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EMERGENT RULES OF COMPUTATION IN THE UNIVERSE LEAD TO LIFE AND CONSCIOUSNESS: A COMPUTATIONAL FRAMEWORK FOR CONSCIOUSNESS

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ABSTRACT

We introduce a computational framework for consciousness. We hypothesize that emergent rules of computation in the Universe lead to life and consciousness. We live in a Universe that has a substrate capable of computing or information processing. We suggest that in principle, any Universe that is capable of supporting information processing and has energy can evolve life and consciousness.

We hypothesize that the Universe encodes rules in the form of physical laws that allow for the emergence of both life and conscious organisms. A key insight is that there are different levels of consciousness starting from atoms to organisms to galaxies. We propose a metric of complexity that can quantify the amount of consciousness in a system by measuring both the amount of information and the capability to process that information.

We hope that this framework will allow us to better understand consciousness and design machines that are conscious and empathetic. Consciousness and life may be a general phenomenon in our information rich Universe and their maybe other structures designed or otherwise that may be capable of it. Consciousness is an emergent property of an information rich Universe that is capable of processing that information in complex myriad ways.

KEY WORDS

emergence, consciousness, computation

CLASSIFICATION

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INTRODUCTION

Consciousness has intrigued humanity for centuries. It is only now with the emergence ofcomplex systems science and systems biology that we are beginning to get a deeper understanding of consciousness.

Information and a computational substrate to process that information is fundamental to our Universe. We hypothesize that the rules of computation in our Universe lead to emergence of life [1] and consciousness [2]. Consciousness is an emergent property of an information richUniverse that is capable of processing that information in complex myriad ways.

CONSCIOUSNESS, INTELLIGENCE AND LIFE: PERSPECTIVES FROM INFORMATION PROCESSING

We hypothesize that consciousness, intelligence and life are different forms of information processing [1, 2]. Information and a computational substrate to process that information serve asthe basis of life, intelligence and consciousness.

The minimal computational unit can be an artificial neuron or reaction diffusion computers [1]. In principle, any of these computing substrates can be used to implement the architecture presented above.

We hypothesize that consciousness, intelligence and life are all different forms of information processing. Consciousness is what information processing "feels" like. Feedback in a complex information processing is consciousness (shown in Figure 1).

We also hypothesize that consciousness is what information processing feels like in a complex system. There is a continuum or different levels of consciousness. Consciousness is also an emergent property of a complex information processing system with feedback. Consciousnessand life may be general properties of our information rich Universe.

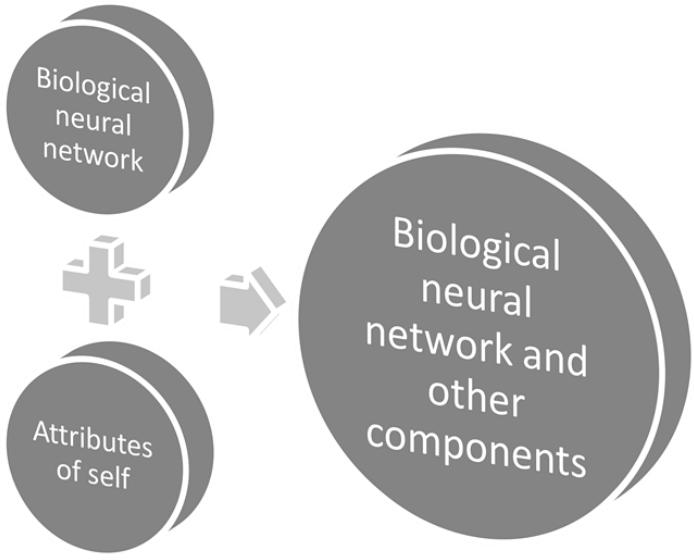

Figure 1. Architecture of consciousness. A biological neural network analyzes the input and output of the core engine and all other modules. This is a simple model with feedback. This is combined with all the attributes of this organism (colour, physical characteristics, the fact that it is not a smartphone, it is not a bird, etc.). The hidden layers of the biological neural network in the brain of an organism will represent the concept of self.

We argue that consciousness is what information processing feels like. A biological neural network can analyze itself. This module would feedback into itself. For example, a small organism like a snail would have some level of consciousness. There are different levels of consciousness. The amount of complexity of this feedback module will determine the level of consciousness.

We note that there are links to quantum theory. In quantum theory, an observer can perturb system just by observing it. Does the Universe only exist if there is an observer? [3]. There are also relationships to the Computable Universe Hypothesis which posits that not only is the Universe a mathematical object, it is composed of computable functions (functions which can be computed and would halt) [4].

Finally, it has been hypothesized before that matter is conscious [5] and that consciousness is a state of matter [3]. Ultimately, consciousness, information and quantum theory may all be related to each other. You need to observe something to make it real (similar to what happens in the double slit experiment). So, somebody must be observing the Universe to make it real. This can be compared to a Universal consciousness (all matter in the Universe is conscious).

The hard problem of consciousness relates to the nature of reality in our Universe. For example, an ant can only observe its surroundings and the Earth is only full of ants. The ant cannot see the Andromeda galaxy. Does it mean that the Andromeda galaxy does not exist for the ant? The hard problem of consciousness argues for the fact that the consciousness is what brings everything in our Universe into existence. Merely knowing more about the underlying physical laws and the state of all particles in it will not help answer the question of why these particles exist and why or how our consciousness can bring them into existence. Monism and panpsychism argue that all matter is conscious.

We argue that there are different levels of consciousness in all matter. Consciousness and information and information processing are different sides of the same coin. It is difficult to answer the question of if the Universe exists without an observer. It may be that conscious beings bring it into existence or that matter exists and different conscious beings see different forms of matter based on their own consciousness. For example, an ant may be able to guide by the stars and will have a different concept of a star than we do. The star exists for both of us. We get different views of the object based on our own consciousness and knowledge [5].

To summarize, we argue that consciousness is what information processing feels like. All matter is conscious but there are different levels of consciousness. The question of whether consciousness brings matter into existence (see ant and star analogy above and discussion below) is truly difficult to answer comprehensively.

Everything we see or observe is interpreted by our brain. Everything is a concept. Let us ask the question did stars exist before anyone could observe them; stars are a concept we created. In a sense that concept could not have existed before the conscious entities that created them exist. Later we argue that conscious entities that have more knowledge have higher levels of consciousness. If we hypothesize that consciousness brings matter into existence, we may be led to additionally speculate that consciousness, knowledge, concepts and matter are related to each other.

Finally, our universe can also be conceived of as a computer [6]. The software is the laws of physics and that along with the hardware (subatomic particles, atoms and molecules) is sufficient to lead to life and consciousness. The laws of physics are software and the physical universe is the hardware. Both hardware and software lead to emergence of life and consciousness.

Emergent rules of computation in the Universe lead to life and consciousness [1, 2]. There may be Universes where there is no life and no consciousness; either the physical laws are not conducive or the physical hardware is non-existent. There may be Universes where the laws of physics are different and there may be no life and no consciousness.

FEEDBACK LOOPS, EMERGENCE AND AN INFORMATION THEORETIC VIEW OF ARTIFICIAL CONSCIOUSNESS

Consciousness is characterized by feedback loops in a complex system. Consciousness is what information processing feels like when there are feedback loops in a complex system that processes information.

It is thought that feedback loops characterize consciousness. There are also different levels of consciousness. Ultimately consciousness is characterized by feedback (analysis of information processing and what information processing feels like), Figure 1. Consciousness is also an emergent property of a complex information processing system with feedback [7].

Consciousness also has been hypothesized to be an emergent property of a complex system. It is like asking what makes water liquid; it is not only a property of the water molecule but also an emergent property.

FEEDBACK LOOPS AND LEVELS OF CONSCIOUSNESS

Feedback loops can lead to consciousness in a complex system. Many different levels of feedback can lead to levels of consciousness [8].

The smallest limit of this maybe in atoms which move around, collide with other atoms, and can be said to be perform computation (and hence also have a certain level of consciousness).

Even plants are intelligent and they can compute and have some level of consciousness [9]. They have some rudimentary intelligence and a computational capability. They can compute where is the Sun, in some cases move their leaves towards the Sun, make toxins when under stress, and calculate when to release seeds. They can sense their environment, build a minimal model of the environment and then act on it.

We hypothesize that intelligence, computational capability and consciousness are related. There are different levels of consciousness which is related to the amount of complexity and information processing capability of the complex system. For example, atoms move when they collide with each other. The rules of movement are dictated by the laws of physics; hence in a sense atoms can be said to compute where to move. This is a rudimentary form of computation. Hence it can be argued that atoms have a very elementary level of complexity and an elementary level of consciousness.

Similar arguments can be made for bacteria and ants which represent a higher level of complexity than individual atoms. It is of note that the complexity in bacteria is dependent on the efficient computation in atoms. Higher organisms build on the complexity and information processing capabilities of their constitutive components.

Individual insects are components of social colonies, and humans themselves are part of societies and a planetary level Gaia [10] that has a higher consciousness. These arguments can be extended to the entire Universe which can be argued to have the highest level of consciousness.

We propose internal model complexity as a metric of consciousness. More levels of feedback and more complexity in information processing may lead to higher levels of consciousness. Information and the capability to process information is a critical component of consciousness and life. The amount of complexity in information processing is a metric of the level of consciousness. Consciousness is what this information processing feels like. A higher level of consciousness is having a higher metric of complexity of both information and the capability to process that information. This metric also naturally suggests that consciousness is a continuum. All beings have some amount of consciousness in them starting from atoms to the whole Universe.

A LINK BETWEEN CONSCIOUSNESS, KNOWLEDGE AND MEMORY

Consciousness and knowledge are inter-related. At some point in time we were not aware of atoms or the other planets. Now we have the knowledge and we are aware of these concepts. It makes us more conscious of our Universe. For example, animals are not aware of planets. They are not conscious of them. But we are because we have the knowledge. Hence, we have a higher level of consciousness. Animals are also conscious. With more knowledge, we can get access to higher levels of consciousness (see Fig. 3 for levels of consciousness and connection with knowledge). There maybe things we are not aware of yet. There may also be other structures that are more intelligent and have access to these higher levels of consciousness.

What does a dog and a human feel like? A dog might wonder why the owner leaves at 8 AM and returns at 6 PM. The concept of work or office is beyond his or her comprehension and consciousness. Similarly, a human also wonders about cosmology and discerns that there are many mysteries that are currently beyond his or her comprehension; these may be accessible to other conscious structures in the Universe.

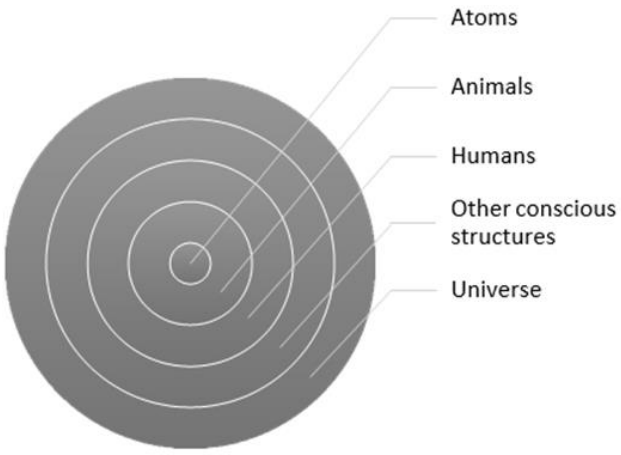

Figure 2. Levels of consciousness and connection with knowledge.

Organisms store information on past actions in memory. They use memories to learn from them, generate new future scenarios from past data and train on this data (Fig. 3). These "reveries" will allow intelligent organisms to effectively combine past actions with newly acquired knowledge. We hypothesize that this leads to more intelligence and ultimately lead to a form of consciousness.

Figure 3. Using past memory to generate new knowledge. Past data is used to generate training data which is combined with new models. This yields new insights and knowledge into a system of interest. This "reverie" model generates new knowledge by combining stored information with a capability to mutate and process that information.

ROLE OF COMMUNICATION IN CONSCIOUSNESS AND INTELLIGENCE

Communication has had an important role in shaping the trajectory of humans. Human brains grew to better communicate with others. This amplified our collective intelligence [1].

We hypothesize that the more intelligent organisms connect these disparate sources of information and form concepts, the more knowledge it will have and the more intelligent and conscious it will become. Humans and other organisms can connect disparate sources of information by communicating with others. Other humans share their own data and information. Collectively they piece together all this information. They advance their understanding. They use these concepts to then further build on, combine with new data and further advance understanding. We can imagine this as a combinatorial epidemic process to explain consciousness as a social emergent phenomenon. The result is intelligence increases over time and so does consciousness.

Combined with memory and reveries (see preceding Section and Figure 3), communication provides a way to progressively increase the level of intelligence and consciousness of a complex system (biological or engineered). Due to this feedback process, consciousness can be gradually built up over time. A similar mechanism was proposed in the bicameral theory of mind [11].

Other animals like birds have primitive communication. At some point in their evolutionary history humans evolved ability to vocalize; this was a more efficient way to communicate. A niche opened in Africa; they could populate that niche. This also co-evolved with the ability to process all this vocal information (communication processing) and a larger brain evolved in humans. Those with larger brains could communicate more and could process that more and had a selective advantage. The formation of societies led to social and collective information processing. This had a runaway effect on vocal and written capability and a brain capable of processing all this information. Furthermore, the evolution of agriculture and collective living likely opened more time to focus on other problems like astronomy and philosophy. Studying these problems would confer long-term benefits on humans. Millennia later these events would culminate in the Industrial Revolution and would lead to even further scientific progress.

SUBJECTIVE EXPERIENCE

We hypothesize that subjectivity is like trying to exhaustively specify the initial conditions and all parameters characterizing a complex non-linear dynamical system (in this case a biological brain) [2]. This is hard to accomplish because we may never have the full dynamical systems model of the brain and even if we did it is exceedingly difficult to simulate it from initial conditions.

We note that there may be conditions we can never fully simulate; even if we had the complete model or dynamical system and determined the initial conditions, using a brain or a machine to simulate another complex system or a Turing machine is in general undecidable. The subjective experience of other conscious animals has been explored before [12]. A bat has sonar. We cannot fully simulate that. We can get a conception of what we think a bat feels [12]. Similarly, we can only get a vague conception of a person who is born deaf or blind.

There may be conceptual structures that are currently beyond comprehension of the biological human brain. The union of the biological brain with machines may allow us to access these structures and higher levels of consciousness.

It may not even be possible to fully simulate another person’s or species mental state; in the completely general case it is undecidable. In specific cases, we may have some hope, like explaining the concept of color to a person who is visually impaired [12].

Some people experience snowflakes in their vision all the time. They think it is normal and that everyone also sees them. How do you define a rose to a person who cannot see and who has never seen a rose? They have their own world view and it is locked in (just like a person seeing snowflakes).

Another example is a dog (who is conscious) but is baffled by a cat who is on the other side of a glass door and he cannot reach. He is wondering how can an object be transparent? It is obvious to us but not to the dog. Similarly, there are other phenomenon that are mysterious to us now.

These are perhaps obvious to other conscious structures and may also become obvious to us in the future also.

ARE THERE OTHER STRUCTURES THAT CAN BE CONSCIOUS?

We ask are there are other complex systems that can be considered to be conscious? For example, is the immune system conscious? It has memory: it remembers pathogens it has seen before. It can adapt to different challenges [13-19] and it has a sense of self (it does not attack cells in the body of the host) [20].

We could also argue that any complex system with feedback can be considered to have a level of consciousness. Other structures based on non-carbon based or other novel computing substrates may be capable of higher levels of consciousness.

WHY DO WE NEED CONSCIOUSNESS?

Could natural selection have selected for consciousness? Empathy is intimately connected with a sense of self. Having a sense of self is essential for survival and it may be why evolutionarily it is important to have consciousness.

There are people called synesthete who have a heightened sense of compassion for other people. They feel intense emotions and empathy for other people to the point where human interactions exhaust them and they can become homebound. Essentially, they are simulating other people and feeling what other people are feeling. They also find it difficult to separate their own self from other people.

Hence the reason we have a sense of self. We hypothesize that having a sense of self aids survival and delineates self from prey or predator. This may also be the reason we do not have a lot of empathy. If we did, we would not have a strong sense of self and may be at a selective disadvantage.

Empathy and consciousness are also related. Apart from being undecidable in general, empathy is also inversely related to a sense of self and hence maybe at a selective disadvantage [2].

Empathy may also confer an evolutionary advantage. The ability to understand others, understand the group, can react to and escape from predators if one can understand that others are also fleeing.

RELATIONSHIP TO A SENSE OF TIME AND SELF

Consciousness also has a relationship to a sense of time [21, 22]. Time maybe a construction of consciousness and a human mental construct. Without space and matter there is no time. Without the subject (self), there is also no sense of time [23].

DISCUSSION

We hypothesize that consciousness is what information processing feels like in a complex system. There are many levels of consciousness and all that is needed for consciousness is a substrate that is capable of computing or information processing.

For example, when atoms collide they can be said to compute what to do next based on the laws of physics; it can also be argued that this is a very basic level or unit of consciousness.

Consciousness pervades our Universe. In principle, any universe that is capable of supporting information processing and has energy can evolve life and consciousness in the current star forming (stellariferous) phase [1, 2].

Consciousness is what information processing feels like in a complex system. There is a continuum or different levels of consciousness. Consciousness is also an emergent property of a complex information processing system with feedback. Consciousness is also like having a sense of self. Consciousness and life may be general properties of our information rich Universe.

Our work is complimentary to integrated information theory [24]; a key difference is we emphasize the dual role of both information and a computational substrate that can process that information.

We hypothesize that there are different levels of consciousness and everything starting from atoms to the entire Universe is conscious. An insight is that there are different levels of consciousness starting from atoms to organisms to galaxies (just as the mystics had said that the entire Universe is conscious). The Universe encodes rules in the laws of physics that allow for the emergence of life and conscious organisms.

We hypothesize that there are different levels of consciousness and we propose a metric that can quantify the level or amount of consciousness in a system. We hope this work will challenge us to come up with new ethical structures that accommodate the fact that we inhabit a Universe that is teeming with conscious structures that deserve our empathy. There is a religion called Jainism that tries not to hurt any living organism including bacteria.

There may be conceptual structures that are currently beyond comprehension of the biological human brain. The union of the biological brain with machines may allow us to access these structures and higher levels of consciousness.

Consciousness can also be gradually built up over time as has been hypothesized before [11] due to learning, a communication language and feedback (bicameral theory of consciousness).

Dreams and voices also have a role in our consciousness as proposed in the bicameral theory of mind [11]. Consciousness is also linked to knowledge. As we know more about our Universe, we become conscious about these phenomena (Fig. 2). Finally, dreams help form concepts and create knowledge and understanding; concepts help us be conscious of phenomenon, Figure 3.

In the words of Marvin Minsky, different "suitcase words" are used to describe consciousness [25, 26]. We can break up consciousness into a lot of steps. For example, let us take the case of someone who crosses the road, turns, and moves. There are a lot of steps involved in this complex process of locomotion. There is nothing magical about it. We do not completely understand it; hence we say it cannot be explained by physical laws [25, 26].

We are also not always conscious (for example, during sleep we are not conscious of our breathing). Sometimes we must meditate to be conscious of these phenomena. We are also not conscious of atoms. Consciousness is what our brain tells us and what natural selection has given us. It is a sense of self.

Empathy and consciousness may also be related to each other. The ability to run a simulation of what another person is feeling like (simulate another person's mental state) is empathy [2]. Apart from being undecidable in general, empathy is also inversely related to a sense of self and hence maybe at a selective disadvantage [2].

In summary, more levels of feedback and more complexity in information processing may lead to higher levels of consciousness. Information and the capability to process information is a critical component of consciousness and life [1, 2]. The amount of complexity in information processing is a metric of the level of consciousness. Consciousness is what this information processing feels like. A higher level of consciousness is having a higher metric of complexity of both information and the capability to process that information. This metric also naturally suggests that consciousness is a continuum. All constituents have some amount of consciousness in them starting from atoms to animals to the entire Universe. Consciousness is an emergent property of an information rich Universe that is capable of processing that information in complex myriad ways.

This also raises the hope of emulating consciousness in machines [2]. We may be able to engineer higher levels of consciousness. Computing paradigms that are not constrained by physical space or our computing substrate (as proposed before [1, 27]) may be capable of higher levels of consciousness. Our greatest contribution as a species may be that we introduce non-biological consciousness into the Universe.

How can we encode these principles and design consciousness in a computer? A tentative basic definition of a conscious machine is "A computing unit that can process information and has feedback into itself". These strategies can be used to design a basic level of consciousness and self-awareness in computers. Previous work has used these design principles to propose a strategy for engineering consciousness in machines [2]. Consciousness can be emulated in machines due to the computational nature of mind [28].

Consciousness may be a general phenomenon in our information rich Universe and their maybe other structures designed or otherwise that may be capable of it. We hope that this framework will allow us to better understand consciousness and design machines that are conscious and empathetic.

Our aim is not to dehumanize what we deem as quintessentially a human phenomenon by casting consciousness as computation. Our hope is that it will give us a sense of wonder and appreciation for our Universe, which is capable of supporting computation which ultimately leads to conscious beings.

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