EC PSYCHOLOGY AND PSYCHIATRY
Review Article

Neuro-Computational Conditions to Simulate Human Consciousness: A Neuroscientific Perspective

Umberto Leon-Dominguez[1]* and Jose Leon-Carrion[2]

[1]*Health Science Division, Department of Psychology, University of Monterrey, Mexico*

[2]*Human Neuropsychology Laboratory, Department of Experimental Psychology, University of Seville, Spain*

***Corresponding Author:** Umberto León-Domínguez, Health Science Division, Department of Psychology, Ave. Ignacio Morones Prieto, University of Monterrey, Monterrey, México.

Received: April 29, 2017; **Published:** June 20, 2017

Abstract

One of the principal limitations faced by models of artificial life in building systems of artificial consciousness is determining whether or not consciousness is inherent to organic systems. Until recently, consciousness was considered a characteristic of organic systems based on carbon, and not on silicon. However, advances in neuroscience have revealed that consciousness is a property which emerges from connective characteristics between different highly specialized neuronal groups. These groups form extensive neural networks which support cognitive functions. Consciousness could thus be viewed as emerging from connective characteristics between different groups, without a need for biological substracts, a qualitative jump in human consciousness simulation. The present paper provides a review of recent models of human consciousness which may support the concept of artificial consciousness. Our model supports the idea that human consciousness, as well as its simulations, is a non-computable determinism system, characterized by their adherence to emergent systems theory.

Keywords: *Neuro-Computational Conditions; Human Consciousness*

Introduction

For centuries, consciousness has been considered part of the soul and exclusive to humans. The notion of the existence of consciousness, or of artificial intelligence, was first debated by Descartes. In the 20th century, this discussion evolved and to this day remains an open debate (for a review, see [1]). Defining consciousness requires prior knowledge of its context, whether it is within a physical system (including quantum mechanics) or a functional system [2-4], which can be programmed, implemented or self-generated in machines. Conscious experience should not be the same in humans and machines, given the difference in their physical make-up. However, it remains unclear whether digital circuits could substitute neuronal circuits and generate conscious experience or qualia. Recent neuroscientific research proposes that consciousness emerges from the connections and synchronization between different neuronal groups [5-7], making small inroads to the possibility of artificially simulating human consciousness.

Human consciousness makes the human being the greatest success in Darwinian evolution. Consciousness should be understood as a holistic phenomenon which permits and generates cognitive functioning. Consciousness is the capacity to integrate both internal and external information into representations for later manipulation. The result of this integration could modify decision making and subsequently, problem solving [5,8]. The capacity to integrate information is limited by spatial-temporal characteristics in the connection between different cerebral structures [6,7,9,10]. Consciousness is thus a dynamic system formed by different neural networks distributed and connected throughout the brain. It is the processing of brain signals and their conversion into cognitive representations, the product of many diverse cortical structures and their dynamic neural states creating a unitary experience [6,7,11]. The consciousness level of a physical system corresponds to a brain system's capacity to integrate information [5]. The disruption of consciousness has been related to a breakdown or collapse in cortical connectivity [6,10]. The objective of the present review is to apply the theoretical knowledge from biological models of consciousness to artificial life models, specifically to models of artificial consciousness.

Theoretical approaches to the study of consciousness in the field of neuroscience

An integrated Global Workspace supporting cognitive functions

One of the most influential theories of consciousness is the "Global Workspace" theory proposed by Bernard Baars [12]. Baars suggests that the brain works as a functionally integrated unit, utilizing cerebral resources to communicate between different processing units along the central nervous system (CNS). In this context, the CNS is viewed as a set of specialized neurons and neural networks distributed throughout the brain, which connect partially or totally depending on the external demands of the individual.

One of the main contributions of consciousness is that it facilitates human cognition in order to resolve day-to-day problems. Human cognition is based on conscious or automatic information processing, which may be sequential or parallel. At the biological level, re-entry processes allow parallel processing to take place, key to human consciousness [13]. This type of information processing makes it possible for distant and distinct cerebral locations to work together, thereby generating a global workspace (GW). This GW supports certain cognitive functions (attention, learning, motor control and executive functions) which inform consciousness of what is occurring in the surrounding environment.

In 1998, Dehaene, Kerszberg and Changeux [14] proposed a Global Workspace (NGW) neural model. Resembling Baars' GW model [14,18], it described a highly connected set of neurons distributed along the brain which generated a global workspace. In this model, different input are integrated and processed to emit specific behaviour that will adequately respond to the external demand. These models differed in that the NGW proposed by Dehaene and his colleagues centred on a more thorough neurobiological analysis of the connectivity between the different neurons and networks. Large-scale connectivity among neural networks plays a key role in the NGW model, which also involves the prefrontal cortex (PFC) as a principal component of long distance communication in brain-scale networks [6,10,17]. In this context, consciousness is formed by the activity of distinct and distant neural networks working as a functionally integrated unit to form a global workspace. When consciousness is generated, different networks integrate into a single hub, forming a GW for cognitive activity. If we apply the GW model to models of artificial consciousness, we then would refer to different specialized algorithms forming a functionally integrated unit from which consciousness would emerge [19].

Consciousness as a system capable of integrating information

Tononi's approach to the study of consciousness is based on the theory that the perception of consciousness depends on a system's capacity to integrate information [5]. According to the author, if this capacity is what causes consciousness, it should depend on neurobiological substrates capable of supporting a wide variety of computational repertoires. Functionally speaking, this biological system cannot be broken down into groups of independent units to produce consciousness. Instead, consciousness emerges from the interaction and synchronization of these units into a single functional unit.

Tononi suggests that the brain houses numerous neural groups, or complexes, which are responsible for integrating information. According to this theory, the amount of consciousness associated with a complex is determined by the quantity of information its elements can integrate, whereas its content is determined by the type of association these complexes share [20]. The integration capacity of this system is most likely higher due to nonlinear switching mechanism which can alter the dynamics of neural map activity at any moment [21,24].

Edelman's global theory on consciousness [14,25,26] discusses the process by which animal vertebrates achieved a cerebral organization that integrates information in one particular manner. His "Theory of Neuronal Group Selection" (TNGS), argues that neural networks were formed by natural selection, requiring a brain sufficiently complex to maintain extensive neural networks and re-entry circuits [14]. Edelman also provides a phylogenetic explanation of the evolution of consciousness. Neural Darwinism (ND) maintains that the brain is comprised of a series of diverse and complex neural groups activated by environmental demands [14]. This activation occurs when a new experience is integrated so as to adapt with those stored in different neural circuits [27]. This concept is known as evolvability [28]. It is possible that neural structures and mechanisms underlying consciousness were selected during phylogenetic evolution because they allowed the organism to plan and prepare for possible future events, and successfully sort them out [27]. The brain, therefore, follows Darwinian principles and possesses the capacity to select neural circuits which have been generated epigenetically [25,26]. Edelman put forth three principals as guides to the development of cerebral organization [27]:

Developmental selection: During cerebral development, the selection of neural groups which correspond to an external event occurs when neurons project in synchrony. While a series of genetic limitations affect cerebral circuit formation, other epigenetic processes open the door to a variety of neural circuits. These circuits form the primary repertoires needed for the selection of appropriate behavioural response. This is one of the major problems facing models of artificial neural networks: while these neural networks form naturally in organisms, they must be predetermined in programs simulating artificial life, intelligence or consciousness, and thus could be considered an impediment to the development of artificial models. However, if viewed from a genetic perspective, human behaviour is also pre-programmed by genetic sequencing. DNA determines the development of the human being while place of birth determines one's epigenetic development. A recent study suggests that computer codes and genetic coding share surprising similarities in the building of a system comprised of different modules [29]. Thus, machines, software and computers with artificial consciousness may also be predetermined by their "DNA", in this case, different algorithms pre-programmed by an external source.

Selection of Experience: Seth and his colleagues propose a model of information processing which identifies the brain as a system of selection rather than instruction [14,30]. According to the TNGS, selective events in the brain are necessarily compressed by the activity of diffuse ascending value systems [14]. In this context, value refers to the emotional valence of an event for an organism, determined by genes and learning [30].

Biologically, value system problems are solved by cerebral nuclei located primarily in the brainstem: locus coeruleus-noradrenergic system, dopaminergic system, cholinergic system and histamine system. The biological efficacy of these systems is evident, but in artificial consciousness models they would need to be substituted by an algorithm capable of positive or negative reinforcement of system outputs, that is, of assessing the output of the algorithm itself. For example, if the energy reserves drop below a certain threshold, an input would automatically be generated to activate an algorithm that produces an output designed to find energy sources. If the batteries are charged, the system would consider this algorithm as successful and the probability of its reactivation would increase to the detriment of other potential algorithms, and vice versa. Similarly, if a valid algorithm begins receiving negative appraisals, it would see less activation in favour of other more successful algorithms.

Re-entry processes in and among cerebral circuits, reciprocal connections and long-distance connections: Re-entry is a cerebral resource assisting parallel connection and disconnection of different neuronal populations [30]. Edelman suggests that re-entry processes are responsible for the emergence of consciousness. This author views re-entry as a selection process which unlike feedback, a serial process, permits parallel connection to different neural groups [14]. The TNGS includes a spatial-temporal description on the coordination and interaction of different cerebral structures [14]. This coordination of neural activity underlying selection processes is achieved primarily by re-entry processes. This system and its capacity to synchronize distant and distinct cerebral areas is what Edelman and Tononi termed the reentrant dynamic core [31]. If we apply this theory to artificial consciousness, it would translate to the existence of a continuously activated "principal algorithm", in charge of regulating the chronometric flow of information towards different components or "algorithm satellites" (highly specialized algorithms that process specific input and produce appropriate outputs).

The input's modality or nature will determine the action taken by the principal algorithm, as it adds or removes different satellite algorithms to improve the system's efficiency. A system with artificial consciousness would therefore be comprised of a principle algorithm which manages the flow of information to different components, and an undetermined number of satellites which are added or removed according to the task at hand. The sum of the principal and satellite algorithms in a neuroscientific context would be referred to as a "dynamic principal algorithm". The more satellite algorithms a system has, the greater the variety of tasks it can perform. The dynamic principal algorithm would resemble a GW [13,15], and its function would resemble the re-entrant dynamic core theory [32].

A cortical system responsible for the emergence of consciousness

Crick and Koch propose that the cortex (cortical system) is where processes necessary for a full conscious experience take place [33,35]. These authors draw a dividing the cortex in two parts, anterior cortex and posterior cortex, which coincides with the central sulcus. The anterior or frontal cortex is formed by the prefrontal cortex (PFC) and the anterior cingulate cortex. Most cerebral areas in the anterior cortex do not detect primary sensory input, working instead with sensory input processed by primary and secondary sensory areas of the posterior cortex. The posterior, or sensory, cortex is comprised of small neural groups which function automatically in hierarchic and stereotyped fashion, due to their lack of reentry circuits. This theory gives birth to the term "*zombie mode*", which is characterized by quick, automatic stereotyped responses [36,37]. Recent research has shown that the PFC can provide cognitive and inhibitory control of automatic and stereotyped responses [38,39].

Crick and Koch [35,40,41] suggest that the anterior and posterior cortices are made up of neural networks capable of integrating small amounts of information. These networks form a complex system of small interconnected neural networks that function quasi-independently of one another. When the neural networks of anterior and posterior regions synchronize, metacognition and consciousness emerge. Our research group carried out experiments on patients with disorders of consciousness and the results were very similar to those of Crick and Koch [6]. Our research focused on the functional state of the cortex in patients with TBI and different consciousness disorders. Subjects were divided into two groups, patients with severe neurocognitive disorder (SND), and patients in the minimally conscious state (MCS) [6]. Behaviourally, SND subjects were able to interact with their environment and respond to its demands, albeit in a dysfunctional manner, whereas patients in the MCS were unable to connect consistently with their surroundings. We compared the resting state networks of these patient groups, using functional connectivity analysis to identify brain connectivity networks in task-free resting state EEG recordings [42,43]. Two methods were applied to ascertain the cause and effect relationships among all electrodes. The first method measured synchronization activity between electrode pairs [44], and the second determined the strength and direction of functional connectivity [10,45,47]. An analysis of the functional connectivity of these networks at rest may be particularly informative, as it provides a means to evaluate brain region interactions independent of task-induced activation/deactivation in patients with altered states of consciousness [48]. Our results revealed the presence of anterior and posterior cortical systems. The executive system is highly intraconnected, corresponding to the anterior region of the cortex, while the cognitive system is part of its posterior region [6]. Like Crick and Koch [35], we found that level of consciousness in the two groups depended on the synchronization produced in high frequency oscillations (beta) between both systems on a precise temporal scale. This synchronization is severely disrupted in patients in the MCS compared to patients with SND, who show better levels of consciousness and a preserved state of alertness.

The key to consciousness and intelligent behaviour is associated with the physical and intra-connective integrity between the executive and cognitive systems [6]. The executive system would deal more with planning and cognitive flexibility, whereas the cognitive system would be more associated with storing experience. By selecting information pertaining to a specific moment [30], the executive system must provide conscious experience with content. Unlike injury to the executive system, which severely impairs executive functions (attention, working memory, cognitive control, inhibitory control and interference control) and hence intelligence, injury to the cognitive system causes sensory and perception deficits, as well as memory loss. This is the challenge for artificial intelligence (as part of artificial consciousness): to create an executive algorithm capable of selecting and activating zombie nodes to respond to the task at hand. This algorithm differs from the principal algorithm in that it provides outputs to the input selected by the principal algorithm as being relevant to a given moment in time. Not all input require outputs-only those which are deemed necessary by conditions predetermined by the programmer or the user.

A neuronal network for selecting and managing the flow of information

Recent research suggests that one of the keys to human consciousness is the selection and regulation of neural information towards different cerebral structures for subsequent processing [7]. The thalamic-cortical system would modulate an individual's state of alert, and thereby, his/her functional ability to process information efficiently and generate qualia (subjective conscious awareness) [5,32,49,52]. The thalamic-cortical system contains a neural sub-network central to conscious behaviour. This sub-network is made up of different thalamic nuclei (reticular thalamic nucleus, intralaminar thalamic nucleus and midline thalamic nuclei) and cortical structures (medial prefrontal cortex and precuneus/posterior cingulated cortex). As a sub-network, it carries out four main functions [7]:

1. Regulate the flow of neural information to reach different cerebral structures specialized in information processing in synchrony.
2. Perceive new information relevant to the system and eliminate information deemed irrelevant.
3. Integrate new information with stored experience.
4. Provide individual with the alertness needed to respond to external stimuli.

This chronometric functional sub-network within the thalamic-cortical system keeps us in an optimal and continuous functional state, allowing high-order cognitive processes, essential to awareness and qualia, to take place. Although this sub-network does not directly participate in the content of awareness or qualia, it indirectly controls and regulates the neural information flow necessary for awareness and qualia to occur [7].

This sub-network only processes new information it considers important for the individual. This selection process is conducted using thresholds which vary in accordance with the individual's physiological state [53,54]. A hungry organism would be more conscious of and sensitive to stimuli indicating the existence of food, as thresholds permitting identification of these stimuli drop [55]. Another characteristic of this sub-network is the role of the PFC. Medial PFC (mPFC) is in charge of providing retrofeedback to thalamic nuclei on the current cortical state, in other words, of the result of the output. This retrofeedback allows thalamic nuclei to get up to speed and respond efficiently to the new stimulus, even when thresholds vary to select relevant stimuli. This sub-network is composed of nuclei which can function independently but are dependent on other nuclei when it comes to conscious information processing. Intraconnected thalamic nuclei are also interconnected with other cerebral structures. Each sub-network and its connections resemble a global workspace model [13,15], and may correspond to Tononi's dynamic core theory [31].

In models of artificial consciousness, these sub-networks could be comparable to the system's principal algorithm, and its interconnected cerebral structures, to the satellite algorithms. These satellites would correspond to structures responsible for automatic information processing, those which Tononi referred to as "complexes" [31,32]. In humans, these sub-networks manage basic attention processes, mnestic and emotional information, and motor and alertness processes. In models of artificial consciousness, this sub-network would adapt to the system's needs for survival and to its design capacity. In artificial consciousness, the principle algorithm manages input and selects those which are most relevant to the system. Once this selection is made, the principal algorithm activates the satellites that can process this input. Relevant input is detected by means of thresholds, similar to thalamic-cortical sub-networks. Like DNA in humans, these programmed thresholds are a basic prerequisite for artificial consciousness, determining the relevance of an input for the system at a given moment in time. These thresholds can be determined externally by humans, or internally by the system itself. In the latter case, the system could modify existing thresholds based on the success of its outputs.

Discussion

Biological models of consciousness provide insight which could help create more precise and efficient models of artificial consciousness. Consciousness emerges from the chronometric connection of distinct and distant neural nuclei into one global workspace that can integrate, process and convert different input into valid output. Eigen's hypercycle theory offers a solution by explaining the self-organizing capacity of living organisms through self-catalytic processes [63]. In a computational perspective, Eigen's hypercycles would be specialized algorithms in specific information processing. For example, when a new stimulus reaches the artificial consciousness system, "detector" algorithms divide the stimulus into different dimensions and process the information, thereby generating a computational cascade which activates more complex algorithms in subsequent levels, and so on. This cascade would follow a hierarchic progression, divided into increasingly complex levels of processing algorithms. Self-catalytic processes would correspond to algorithms which provide positive and negative retrofeedback to one another. This overall process would synchronize the computation of diverse algorithms within a single artificial global workspace.

A recent study revealed that the human behaviour and its variability is defined by the degree of long-range connectivity, and not by the independent activation of different neural nodes [56]. This implies the existence of extensive neural networks comprised of nodes whose connection and synchronization lead to the emergence of consciousness. Furthermore, systems formed by computational units appear to adapt better to dynamic environments, given that reprogramming different computational units is easier than reprogramming a single entangled monolithic network [57,59]. These computational units would correspond to basic cognitive processes and their interaction would generate more complex cognitive functions [60,61]. A system with functional differentiation distributed among different computational units would facilitate the design of models of artificial consciousness. A model of artificial consciousness based solely on one algorithm would be much slower and less efficient in administering energy and temporal resources needed to simulate consciousness. The artificial simulation of consciousness should be based on the integration of diverse algorithms and circuits to form an Artificial Global Workspace (AGW). The key is to design an efficient algorithm capable of organizing overall system activity (principal algorithm).

Artificial Global Workspace system comprised of different functional algorithms capable of integrating a great repertoire of input

The study of consciousness reveals that building systems of artificial consciousness based solely on one algorithm has higher energy costs, more elaborate programming requirements and slower information processing capacity. Neuroscience has shown us that the most efficient systems contain a great number of algorithms capable of integrating themselves into one AGW. The AGW would thus be a dynamic meta-algorithm, comprised of different functional algorithms that are added to or eliminated from the AGW based on the processing of diverse input. These functional algorithms and their circuits must process both serial and parallel input to improve the efficacy and speed of information processing.

The need for a principal algorithm to select input relevant to the system

Edelman suggested that the function of the human brain is based on principals of selection similar to those functioning in evolution long before the use of logic [25]. This "selectionism" theory would recommend delaying the search for human logic in models of artificial consciousness, to first provide the brain with mechanisms to selection input that is relevant to the system. One of the principal characteristics of any artificial consciousness system is the capacity to differentiate between relevant and irrelevant input. This is done by programming a principal algorithm which would be the base of the AGW. This algorithm would have two main functions:

1. Select input that are relevant to the system.
2. Activate and deactivate satellite algorithms needed to process these input.

The principal algorithm would ultimately be the functional state of the AGW. The principal algorithm would use thresholds to select relevant input. These thresholds should be programmed by external sources as if it were the artificial consciousness system´s DNA. On the other hand, this system should be equipped to modify threshold sensitivity based on the success of the output in achieving the system's objectives.

The conversion of input into adequate output

Once relevant input has been selected and integrated, the system must process and integrate the input into valid and coherent output. To do this, the artificial consciousness system needs an executive algorithm to temporally and sequentially organize the processing of selected input, while selecting adequate output algorithms. Moreover, the executive algorithm must be able to apply the system's past experience when integrating new output so as to organize a coherent response to the system's needs.

The executive algorithm and its organization, integration and output capacities form part of the field of artificial intelligence, given that its principal function is more related to problem solving than to detecting and processing information. The programmer should design diverse algorithms that provide the system with output that coincides with the potential results generated by the integration of input with stored experience. Furthermore, given the system's modular design (AGW), programmers should also be able to confer new algorithms to the system that respond to initially unforeseen input. Obviously, this is not a static mechanism, but rather an evolving modular system designed to respond efficiently to its interaction with the environment. To this end, its programmers will be able to incorporate new functional algorithms aimed at optimizing the systems adaptability to its surrounding.

System selection of valid algorithms (artificial value system)

One of the principal characteristics of systems with artificial consciousness is their ability to select the most efficient and valid algorithms over ineffective ones. A recent study demonstrated that technological systems can also meet this requirement [29]. Generated output, and its consequences for the artificial consciousness system, is what determines the most efficacious output for the system's objectives. An artificial value system (AVS) should inform the principal algorithm of the success of algorithms selected for input processing and output production. As a result, the principal algorithm increases its efficiency by using results obtained from its computational operations. At first, the system is chaotic, selecting satellite algorithms based on probability (Bayesian system), but over time, this selection process will be better informed and fine-tuned, to ultimately respond to the success of its output and its consequences on the system. Programmers should design models of artificial consciousness that generate dynamic systems capable of self-management and development in a specific environment. When the principal algorithm is informed of the results of its own computational operations, it will be able to choose whether to keep this algorithm, replace it, or modify the thresholds for input selection. This gives one the sense that the organism is indeed conscious of its own actions.

From neurons to computational networks: a model for artificial consciousness

Here we provide a functional diagram which integrates consciousness theories and findings from the literature to simulate the neural networks of human consciousness. Our objective is to provide a diagram which attempts to replicate, at the computational level, neuronal group connectivity and functionality involved in consciousness (Figure 1).

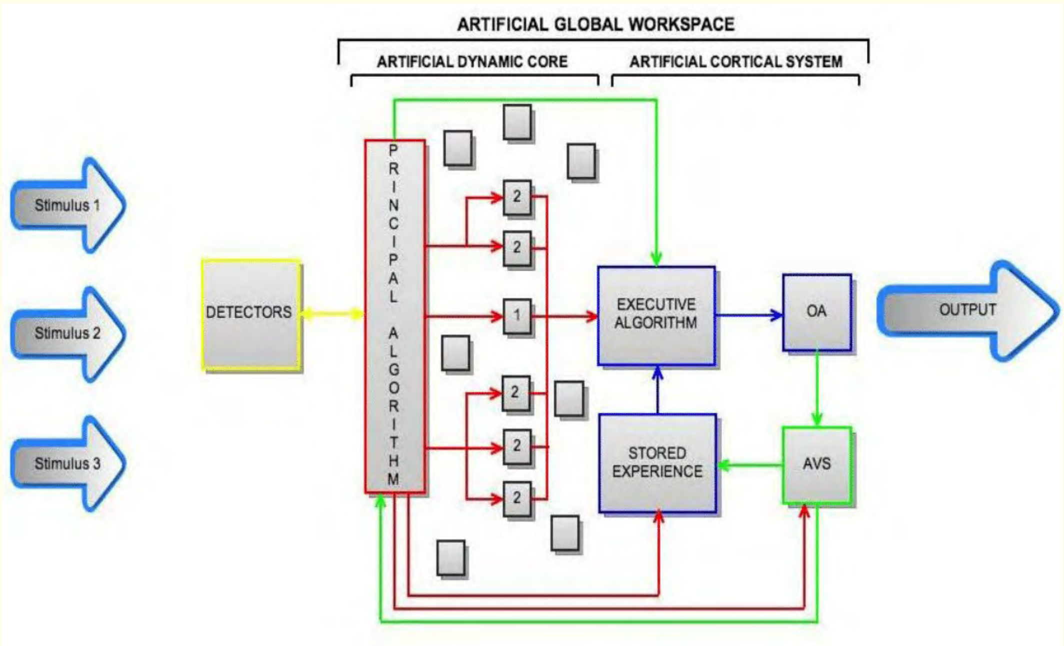

Figure 1: *Functional diagram of the cerebral organization of diverse nuclei intervening in human consciousness presented as a computational network to simulate artificial consciousness. OA: output algorithms; AVS: artificial value system. Finding a way to synchronize the activity of different algorithms within one global system (artificial global workspace) remains a challenge. Eigen's hypercycle theory offers a solution by explaining the self-organizing capacity of living organisms through self-catalytic processes [63]. In our model, Eigen's hypercycles would be specialized algorithms in specific information processing. For example, when a new stimulus reaches the artificial consciousness system, "detector" algorithms divide the stimulus into different dimensions and process the information, thereby generating a computational cascade which activates more complex algorithms in subsequent levels, and so on. This cascade would follow a hierarchic progression, divided into increasingly complex levels of processing algorithms. Self-catalytic processes would correspond to algorithms which provide positive and negative retrofeedback to one another. This overall process would synchronize the computation of diverse algorithms within a single artificial global workspace.*

Figure 1 is broken down into four levels:

Level 1 (yellow): Different external devices installed in the artificial consciousness system detect three distinct stimuli or three dimensions of one stimulus. The detection of three stimuli indicates that they have passed externally predetermined or self-regulated thresholds. Detected stimuli are passed on to the next level.

Level 2 (red): The "principal algorithm" selects the satellite algorithms needed to process the stimulus information. These algorithms are specific and automatic highly-specialized computational operations. Figure 1 also shows satellite algorithms which were not selected for this particular information (but may be used future processing). The principal algorithm also sends a signal to "Stored Experience" that stimuli have been detected and certain associated output algorithms should be activated which represent a determined probability of success. The principal algorithm finally informs the AVS of the needs of the system. This information remains on stand-by in the AVS until processing is completed, at which point this action is assessed for its success or failure for the system.

Level 3 (blue): This level's principal nucleus, the executive algorithm, is more related to artificial intelligence, using stored experience to assess information processed by satellite algorithms and ultimately select the output best suited to meet the system's needs. The executive algorithm carries out a series of computations that relate the processed information with a wide selection of output from "stored experience". These computations will lead to the selection of the most cost-effective output with the highest probability of success. Once the output algorithm (OA) is determined, the executive algorithm selects and activates this output. When the selection process is complete, and the determined action has taken place, the system will assess the success or failure of this output.

Level 4 (green): This level is fundamental for simulating self-learning and self-awareness. Once the OA informs the AVS if the selected output, the latter reviews this process to verify that the system's needs have been met. If the entire process is deemed successful, the AVS informs stored experience and the principal algorithm of this satisfactory procedure. In turn, the AVS augments the probability of success for the selected satellite and output algorithms.

What happens in stances when the system's needs or objectives are not met? First of all, the AVS reduces the probability of success for the output selected from stored experience, which also reduces it probability of being selected by the executive algorithm under similar conditions in the future. The principal algorithm is also informed of this failed output, and if the situation is urgent, it will inform the executive algorithms that another decision, or new computations, must be made. Furthermore, the system must self-regulate itself, and find explanation for the failed output. If the new output selected by the principal algorithm is successful, its probability as a successful option will increase while that of the prior output will decrease.

The success of simulating human consciousness in artificial models will be determined by the number of algorithms the system can integrate and process in an AGW. What remains unanswered is whether the human mind is determined by its neuronal connections, or if unprogrammed, random processes modify cerebral activity, and thus the individual's ultimate behaviour. Interestingly, there are more neuronal networks in the human brain than there are particles in the universe [31]. In this light, the human mind could conceivably be determined by neuronal connections. However, their elevated number makes computation practically impossible, especially when you consider that the system's complexity would increase exponentially as satellite algorithms and outputs were added. In other words, the human brain functions on the principles of incomputable determinism. Thus, the future of artificial consciousness resides in the creation of an equally complex and integrated system which simulates the neural networks of human consciousness. According to Weiskrantz, the pattern of activity among several regions would be more critical for awareness than the activity in a particular brain region [64].

Conclusion

Advances in the study of human consciousness can determine the future of building or programming systems of artificial neural networks. Consequently, consciousness is a phenomenon stemming from the connective characteristics of different neuronal groups which are highly specialized in processing and integrating neural information. Systems of artificial consciousness should be programmed in the same manner in order to produce human consciousness. The neuro-computational conditions of artificial consciousness is based on a complex, non-computable deterministic system, with consciousness as an emergent characteristic dependent on the number of parts which constitute the system, and its connectivity patterns. Thus, the building of artificial consciousness requires the implementation of at least four computational conditions:

1. Systems of artificial consciousness should be comprised of different functional units which can integrate themselves into one unit to generate an AGW. The functional units are highly specialized algorithms designed to processes input.

2. The AGW should include a principal algorithm that uses thresholds to select relevant input. This principal algorithm should also select satellite algorithms which will be added or eliminated from the AGW based on the validity of their processing and integrating input. Hence, input selection would be determined by pre-programmed thresholds, while the selection of satellite algorithms would be determined by their energy efficiency.

3. The system should also include an executive algorithm, whose role is to integrate computational operations from the satellite algorithms with stored experience. The executive algorithms would also select the most appropriate output for problem solving based on the results of input integration.

4. The artificial value algorithm should inform the principal algorithm of the results of output and computational operations, thereby increasing the system's efficacy by perfecting the selection of satellite algorithms and threshold modification. The final product is a system with artificial consciousness that is aware of its surroundings and mimics self-awareness.

Bibliography

1. Rajakishore N. "A Cartesian critique of the artificial intelligence". *Philosophical Papers and Reviews* 2.3 (2010): 27-33.

2. Block N. "Troubles for Functionalism". *Minnesota Studies in the Philosophy of Science* 9 (1978): 261-325.

3. Bickle J. "Philosophy and Neuroscience: A Ruthlessly Reductive Account". Dordrecht: Kluwer Academic (2003).

4. Putnam H. "The nature of mental states in Capitan and Merrill (eds)". Art, Mind and Religion: University of Pittsburgh Press (1967).

5. Tononi G. "An information integration theory of consciousness". *BMC Neuroscience* 5 (2004): 42.

6. Leon-Carrion J., *et al*. "Synchronization between the anterior and posterior cortex determines consciousness level in patients with traumatic brain injury (TBI)". *Brain Research* 1476 (2012): 22-30.

7. León-Domínguez U., *et al*. "A chronometric functional sub-network in the thalamo-cortical system regulates the flow of neural information necessary for conscious cognitive processes". *Neuropsychologia* 51.7 (2013): 1336-1349.

8. Mair RG and Hembrook JR. "Memory enhancement with event-related stimulation of the rostral intralaminar thalamic nuclei". *Journal of Neuroscience* 28.52 (2008): 14293-14300.

9. Gaillard R., *et al*. "Converging intracranial markers of conscious access". *PLoS Biology* 7.3 (2009): e61.

10. Pollonini L., *et al*. "Information communication networks in severe traumatic brain injury". *Brain Topography* 23.2 (2010): 221-226.

11. León-Carrión J., *et al*. "Efficient learning produces spontaneous neural repetition suppression in prefrontal cortex". *Behavioural Brain Research* 208.2 (2010): 502-508.

12. Baars BJ. "Global workspace theory of consciousness: toward a cognitive neuroscience of human experience". *Progress in Brain Research* 150 (2005): 45-53.

13. Edelman GM. "Naturalizing consciousness: a theoretical framework". *Proceedings of the National Academy of Sciences of the United States of America* 100.9 (2003): 5520-5524.

14. Dehaene S., *et al*. "A neuronal model of a global workspace in effortful cognitive tasks". *Proceedings of the National Academy of Sciences of the United States of America* 95.24 (1998): 14529-14534.

15. Dehaene S and Changeux JP. "A hierarchical neuronal network for planning behavior". *Proceedings of the National Academy of Sciences of the United States of America* 94.24 (1997): 13293-13298.

16. Sergent C and Dehaene S. "Neural processes underlying conscious perception: experimental findings and a global neuronal workspace framework". *Journal of Physiology (Paris)* 98.4-6 (2005): 374-384.

17. Dehaene S and Naccache L. "Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework". *Cognition* 79.1-2 (2001): 1-37.

18. Dehaene S and Changeux JP. "Experimental and theoretical approaches to conscious processing". *Neuron* 70.2 (2011): 200-227.

19. Clune J., *et al*. "The evolutionary origins of modularity". *Proceedings Biological Sciences* 280.1755 (2013): 20122863.

20. Tononi G. "Consciousness as integrated information: a provisional manifesto". *Biological Bulletin* 215.3 (2008): 216-242.

21. Friston KJ., *et al*. "Value-dependent selection in the brain: simulation in a synthetic neural model". *Neuroscience* 59.2 (1994): 229-243.

22. Tononi G., *et al*. "Reentry and the problem of integrating multiple cortical areas: simulation of dynamic integration in the visual system". *Cerebral Cortex* 2.4 (1992): 310-335.

23. Pouget A., *et al*. "A computational perspective on the neural basis of multisensory spatial representations". *Nature Reviews Neuroscience* 3.9 (2002): 741-747.

24. Salinas E. "Fast remapping of sensory stimuli onto motor actions on the basis of contextual modulation". *Journal of Neuroscience* 24.5 (2004): 1113-1118.

25. Edelman GM. "Neural Darwinism: The Theory of Neuronal Group Selection". Basic Books, New York (1987).

26. Edelman GM. "Neural Darwinism: selection and reentrant signaling in higher brain function". *Neuron* 10.2 (1993): 115-125.

27. Edelman GM., *et al*. "Biology of consciousness". *Frontiers in Psychology* 2 (2011): 4.

28. Pigliucci M. "Is evolvability evolvable?" *Nature Reviews Genetics* 9.1 (2008): 75-82.

29. Pang TY and Maslov S. "Universal distribution of component frequencies in biological and technological systems". *Proceedings of National Academy of Sciences of the United States of America* 110.15 (2013): 6235-9.

30. Seth AK., *et al*. "Theories and measures of consciousness: an extended framework". *Proceedings of National Academy of Sciences of the United States of America* 103.28 (2006): 10799-804.

31. Edelman GM and Tononi G. "A universe of consciousness: how matter becomes imagination". Basic Books: New York (2000).

32. Tononi G and Edelman GM. "Consciousness and complexity". *Science* 282.5395 (1998): 1846-1851.

33. Crick F and Koch C. "Why neuroscience may be able to explain consciousness". *Scientific American* 273 (1995): 84-85.

34. Crick F and Koch C. "Consciousness and neuroscience". *Cerebral Cortex* 8.2 (1998): 97-107.

35. Crick F and Koch C. "A framework for consciousness". *Nature Neuroscience* 6.2 (2003): 119-126.

36. Koch C and Crick F. "The zombie within". *Nature* 411.6840 (2001): 893.

37. Milner D and Goodale MA. "The Visual Brain in Action". Oxford University Press 27 (1998): xvii + 248.

38. León-Carrión J., *et al*. "The hemodynamics of cognitive control: the level of concentration of oxygenated hemoglobin in the superior prefrontal cortex varies as a function of performance in a modified Stroop task". *Behavioural Brain Research* 193.2 (2008): 248-256.

39. van Gaal S and Lamme VA. "Unconscious High-Level Information Processing: Implication for Neurobiological Theories of Consciousness". *Neuroscientist* 18.3 (2012): 287-301.

40. Crick F and Koch C. "Are we aware of neural activity in primary visual cortex?" *Nature* 375.6527 (1995): 121-123.

41. Crick F and Koch C. "Constraints on cortical and thalamic projections: the no-strong-loops hypothesis". *Nature* 391.6664 (1998): 245-250.

42. Greicius MD., *et al*. "Functional connectivity in the resting brain: a network analysis of the default mode hypothesis". *Proceedings of National Academy of Sciences of the United States of America* 100.1 (2003): 253-258.

43. Beckmann CF., *et al* "Investigations into resting-state connectivity using independent component analysis". *Philosophical Transactions of the Royal Society B. Biological Sciences* 360.1457 (2005): 1001-1013.

44. Bendat JS and Piersol AG. "Random data: analysis and measurement procedures". Hoboken (NJ): John Wiley & Sons (2010).

45. Seth AK. "Causal connectivity of evolved neural networks during behavior". *Network* 16.1 (2005): 35-54.

46. Seth AK and Edelman GM. "Distinguishing causal interactions in neural populations". *Neural Computation* 19.4 (2007): 910-933.

47. Cui J., *et al*. "BSMART: a Matlab/C toolbox for analysis of multichannel neural time series". *Neural Network* 21.8 (2008): 1094-1104.

48. Buckner RL., *et al*. "The brain's default network: anatomy, function, and relevance to disease". *Annals of the New York Academy of Sciences* 124 (2008): 1-38.

49. Plum F. "Coma and related global disturbances of the human conscious state". New York: Plenum Publishing Corporation (1991).

50. Llinás R., *et al*. "The neuronal basis for consciousness". *Philosophical Transactions of the Royal Society B: Biological Sciences* 353.1377 (1998): 1841-1849.

51. Llinás RR and Ribary U. "Consciousness and the brain. The thalamocortical dialogue in health and disease". Annals of the New York Academy of Sciences 929 (2001): 166-175.

52. Tononi G and Laureys S. "The neurology of consciousness: An overview". In S. Laureys & G. Tononi (Eds.) The Neurology of Consciousness: Cognitive Neuroscience and Neuropathology. Elsevier Ltd (2009).

53. Liu XB, and Jones EG. "Predominance of corticothalamic synaptic input to thalamic reticular nucleus neurons in the rat". *Journal of Comparative Neurology* 414.1 (1999): 67-79.

54. Min BKA. "Thalamic reticular networking model of consciousness". *Theoretical Biology and Medical Modelling* 7 (2010): 10.

55. Freeman WJ. "Mass action in the nervous system". New York: Academic Press (1975).

56. Mueller S., *et al*. "Individual Variability in Functional Connectivity Architecture of the Human Brain". *Neuron* 77.3 (2013): 586-595.

57. Kashtan N and Alon U. "Spontaneous evolution of modularity and network motifs". *Proceedings of National Academy of Sciences of the United States of America* 102.39 (2005): 13773-13778.

58. Kashtan N., *et al*. "Varying environments can speed up evolution". *Proceedings of National Academy of Sciences of the United States of America* 104.34 (2007): 13711-13716.

59. Wagner GP., *et al*. "The road to modularity". *Nature Reviews Genetics* 8.12 (2007): 921-931.

60. Barabási AL and Oltvai ZN. "Network biology: understanding the cell's functional organization". *Nature Reviews Genetics* 5.2 (2004): 101-113.

61. Süel G. "Use of fluorescence microscopy to analyze genetic circuit dynamics". *Methods in Enzymology* 497 (2011): 275-293.

62. Edelman GM and Mountcastle VB. "The Mindful Brain: Cortical Organization and the Group-Selective Theory of Higher Brain Function". MIT Press, Cambridge, MA (1978).

63. Eigen M and Schuster P. "The hypercycle: A principle of natural self-organization". Springer-Verlag, New York (1979).

64. Weiskrantz L. "Consciousness lost and found: a neuropsychological exploration". New York City: Oxford University Press (1999).

Volume 4 Issue 1 June 2017