have given rise to such a relationship between the brain and universe. Given the high demand in fields like theoretical physics for a system capable of modeling the universe, I suggest a systematic comparison of the ideas emerging out of physics concerning the fundamental nature of the universe, and the ideas emerging out of neuroscience concerning the fundamental nature of the brain and mind.

Key Words: metaphysics, neuroscience, physics, artificial intelligence, complexity

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Introduction

The size and dynamics of physical structures throughout the universe can vary across an enormous range of spatial and temporal scales. On the smallest scales, there are elementary particles described by the standard model of particle physics. On more intermediate scales, there are objects that we perceive in our everyday environments. Finally, on the largest scales, there are galaxies and even larger cosmic structures made out of galaxies. In addition to size and dynamics, physical structures also vary in terms of their level of complexity. According to the leading account in physics of how our universe began, it was initially in a very simple state just after the big bang but has since evolved such that, in localized regions—namely within galactic structures—systems that are more and more complex arose (Christian, 2008). The right ingredients and conditions existed on

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Earth so that it became a location within the universe where this increase in complexity was able to cross the threshold of life, and then evolve to produce humans. Central to the human experience is the human brain, perhaps the most complex physical structure known to humanity. Today, scientists are beginning to find surprising similarities between the universe and the human brain specifically, and to brain-like systems in general. Could the human brain actually be a model of the universe? Over the past several years, this is a topic that I have explored deeply and have also written about (Felton, 2022). In this article, I explore some reasons why such a hypothesis should be seriously considered. I also suggest a few ways to test this hypothesis. Finally, I consider some of its implications.

Observed structural and dynamical similarities between the universe and brain

If you were to investigate whether the human brain is a model of the universe, you might begin by considering an image of the brain and comparing it to an image of the universe on very large spatial scales. The largest image of the universe that we have is actually a simulation that is created using the best available information in the field of cosmology. This image is well-known and is often referred to as the cosmic web of matter. It consists of a network of galaxy clusters of various sizes, two-dimensional distributions of galaxies called sheets, one-dimensional arrays of galaxies called filaments, and regions of empty space in between these structures called voids. Based on this initial comparison, you would most likely conclude that an image of the human brain and an image of the cosmic web do not look anything alike.

Instead of comparing a picture of the brain with a picture of the cosmic web, one could compare network structure in the brain to the cosmic web. This makes more sense because the cosmic web of matter is nothing but a gigantic network of galactic structures. Vazza and Feletti (2020) have shown quantitively that indeed, neural networks in the human brain and the network of galactic structures that make up the cosmic web are very similar. In a recent *Time Magazine* article, physicist Sabine Hossenfelder (2022) considers whether this finding could be taken as evidence that the universe is capable of thinking, as if it were a cosmic brain. She concludes that while there are challenges to this being true posed by limitations of classical modes of communication, the nonlocal nature of the universe revealed by quantum mechanics may make it more of a realistic possibility. Ultimately, Hossenfelder argues that there is nothing within our best theories in modern physics that rule out the possibility that the universe is brain-like and capable of thought.

In addition to the similarity found to exist between neural networks in the brain and the cosmic web of matter, recent research has unearthed other unexpected similarities between the human brain (or brain-like systems) and the universe. For another direct comparison between the human brain and universe, consider first that quantum theory says that, on a fundamental level, spacetime is not continuous; rather, it is discrete, consisting of tiny individual units of spacetime on the smallest possible spatiotemporal scales. Furthermore, all physical events are a form of interaction between entities, such as elementary particles, at these discrete units of spacetime. Based on this formulation, the large-scale structure of spacetime in our universe can be viewed as a complex causal network where the discrete units of spacetime are nodes and the fundamental forces of nature are links between nodes. It has been shown that the network encoding the large-scale structure and dynamics of spacetime is in many ways similar to the large-scale structure and dynamics of other complex networks that have appeared in nature and society (Krioukov *et al.,* 2012). The outermost part of the human brain, the neocortex, which is the region primarily responsible for our higher-order cognitive abilities, is one such complex network that has been identified as sharing structural and dynamical properties with the quantum causal network model of spacetime.

Recently, there has been research that explores a direct comparison between the universe and brain-like systems, or simply neural networks. For example, consider that on one hand, string theory is believed by many to be one of the most promising candidates for a “theory of everything”, that is, a theory that unifies our two crown jewels of modern physics, quantum mechanics and relativity theory. String theory suggests that all physical matter results from the vibrations of unimaginably small filaments of energy within a topologically-complex spacetime that possesses much more than the three spatial dimensions we directly perceive. Now consider that, in a seemingly unrelated field of research, artificial neural networks have emerged as powerful tools for processing information. This technology is only loosely modeled after the human brain because its fundamental components are artificial neurons that are simpler than real neurons, and the connectivity between them captures only some of what is observed in real brains (Cole and Ahmad, 2019). Nonetheless, it has recently been shown that, under certain conditions, the behavior of artificial neural networks undergoing training (learning) can approximate features of systems described by quantum mechanics, general relativity, and string theory (Vanchurin, 2020). That is, one can see fundamental aspects of quantum mechanics, relativity theory, and string theory within the dynamics of an artificial neural network undergoing learning, leading to the suggestion that, fundamentally, the entire universe might in fact be a neural network. Note also that there is currently a trend to advance artificial neural networks by making them more “brain-like” in terms of more realistic artificial neurons and more realistic connectivity joining them (Hassabis *et al.,* 2017). It will be interesting to continue to track the existence of correspondences between artificial neural networks as they become more brain-like and the picture of the universe emerging out of physics.

Challenges to comparing the universe and brain

How can we further investigate if there are structural and dynamical characteristics shared between the universe and the brain? This would not be a trivial endeavor, because in the field of physics there are several theoretical proposals that attempt to explain the fundamental nature of the universe. Likewise, there are several proposals in the field of neuroscience that attempt to explain the nature of the brain and mind. One reasonable approach to evaluating similarity between the universe and brain would be to first survey the different proposals in the fields of physics and neuroscience, respectively. Then one could attempt to synthesize the compatible elements from accepted findings, as well as from the theoretical frameworks that have shown promise, to construct qualitative models of the universe and the brain, respectively, and then compare the two.

Because there is a wide range of viable theoretical proposals in physics and neuroscience to address unanswered questions, there are sure to be a wide variety of qualitative models that could be obtained to represent the universe and the brain. Each model constructed in this fashion should be considered as an attempt to represent just one view of the universe and brain that is emerging out of the fields of physics and neuroscience, respectively. However, if it turns out that there are very similar views of the universe and the brain that are based on leading theories in physics and neuroscience, then it will be up to the scientific community to determine if it is just a coincidence or an indication that there is a deep connection between the structural organization and dynamics of the two systems.

The significance if the human brain is a model of the universe

If the human brain and the universe have analogous structural organization and dynamics, then it means that the brain can be used as a model of the universe, and vice versa. Such a principle can provide physicists searching for a theory of everything with a model system to make observations on, opening up a whole new way to investigate and validate their theories, a luxury that many of our most recent theoretical endeavors severely lack. For example, recall that string theory is widely identified as one of the most promising frameworks for extending our understanding of the universe beyond the capabilities of relativity theory and quantum theory alone. However, string theory predicts entities—such as strings and the tiny curled-up extra dimensions that strings need to vibrate in—that have virtually no chance of ever being experimentally verified via conventional means, such as particle accelerators (Brooks, 2011). Therefore, the ability to make observations on a physical system that has properties very similar to those possessed by the universe will allow string theorists to establish, via observational evidence, string theory's relevance for describing the universe.

But note that if the human brain and the universe have analogous structural organization and dynamics, then ultimately the flow of information can occur in two directions. That is, it wouldn't just be physicists who would benefit from being bestowed a model system upon which they could make observations; neuroscientists would also benefit because now a larger set of insights and concepts in theoretical physics can become an inspiration and a guide to their future research efforts. Currently, there are numerous collaborations between neuroscientists and physicists where the toolbox used by physicists to characterize physical systems has experienced great success when applied to the study of the brain (Popkin, 2016). However, identifying a picture of the universe emerging out of physics as a viable model of the human brain would provide higher-level intuition and theoretical constraints for scientists who attempt to decode the ways of the brain.

How self-similar can the universe be?

If the human brain is a model of the universe, it could mean that the universe has self-similar qualities like a fractal and that we, or at least portions of our brains, are the miniature versions of it. Fractal phenomena like this are not at all uncommon. They can be found all throughout nature due to the prevalence of nonlinear dynamical processes (Çambel, 1993). However, it should be noted that, if indeed the universe is fractal in this way, then based on the known properties of fractals the fidelity of any miniature copies would depend on the type of self-similarity supported by the universe (Strogatz, 2008). In other words, if the universe is like an idealized and infinite mathematical fractal, then in theory it is indeed possible for strict self-similarity—exact replicas—to exist on smaller spatiotemporal scales; but if the universe is a fractal that only supports approximate self-similarity, then it is only possible for an approximate replica system to exist inside it. It should also be pointed out that given the current view of the universe emerging out of modern science, a fractal distribution of matter is just a subset of what it could mean for the universe to be self-similar. In other words, there are concepts being introduced by fields within physics, like string theory, that have a dramatic effect on what a miniature copy of the universe would actually look like.

As far as we know, the only ideal mathematical fractals that exist do so in our computer simulations. What we have seen in nature are fractal structures and processes that exhibit approximate self-similarity (Strogatz, 2008). In well-studied non-linear dynamical systems that exhibit self-similarity—like the Mandelbrot set and logistics map—what often exists is a multitude of substructures and processes that range anywhere from subtly similar to nearly exact copies of the larger system. However, in many cases, even though the miniature copies are not exact copies of the larger system, they are often similar enough that they can still be used as a model of the larger system to some extent. This may also be the case for the human brain in the event that the universe is self-similar and the human brain is a manifestation of this self-similarity. In other words, the similarity doesn't have to necessarily be exact, but it could be close enough that knowledge of the analogous structural organization and dynamics may prove to be a useful principle for advancing our understanding of both the universe and the brain.

The high likelihood that no two human brains can ever be exactly the same implies that what may be analogous to the universe is a general topological structure common to all human brains, yet still distinguishable from brains in the rest of the animal kingdom. It may be possible to identify a human-specific topology using algebraic topology, a mathematical discipline that is increasingly applied to the study of the brain on multiple spatial scales, revealing structures who's features can be readily characterized using well-known topological concepts (Reimann *et al.,* 2017; Sizemore *et al.,* 2018; Sizemore *et al.,* 2019).

Interestingly, these very same analysis tools have also proven effective in our attempts to improve and extend our ability to describe the universe on the most fundamental level. Algebraic topology is currently being used to encode the probabilities of the various particle interactions allowed by the Standard Model of Particle Physics into an abstract object known as the "amplituhedron" (Wolchover, 2013; Ananthaswamy, 2017). The amplituhedron is characterized by the same topological concepts used to characterize network structures in the brain. In other words, the amplituhedron, which encodes Standard Model particle interactions, has similar topological features as microcircuits in the neocortex. In addition, the mathematics of string theory is based on algebraic geometry and the solutions to equations in string theory have geometrical interpretations with topological features like both the amplituhedron and microcircuits in the brain. The application of this type of topological analysis to both the brain and the universe makes it possible to more quantitatively compare both systems.

If there is a topological configuration that applies to both the human brain and the universe, how could such a condition arise? The answer may lie in the possibility that, over time, complexity in the universe has increased in localized regions, namely within galactic structures where there are stars that create complex atoms, planets that form from stellar remnants, and, at least here on earth, where life and human society has evolved (Christian, 2008; Chaisson, 2010). The result of the universe increasing in complexity like this during the course of its evolution could be that it has crossed the threshold for deterministic chaos and has begun to manifest various degrees of self-similarity. It has been suggested that the evolution of life on earth is a process that is more accurately described by deterministic chaos (Bennett, 2010), which would make life a likely place for the universe to manifest its self-similarity. For example, it could be that currently on earth, a more subtle form of the universe's self-similarity manifests as non-primate mammalian brains, like those of dogs and cats. Then, a stricter form of the universe's self-similarity could manifest as non-human primate brains, like those of macaques and chimpanzees. Ultimately, an even stricter form of the universe's self-similarity could appear in the form of the human brain. In this view, even the brains of extinct archaic humans would also represent highly strict forms of the universe's self-similarity, although most likely less than human brains but more than the brains of the other remaining primates today.

Self-similarity could ultimately be key to understanding why the human brain evolved to have the form it has and function as successfully as it does, because having the same (or even roughly the same) form as the universe as a whole would endow the human brain with the functionality required for creating accurate models of the universe (Conant and Ashby, 1970). If the human brain is a physical model of the universe, then it could be a clear example of form defining function. Furthermore, a general principle may be that consciousness itself is a product of the universe's ability to become self-similar, such as when evolution produces species of life on earth whose brains have structural and dynamical similarities to the universe as a whole. The stricter the similarity between a brain and the universe, the richer the conscious experience that would be possible within that brain.

Conclusion

More and more, modern science is uncovering surprising similarities between the universe and the human brain. Given the high demand for a system capable of modeling the universe, whether it be a computer simulation or a real physical system, these findings call for a systematic comparison of the ideas emerging out of physics concerning the fundamental nature of the universe, and the ideas emerging out of neuroscience concerning the fundamental nature of the brain and mind. Identifying analogous structural organization and dynamics of these two systems could lead to a powerful guiding principle for the advancement of our understanding of the universe, the human brain, and the relationship between the two.

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