Exploring the Role of Artificial Intelligence in Cognition Through the Mechanism of Morphological Computation

Sanchia Petrina Rao* and Tejaswini Padikkal

Department of Psychology, Jyoti Nivas College, Bengaluru, India

Email of corresponding author: spetrina7@gmail.com

Abstract: Our brain is endlessly able to process, perceive, remember and organize information. These processes are involved in our cognition and intelligence forming the basis of our ability to think and carry out activities. Artificial Intelligence refers to the simulation of intelligence in machines that are programmed to think and carry out activities. The concept of Cognition and AI have long before been imagined and embodied by various Greek Philosophers, but lately studies have had many breakthroughs. Using the Cognitivist approach along with its biological processes to computation simulations provided a refined understanding of intelligent behaviour in natural and artificial systems. This proved that efficient AI solutions were inspired by human processes and heuristics. Traditionally, in robotics, artificial intelligence, and neuroscience, there has been a focus on the study of the control or the neural system itself. Recently, there has been an increasing interest in the aspect of 'embodiment' not only in robotics and artificial intelligence but also in neurosciences, psychology, and philosophy. Computation about embodiment is a key aspect in creating a more efficient and accurate functioning to that of living organisms.

Keywords: Cognition; Artificial Intelligence; Morphological Computation; Embodiment; Psychology.

1. INTRODUCTION

The human brain is always active, endlessly processing, perceiving, remembering, and organizing information. Activities like being able to read, writing, comprehending, operating a machine, making important decisions, and turning a doorknob efficiently and effectively all come down to complex processes that the brain does. These complex processes are involved in human cognition and form the basis of our ability to think and carry out all the activities mentioned above and so much more. Cognition encompasses the processes associated with perception, knowledge, problem solving, judgment, language, and memory. Scientists studying cognition are searching for ways to understand how we integrate, organize, and use our conscious cognitive experiences without being aware of our unconscious processes. These processes have a wide-ranging impact that influences everything from day to day life and our overall health.

Artificial Intelligence is a term we are very familiar with, especially in this day and age. We live and breathe using technology. It is practically dominating our daily lives, now, more so than ever. To understand what AI is, we need to first know what Intelligence is. Robert Sternberg defines intelligence as "The mental abilities necessary for adaptation to, as well as shaping and selection of, any environmental context". The late John McCarthy coined the term Artificial Intelligence (AI) in 1955 AI refers to the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions. The term may also be applied to any machine that exhibits traits associated with a human mind such as learning and problem-solving. Artificial intelligence is based on the principle that human intelligence can be defined in a way that a machine can easily mimic it and execute tasks, from the most simple to those that are complex. Machines are wired using a cross-disciplinary approach based on mathematics, computer science, linguistics, psychology, and more.

Artificial Intelligence and Cognition have been researched and started making their mark for a while now. The study of how we think dates back to the time of the ancient Greek philosophers Plato and Aristotle. These two concepts were imagined as artificial devices in the embodiment of the imagined Hephaestus' Bronze robot Talos along with the automatons of the Hero of Alexandria and the carved ivory statue of Galatea in the retelling of the Pygmalion. We see that this thought of automation has long before been imagined but in the past 30-40 years we have really seen Cognitive computing shaping our lives.

An example of where AI uses cognition is the infamous Turing test, named after Alan Turing, who developed machine learning during the 1940s and 1950s. Turing introduced the test in his 1950 paper called "Computing Machinery and Intelligence" while at the University of Manchester. The test is a method of inquiry in artificial intelligence (AI) for determining whether or not a computer is capable of thinking like a human being. Being a popular test also invited criticism, which led to other tests being devised from it. Today, we see Artificial Intelligence and its great impact on cognition with the use of these other tests, which you may have heard of. Some of them include The Reverse Turing test, Total Turing test, the Minimum Intelligent Signal Test, the Marcus test, and The Lovelace test 2.0. These are all tests and software that are used, which portray the major impact and the variety that AI and cognition have to offer to help better our lives. Interestingly, testing the theory of the infamous Turing Test on our very own Siri, Alexa, Cortana, and Google Assistant resulted in the test winning over. Even so, Many researchers and scientists are battling over its reliability. Carpenter says, "Passing the test does not prove intelligence but merely shows that the machine can imitate intelligence. That doesn't mean attempting to pass the test is pointless, however". While the Turing Test appeared to be the ultimate test of man and machine, it's since lost its worth. As Carpenter says, it's a test to imitate intelligence, not a test of intelligence itself. Alexa, and Siri may seem intelligent, but we have a long way to go until AI systems become fully intelligent. In the age of the machine, it's interesting to note the milestones achieved along the way: intelligent personal assistants on our phones, computer programs that learn and mimic human thought on our computers, voice-enabled speakers and so much more. Computation about embodiment is one of the key aspects in creating an efficient and accurate mode of functioning for living organisms. Hence, research into this area is becoming increasingly essential for a more sustainable life.

2. DISCUSSION

Concerning the research article titled "From Human to Artificial Cognition and Back: New Perspectives on Cognitively Inspired AI Systems", we learn the basics of Cognitive Computation. As we've covered the basics of Artificial Intelligence in Cognition, there is a field in this line known as Cognitive Computation in AI. This topic has a wide range of publications, especially in recent years. The scientific vision of the early Artificial Intelligence (AI) can be successfully synthesized by the words of Pat Langley (2012): "AI aimed at understanding and reproducing in computational systems the full range of intelligent behavior observed by humans".

This approach, known as the 'cognitivist' approach to AI according to the terminological distinction provided by Vernon (2014), borrowed its original inspiration from a historical perspective– from the methodological approach in 1991, developed by scholars in cybernetics. In this perspective, the computational simulation of biological processes was assumed to play a central epistemological role in the development and refinement of theories about the elements characterizing the nature of intelligent behavior in natural and artificial systems. Therefore, it was also important for AI solutions to be inspired by human processes and heuristics.

Thanks to the computational approach to Cognitive Science, intelligent systems based on computational models and architectures of cognition have been also proposed to provide a deeper understanding of human thinking, as originally suggested in the manifesto of Information Processing Psychology (IPP). In the last few years, the cognitive approach to AI gained a renewed consideration, both from academia and industry, in wide research areas such as Knowledge Representation and Reasoning, Robotics, Machine Learning, Bio-Inspired Cognitive Computing, Computational Creativity, and further research fields that aspire to Human-Level Intelligence (also called AGI, Artificial General Intelligence) in designing computational artifacts.

The AIC (Artificial Intelligence and Cognition) workshop plays a recognized role in the development and promotion of this field. The AIC workshop series on Artificial Intelligence and Cognition, started in 2013 stemming from the need of creating an international scientific forum for the discussion and the presentation of the theoretical and applied research developments in the field of Cognitively-inspired Artificial Intelligence, Cognitive Artificial Systems, and Computational Cognitive Science/Neuroscience. In particular, models and systems based on the methodological approach known as functionalism and, therefore, purely based on a weak equivalence in terms of functional organization between cognitive processes and AI procedures, are not good candidates for providing advances in science of cognitive AI (for example, of technologies like IBM Watson. In this case, the adoption of the expression "cognitive system" represents a misuse). To combat this, the use of a more structuralist approach is considered. It can be useful both to advance the science of AI in terms of technological achievements (e.g. in tasks that are easily solvable for humans but very hard to solve for machines, such as, for example- in common sense reasoning) and to play the role of "computational experiments", able to provide insights and results useful in refining or rethinking theoretical aspects concerning the target biological system used as a source of inspiration.

This article is merely an introduction to this topic and therefore it did not cover all the aspects of how Cognitive computation is viewed today and its scope. The applications mentioned were very less detailed, but they did give a broad prospect about the line. This paper, along with others that were published in collaboration with the AIC aimed to promote the knowledge of computation, which gave rise to numerous other papers in the same field.

Morphological Computation: With the basics of computation in mind, there is another important kind of computation that aids in the efficient functioning of AI systems to have a good and strong cognitive and behavioral outcome. The research paper titled "Morphological computation for adaptive behavior and cognition", coauthored by Rolf Pfeifer, Fumiya Iida, and Gabriel Gómez has done in 2006, investigates Morphological Computation. Traditionally, in robotics, artificial intelligence, and neuroscience, there has been a focus on the study of the control or the neural system itself. Recently, there has been an increasing interest in the aspect of 'embodiment' not only in robotics and artificial intelligence but also in neurosciences, psychology, and philosophy. In this paper, morphological computation is demonstrated as to how it can be exploited on one hand for designing intelligent, adaptive robotic systems, and on the other hand for understanding natural systems.

The term 'embodiment' in this context usually means intelligence requires a body, but this only touches the surface of what it means. The concept has deeper and more important implications, concerned with the relation between physical and information (neural, control) processes. Morphological computation is about connecting the body, brain, and environment. To explain this phenomenon and prove their theory, there are a series of experiments and studies conducted to elucidate this occurrence. In the past, we noticed that robotics has always been concerned with accuracy, speed, and controllability. But in recent years, there has been a shift in the focus to a more 'adaptive' and 'autonomic' approach. Coming back to our main word of concern 'embodiment', we see that any work done on a physical object is concerned with this phenomenon. But, this only considers features like gravity, friction, torque, inertia, energy dissipation and so on and so forth. However, there is a non-trivial meaning of embodiment, namely that there is a tight interplay between the physical and the information-theoretic aspects of an agent, or generally, the information-theoretic implications of embodiment. One simple but fundamental insight, for example, is that whenever an agent behaves in whatever way in the physical world, it will by its very nature of being a physical agent, affect the environment, and in turn, be influenced by it, and it will generate sensory stimulation. For example, if you walk in the street, the optic flow will be induced in your visual sensors, and tactile and perception stimulation in your feet and motor system. Because of the intrinsic physical dynamics, there will certainly be preferred walking patterns, corresponding to energy-efficient movement. Thus, there is a continuous tight interaction between the motor system and the various sensory systems, a sensory-motor coordination. Typically, behaviors in natural agents are sensory-motor coordinated.

It turns out that materials, for example, can take over some of the processes normally attributed to control, a phenomenon that is called "morphological computation". There is no taxonomy of morphological computation yet, but we can roughly distinguish between sensor morphology taking over a certain amount of computation, similarly for shape and materials, and the interaction with the environment. In an embodied agent, by the mere fact of it being physical, all aspects–sensors, actuators, limbs, and the neural system–are always highly connected: changes to one component will potentially affect every other component. From this perspective, we should never treat sensory and motor systems separately.

An interesting example explored in this paper includes "Grasping". Grasping—the 'Yokoi hand'-can be used as a robotic and a prosthetic hand and is partly built from elastic, flexible, and deformable materials. For example, the tendons are elastic, the fingertips are deformable and between the fingers, there is also deformable material. Because of the morphology of the hand, the hand will automatically self-adapt to the object it is grasping. Thus, there is no need for the agent to 'know' beforehand what the shape of the to-be-grasped object will be. The author concludes by stating the following, "Because of this morphological computation, control of grasping is very simple, or in other words, very little brain power is required for grasping". This statement holds a lot of weight. It is interesting to note because, in cognitive computation in AI, we see that the brain is the major organ responsible for almost all functioning of the body. Here, because they can replicate certain gestures/behavior in a robot where there is "embodiment" being portrayed, this shows that a physical body isn't needed for intelligence to thrive. In the case of another study done based on the 'fish' morphology. We see that the environment is playing a huge role in the functioning of the 'artificial fish – Wanda'. This interaction of the physical body and the environment takes over essential aspects of control of a task, which simplifies not only the controlling aspect but also the morphology of the agent – 'Wanda'. The paper concludes by looking at the neural system only the function of the neural system cannot be understood: we must take the way it is embedded into the agent and the specific types of interactions with the environment into account as well. Secondly, not everything needs to be controlled by the brain: the morphological computation takes over or distributes computational or control functions to the morphology, materials, and system–environment interaction.

If we are interested in the brain function, i.e. the role the brain plays in subtending behavior, the entire agent and the interactions with the environment must be taken into account. Recent insights in biomechanics, for example, suggest that in rapid locomotion in animals, an important role of the brain is to dynamically adapt the stiffness and elasticity of the muscles, rather than very precisely controlling the joint trajectories. This way, the muscles can take over some of the control functions, e.g., the elastic movement on impact and adaptation to uneven ground. For robotics, the idea of morphological computation provides new ways of looking at behavior generation; in the past, the focus has been very much on the control side.

If we look more closely at this whole relationship between control and behavior exhibition, we see that control is associated with the brain. This has always been the case. Although, to produce behavior that is more forward and controlling at the same time, the use of morphology kicks in. This is because morphology has a direct relation to the environment and the sense first hand. The control aspect is the secondary receiver after the physical aspects have gone through it. But, what this paper fails to produce is the evidence that the morphological aspect is the sole proprietor for the movement/ adaption of the entire agent. We don't know "how much" or "how little", an agent requires computation to function efficiently. It is but a merely plausible aspect where the notion of computation in the context of morphology or dynamics may require fundamental reconceptualization, which is in itself a challenging research topic.

The whole concept of the embodied object is challenged, because for example, in the case of the grasping hand, the elastic material and the fingers would have to have some kind of memory to link the object in its grasp to something. This part of the sequence requires a certain memory level to be sustained in the robot. A research paper titled "The role of feedback in morphological computation with compliant bodies" combats the drawbacks of the above paper by saying that fading memory which is present in the previous paper is not essential to carry out the phenomenon of morphological computation. This article supports the theory by saying it can be extended to cover not only the case of fading memory responses to external signals but also the essential case of autonomous generation of adaptive periodic patterns, e.g., needed for locomotion. The theory predicts that feedback into the morphological computing system is necessary and sufficient for such tasks, for which a fading memory is insufficient.

While the above research topic touches the area of 'memory', the research paper titled "Cognition as Embodied Morphological Computation" authored by Gordana Dodig-Crnkovic in the year 2018 touches the aspect of embodiment. As seen in the research article elucidating- 'embodiment does not require a body' we see that here, the author explains exactly what 'embodiment' is entitled to, especially when linked to soft robots using AI. The paper states the new idea of cognition as a complex multiscale phenomenon evolved in living organisms based on bodily structures that process information, linking cognitivism and EEEE (embodied, embedded, enactive, extended) cognition approaches. With the base idea that morphological computation in cognizing agents, emerges in evolution through interactions of a (living/ cognizing) agent with the environment.

Biologically speaking, every single cell, while alive, constantly cognizes. It registers inputs from the world and its own body, ensures continuous existence through morphological processes run on metabolic production of energy. It is avoiding dangers that could cause disintegration or damage, adapting its morphology to the environmental constraints. Physio-chemical-biological processes present morphological computation on different levels of the organization. They depend on the morphology of the organism: its material, form, and structure. Morphological computation is modeled as a dynamics of a structure of nodes (agents) that exchange (communicate) information.

The area of cognition faces a few challenges while being used in Morphological computation, these include emotion, consciousness, the environment, body, and social challenges. If we see these areas by their face value, we see that these are all evident in living organisms. But, interestingly, morphological computation tackles all these aspects when it comes to AI. It cannot directly replace all these functions but for a robot, it uses the mechanisms that living organisms use to process these processes in making the robot efficient in completing a task.

By looking into the most latest research paper published in 2020 by Gordana Dodig Crnkovic on the "Natural Morphological Computation as Foundation of Learning to Learn in Humans, Other Living Organisms, and Intelligent Machines", it very clearly lays the foundation wherein conclusion to this review we can directly connect our human cognition and AI cognition using morphological computation. Here, the author elucidates the use of morphological computation in learning and meta-learning by comparing the processes in humans and intelligent machines. Morphological computation is proposed as a mechanism of learning and meta-learning, necessary for connecting the pre-symbolic (pre-conscious) with the symbolic (conscious) information processing. In the framework of info-computational nature, morphological computation is information restructuring through computational processes which follow physical laws. It is grounded in the notion of agency.

We can also understand its significance by connecting to the infamous Turing test- which was introduced at the beginning of this review.

Morphological computation is represented as information communication between agents/actors of the Hewitt actor model, distributed in space, where computational devices communicate asynchronously and the entire computation is generally not in any well-defined state. Unlike Turing computation, which is a mathematical–logical model, Hewitt computation is a physical model. The Hewitt computation provides the consequent formalization mentioned above. Symbol manipulation in this case is physical object manipulation, in the sense of Brooks "the world is its own best model".

3. CONCLUSION

To summarize, knowledge generation places information and computation in focus, as information and its processing are essential structural and dynamic elements that characterize the structuring of input data (data → information → knowledge → meta-knowledge) by an interactive computational process going on in the agent. Since contemporary deep-learning-centered AI, is gradually developing from the present state System 1 (connectionist, sub-symbolic) coverage towards the System 2 (symbolic), with agency, causality, consciousness, and attention as mechanisms of learning and meta-learning, it searches for mechanisms of transition between two systems. An inspiration for technology development, the human brain is of interest as the center of learning in humans. In its development, deep learning is inspired by nature, assimilating ideas from neuroscience, cognitive science, biology, and more. The AI approach to understanding, via decomposition and construction, is close to other computational models of nature in that it seeks testable and applicable models, based on data and information processing.

By looking from the perspective of behavior and cognition, we can see that cognition is much more than what it seems to be. AI in cognition has made its impact on the world and is increasing each day. Computation about embodiment is a key aspect in creating a more efficient and accurate functioning to that of living organisms. This relation between our biological functions and using its functioning to make AI more efficient is a very effective approach but still has a long way to go.

REFERENCES

[1] Lieto, A., Radicioni, D.P. (2016). From Human to Artificial Cognition and Back: New Perspectives on Cognitively Inspired AI Systems.

[2] Pfeifer, R., Iida, F., & Gómez, G. (2006). Morphological computation for adaptive behavior and cognition. *International Congress Series*, *1291*, 22–29. https://doi.org/10.1016/j.ics.2005.12.080

[3] Hauser, H., Ijspeert, A. J., Füchslin, R. M., Pfeifer, R., & Maass, W. (2012). The role of feedback in morphological computation with compliant bodies. *Biological cybernetics*, *106*(10), 595-613. https://doi.org/10.1007/s00422-012-0516-4

[4] Dodig-Crnkovic, G. (2018). Cognition as Embodied Morphological Computation. *Philosophy and Theory of Artificial Intelligence 2017*, 19–23. https://doi.org/10.1007/978-3-319-96448-5_2

[5] Dodig Crnkovic, Gordana. (2020). Natural Morphological Computation as Foundation of Learning to Learn in Humans, Other Living Organisms, and Intelligent Machines. Philosophies. https://doi.org/10.3390/philosophies5030017

[6] Pressbooks. What is Cognition? Retrieved from https://opentext.wsu.edu/psych105/chapter/7-2-what-is-cognition/

[7] Cherry K. (2020).VeryWellMind. What is Cognition? Retrieved from https://www.verywellmind.com/what-is-cognition-2794982

[8] Ruhl C. (2020). Simply Psychology. Intelligence: Definition, Theories and Testing. Retrieved from https://www.simplypsychology.org/intelligence.html

[9] Frankenfield J. (2020). Investopedia. Artificial Intelligence (AI). Retrieved from https://www.investopedia.com/terms/a/artificial-intelligence-ai.asp

[10] Roe C. (2014). Dataversity. A Brief History of cognitive computing. Retrieved from https://www.dataversity.net/brief-history-cognitive-computing/#

[11] Rouse M. (2019). SearchEnterpriseAI. Turing test. Retrieved from https://searchenterpriseai.techtarget.com/definition/Turing-test

[12] D'Elena B. Claire. Down the Rabbit Hole: Testing the Turing Test. Retrieved from https://www.30secondstofly.com/ai-software/turing-test-examined/

[13] AIC. (2020). Artificial Intelligence and cognition. Retrieved from http://www.aicworkshopseries.org

[14] Castelfranchie C., Frixione M., Sandini G., Sharkey A. (2014). AIC. Advances in artificial intelligence and cognition. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.703.6395&rep=rep1&type

Received on 05-04-2021 Accepted on 15-04-2021 Published on 02-05-2021

© 2021 Sanchia Petrina Rao and Tejaswini Padikkal; Licensee ATSK Publishers.
This is an open access article licensed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/) which permits unrestricted, noncommercial use, distribution and reproduction in any medium, provided the work is properly cited.