An affective computational model for machine consciousness

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Abstract

In the past, several models of consciousness have become popular and have led to the development of models for machine consciousness with varying degrees of success and challenges for simulation and implementations. Moreover, affective computing attributes that involve emotions, behavior and personality have not been the focus of models of consciousness as they lacked motivation for deployment in software applications and robots. The affective attributes are important factors for the future of machine consciousness with the rise of technologies that can assist humans. Personality and affection hence can give an additional flavor for the computational model of consciousness in humanoid robotics. Recent advances in areas of machine learning with a focus on deep learning can further help in developing aspects of machine consciousness in areas that can better replicate human sensory perceptions such as speech recognition and vision. With such advancements, one encounters further challenges in developing models that can synchronize different aspects of affective computing. In this paper, we review some existing models of consciousnesses and present an affective computational model that would enable the human touch and feel for robotic systems.

Keywords: Machine consciousness, cognitive systems, affective computing, consciousness, machine learning

1. Introduction

The definition of consciousness has been a major challenge for simulating or modelling human consciousness [1, 2]. However, a broad definition of consciousness is the state or quality of awareness which features sentence, subjectivity, the ability to experience through sensory perceptions, the state of wakefulness, the sense of ego, and the control of the mind with awareness of thought processes [3, 4, 5, 6, 7].

The challenges in the definition and models of consciousness affects the implementation or simulation study of consciousness. In the past, simulation study has been presented for certain models of consciousnesses, such as the model of information flow from global workspace theory[3]. Shanahan presented a study where cognitive functions such as anticipation and planning were realised through internal simulation of interaction with the environment. An implementation based on weightless neurons was used to control a simulated robot [8]. Further attempts were made to model specific forms of intelligence through brute-force search heuristics to reproduce features of human perception and cognition, including emotions [7].

Moreover, small scale implementations can consider models based from consciousness in animals that are needed for their survival. Although intelligence demonstrated in solving the tasks vary [9, 10], limiting definitions of consciousness to humans is speculative as all living beings tend to have certain attributes that overlap with human consciousness. Some of the undomesticated animals such as rodents have a history of survival in challenging and wide range of climate and environments [11]. There are some studies that show that animals such as rats seem to express some aspects of consciousness, that is not merely for survival. They feature social attributes such as empathy which is similar to humans [12, 13]. High level of curiosity and creativity are major attributes of consciousness which could be a factor that distinguishes humans from rest of the animals [14, 15, 16]. While intelligence is also an underlying aspect of consciousness, it has been shown that intelligence is a necessary, however, not sufficient condition for creativity [17]. However, apart from humans, other animals also show certain levels of creativity [18]. There has been attempts to enhance existing models in unconventional ways through means to incorporate non-materialistic aspects of consciousnesses through studies of near-death experiences [19]. Furthermore, ideas from psychology and quantum mechanics have also been integrated in a study that challenge the materialistic view of consciousness [20].

In an attempt to empirically study consciousness, Tononi proposed the information integrated theory of consciousness to quantify the amount of integrated information an entity possesses which determines its level of consciousness [21]. The theory depends exclusively on the ability of a system to integrate information, regardless of having a strong sense of self, language, emotion, body, or an environment. Furthermore, it attempts to explain why consciousness requires neither sensory input nor behavioural output in cases such as during the sleeping state. Further work was done with application of integrated information to discrete networks as a function of their dynamics and causal architecture [22]. Information integrated theory 3.0 further refined the properties of consciousness with phenomenological axioms and postulates to lay out a system of mechanisms to satisfy those axioms and thus generate consciousness [23]. It was suggested that systems with
a purely feed-forward architecture cannot generate consciousness, whereas feed-back or recursion of some nature could be an essential ingredient of consciousness. This was based on a previous study, where it was established that the presence or absence of feed-back could be directly equated with the presence or absence of consciousness [24].

David Chalmers highlighted the explanatory gap in defining consciousness and indicated that the hard problem of consciousness emerges from attempts that try to explain it in purely physical terms [1]. Integrated information theory is based on phenomenalological axioms which begins with consciousness and indicates that complex systems with some feedback states could have varying levels of consciousness [23]. However, this does not fully support the motivations for consciousness experience as defined by Chalmers that look at consciousness experience or qualia from first and third person perspectives and the relationship between them [25].

The field of affective computing focuses on the development of systems that can simulate, recognize, and process human affects which essentially is the experience of feeling or emotion [26, 27, 28]. Affective computing could provide better communication between humans and artificial systems that can lead to elements of trust and connectivity with artificial systems [29]. The motivation to have affective models in artificial consciousness would be towards the future of mobile technologies and robotic systems that guide in everyday human activities. For instance, a robotic system which is part of the household kitchen could further feature communication that builds and connectivity from features of affective computing [30]. In the near future, there will also be a growing demand for sex robots, therapeutic and nursing robots which would need affective computing features [31, 32]. Moreover, the emergence of smart toys and robotic pets could be helpful in raising children and also assist the elderly [32]. Although mobile application-based support and learning systems have been successfully deployed, they are often criticized for having less physical interactions [33]. In such areas, affects in robots could lead to further help such as stress management and counselling.

Personality is an integral part of consciousness [34]. However, in the past, the proposed models of consciousness have not tackled the feature of personality [35]. In the past, a study presented the influence of different types of personality on work performance for selection, training and development, and performance appraisal of workers [34]. Nazir et. al further presented culture-personality based affective model that included the five dimensions of personality [36]. Carver and Scheier used control theory as a conceptual framework for personality which provides an understanding of social, clinical and health psychology [37]. Although these studies have been very popular in areas of psychology, there has not been much work done to incorporate understanding of personality in models of machine consciousness.

We note that element of hunger and pain are some of the leading biological attributes for survival which contributes to human personality and affects. Starzyk et. al presented motivated learning for the development of autonomous systems based on competition between dynamically-changing pain signals which provided an interplay of externally driven and internally generated control signals [38]. The use of abstract notion of pain as a motivational behaviour for a goal such as food can lead to features in affective model for machine consciousnesses. Although several prominent models of machine consciousness have been present, their limitations exist in terms of addressing the features of human affects that could lead future implementations in robot systems and other related emerging technologies. In such systems with human affects, there would be a wider impact in terms of social acceptance, trust and reliability. However, the limitations that exist in humans could also pose a threat. We limit our focus on the development of affects that could lead to personality in artificial consciousness without much emphasis for implications or social acceptable of such systems.

In this paper, we review some existing models of consciousnesses and present an affective computational model of machine consciousness with the motivation to incorporate human affects and personality. We promote a discussion of using emerging technologies and advances in machine learning for developing the affective computational model.

The rest of the paper is organised as follows. Section II provides a background on consciousness and existing models. Section III presents the proposed model and Section IV provides a discussion with further research directions while Section V concludes the paper.

2. Background and Related Work

2.1. Studies of consciousnesses

Although certain foundations in the definition of consciousness have emerged [3, 4, 6], there has been the need for a definition that can fulfill the needs from the perspective of various fields that include neuroscience, psychology and philosophy. Historically, the study of consciousness has been the subject of various groups and phases in ancient and modern history that include those both from Eastern [39, 40] and Western philosophical traditions [41].

There are some difficulties in defining consciousness that led to identifying areas known as the easy and the hard problems of consciousness [42, 43] from perspectives of neurobiology and neurophilosophy. Chalmers introduced the hard problem which highlights the explanatory gap of defining the conscious experience, though which sensations acquire characteristics, such as colors and taste [1]. The rest of the problems are the ‘easy problems’ that generally refer to the functions such as accessibility and reportability, however, they are also unsolved problems in cognitive science [1, 25]. The easy problems of consciousness constitute of the ability to discriminate, integrate information, report mental states, and focus attention. These could be deduced and modeled through advances in artificial intelligence [44]. Chalmers also proposed a pathway towards the science of understanding consciousness experience through the integration of third-person data about behavior and brain processes with first-person data about conscious experience [25]. Moreover, the easy problems in consciousness could be tackled by constructs in weak artificial intelligence (AI) [45]. Note that
strong AI refers to the notion that machines can think similar to humans and possess some level of consciousness and sentience, while weak AI refers to machines that can be made to act as if they are intelligent [45].

There have also been concerns about the ability of neuroscience to explain properties of consciousness [46, 1, 47]. Chalmers argued that neuroscience is good in explaining easy problems of consciousness and faces major challenges in the hard problems [1]. The mind-body problem is one of the historical challenges about the nature of consciousness [48]. In this problem, there is a dilemma about the relationship of the mind with the brain since mental states and processes such as thinking are non-physical while the human body is a physical entity [49, 50]. Uncertainties in definitions of consciousness [2] have been also promoting views of consciousness that have been more metaphysical and spiritual [51, 52]. There has also been evidence of consciousness related abnormalities in physical systems suggesting that consciousness can alter the outcome of certain physical processes such as random-number generators [53]. Although these topics are interesting, certain restrictions need to be placed in the development of machine consciousness that can lead to the development of robotics and other related intelligent systems that can assist in human decision making and also carry out everyday tasks. We, therefore, limit out definition of consciousness merely to that which can help in the formulation of problem-solving techniques, which may restrict to models relation to information theory of consciousness [54] that could lead to software systems or models that to replicate consciousness to a certain degree.

One of the issues of the mind-body problem has been in the explanation of the links that govern the physical (brain) with the non-physical (mind). This can be seen as analogous to the relationship between hardware and software systems. Wang presented a study with a comprehensive set of informatics and semantic properties and laws of software as well as their mathematical models [55]. In order to provide a rigorous mathematical treatment of both the abstract and concrete semantics of software, a new type of formal semantics known as the deductive semantics was developed. Later, a theoretical framework of cognitive informatics that was shown to be a trans-disciplinary inquiry of the internal information processing mechanisms and processes of the brain and natural intelligence [56]. Furthermore, Wang et al. presented an architecture, theoretical foundations, and engineering paradigms of contemporary cybernetics with a link to computational intelligence has been introduced in the cybernetic context and the compatibility between natural and cybernetic intelligence was analyzed [57]. Moreover, Wang presented a formal model and a cognitive process of consciousness in order to explain how abstract consciousness is generated. The hierarchical levels of consciousness were explored from the facets of neurology, physiology, and computational intelligence. A rigorous mathematical model of consciousness was created and the cognitive process of consciousness is formally described using denotational mathematics [58].

### 2.2. Existing models for machine consciousness

Over the last few decades, various attempts have been made to use studies of consciousnesses for models or development of machine consciousness. While there are various models with certain strengths and limitations, in general, there lacks simulation study for these models. Gamez initially presented a review of the progress in machine consciousness where the literature was divided into four groups that considered of the external behavior, cognitive characteristics, architecture that correlates with human consciousness, and phenomenally conscious machines [59]. Reggia later presented a review where machine consciousness was classified into five categories based on recurring themes on the fundamental issues that are most central to consciousness [60]. These included a global workspace, information integration, an internal self-model, higher-level representation, and attention mechanisms. With a number of challenges related to definition and understanding of consciousness, it was highlighted that the way forward to examine the inter-relationships between the five approaches. Hence, it will remain very difficult to create artifacts that truly model or support analogous artificial conscious states.

Although various models have been discussed in detail in the reviews, we limit our discussion to some of the recent models that closely relative to this paper. Starzyk and Prasad presented a computational model of machine consciousness which was driven by competing motivations, goals, and attention switching through the concept of mental saccades [61]. Reggia argued that the efforts to create a phenomenally conscious machine have not been much less successful due to the computational explanatory gap which refers to the inability to explain the implementation of high-level cognitive algorithms in terms of neuro-computational processing [62]. It was highlighted at the present time, machine consciousness has not presented a compelling demonstration of phenomenal consciousness and further has not given any indications for it to emerge in the future.

The social and cognitive aspects that deal with attention and awareness can be helpful in further understanding certain aspects of consciousnesses [63]. Graziano and Kastner presented a hypothesis where they viewed awareness as a perceptual reconstruction of the attentional state. They proposed that the machinery that computes information about other peoples awareness is the same machinery that computes information about our own awareness [64]. They proposed that attention and the attention schema co-evolved over the past half-billion years and may have taken on additional functions such as promoting the integration of information across diverse domains and promoting social cognition. Their hypothesis further leads to a mechanistic theory of consciousness that outlined how a brain with an attention schema may conclude that it has subjective awareness [65]. In the attention schema theory, consciousness is viewed beyond philosophy, towards developing basic properties can be engineered into machines. It is seen as a fundamental part of the data processing machinery of the brain where awareness is an internal model of attention. They further argued that the attention schema theory provides a possible answer to the puzzle of subjective experience whereby the brain computes a simplified
model of the process and the current state of attention which is the basis of subjective reports [66]. Moreover, the theory was partially based on the logic of model-based control motivated by how the brain computes a model of the body through the body schema and uses it in the control of the body. Hence, they suggested that a simplified model of attention through an attention schema would be useful in controlling attention. Lamme presented definitions of visual attention and awareness that distinguished between them and also explained why they are intricately related. It was suggested that there was overlap between mechanisms of memory and awareness than between those of attention and awareness. Moreover, it was also highlighted that phenomenal experience origin from the recurrent interaction between groups of neurons [24].

2.3. Simulation of aspects of consciousness

Throughout modern digital history, there have been a number of developments in areas of artificial intelligence that mimic aspects or attributes of cognition and consciousness. These developments have been made with the hope to replicate and automate some of the tasks that are undertaken by humans given the industrial demand and constraints of humans on carrying out demanding tasks in limited time. The replication of some of the biological attributes include the feature of learning with machine learning [67] and the attribute of reasoning and planning with automated reasoning [68]. The attribute which deals with sensory perceptions includes the sense of hearing with speech recognition which covers areas such as voice and speaker identification [69]. Moreover, visual perception is covered through computer vision [70] with specific cases such as face [71], facial expression [72], and object recognition [73]. The attributes of biological motor control have been covered by autonomous movement in humanoid robots [74], while learning to drive has been covered through autonomous driving systems [75]. Although these fields have emerged, there are a number of challenges that include those in computer vision and speech recognition, especially in dealing with noisy and dynamic environments in real-world applications [76, 77].

The field of natural language processing aims to make computer systems understand and manipulate natural languages to perform the desired tasks [78]. It has been one of the major attributes of cognition and consciousness [79]. One of the major breakthroughs that used natural language processing for cognitive computing has been the design of Watson, which is a system capable of answering questions posed in natural language developed by David Ferrucci [80, 81]. Watson won the game of Jeopardy against human players [82]. It had access to 200 million pages of structured and unstructured content including the full text of Wikipedia. Moreover, IBM Watson was not connected to the Internet during the game. There are a number of applications of Watson technology that includes various forms of search that have semantic properties. Specially, Watson has a high potential for health care for an evidence-based clinical decision support system that affords exploration of a broad range of hypotheses and their associated evidence [83]. Furthermore, it can help in developing breakthrough research in medical and life sciences with a further focus on Big Data challenges. Hence, it was shown that Watson can accelerate the identification of novel drug candidates and novel drug targets by harnessing the potential of big data [84].

With such a breakthrough for development of Watson for cognitive computing, there remains deep philosophical questions from perspective of natural and artificial consciousness [85]. Koch evaluated Watson’s level of consciousnesses from perspective of integrated information theory of consciousnesses [86, 22] that views the level of consciousness based on complexity and how integrated the forms of information are in the system. Watson’s capabilities motivated to further study the philosophy, theory, and future of artificial intelligence based upon Leibniz computational formal logic that inspired a ‘scorecard’ approach to assessing cognitive systems [87]. Metacognition refers to a higher order thinking skills that includes knowledge about when and how to use particular strategies for learning or for problem solving [88]. In relation to metacognition, Watson relied on a skill very similar to human self-knowledge as it not only came up with answers but also generated a confidence rating for them. Therefore, Watson possessed elements of metacognition similar to the human counterparts in the game of Jeopardy [89]. More recently, AlphaGo was developed by Google to play the board game Go which became the first program to beat a professional human player without handicaps on a full-sized 19 × 19 board [90]. It used deep learning and learned abstract information from visual board data given by experts. Then it played against itself across multiple computers through reinforcement learning. Although AlphaGo has been very successful, one can argue that it demonstrated a very constrained aspect of human intelligence that may not necessarily display consciousness.

Furthermore, ethics and morality are considered as one of the fundamental aspects of human consciousness. Hence, one of the future challenges will be to feature attributes of morality in artificial consciousness. There have been questions about the moral aspects of the rise of robotic or digital systems that will have a certain level of consciousness [91, 92, 93]. Colin et. al proposed moral Turing test with the hope to attain moral perfection in computational systems [91]. Farthemore and Whitby questioned the requirements of a moral agent has been also presented a number of conceptual pre-conditions for being a moral agent [92]. Arnold and Scheutz argued against moral Turing test and proposed system of verification which demands the design of transparent, accountable processes of reasoning for the performance of autonomous systems [93]. The issues related to morality would need to be integrated with systems that feature artificial consciousness as it could have a wide range of implications in cases when the system is given tasks, or in charge of making decisions that pose a danger to living systems. This raises further philosophical questions on the implications of artificial consciousness.
3. An affective computational model

3.1. Preliminaries

Humans have long desired a future when advances in robotics will help solve some of the challenges facing humanity. It is well-known that advances in robotics and artificial intelligence provide potential for advances in health and agriculture. There is hope for addressing some of the most challenging problems such as the need for food, water, and shelter. One would be glad to have a humanoid robot that can plant for the entire household and also help in preparation of food and household activities. However, this will also give rise to philosophical and ethical issues. The implementation of machine consciousness in technological systems will affect human workforce, social behaviour, and culture.

The rapid advances in emerging technologies such as Internet of Things (IoT) [94] is leading to increasingly large collection of data. IoT has the potential to improve the health, transportation, education, agriculture, and other related industries. Apart from the dimensionality of the data, there are other challenging factors that include complexity and heterogeneous datasets [95] which makes the area of big data challenging [96, 97]. Recent success in the area of deep learning [98, 99] for computer vision and speech recognition tasks have given motivation for the future implementation of conscious machines. Howsoever, this raises deeper questions on the nature of consciousness and if deep learning with big data can lead to features that contribute or form some level of consciousness. Through the perspective of integrated information theory (IIT) [21, 23], complex structures in the model with feedback loops could lead to certain degrees of consciousness. Therefore, from the deep learning perspective, conventional convolutional networks do not fall into this category as they do not have feedback connections. However, if we consider recurrent neural networks [100], some of the architectures with additional information processing would fall in the category of consciousness from the perspective of IIT. The challenge remains in incorporating them as components form part of a larger model for machine consciousness [101]. In such model, deep learning, IoT, and big data would replicate sensory perception.

Once the simulation of input sensor organs is addressed (speech and vision), the challenge of an effective model of machine consciousness would be to make sense of the data and also provide higher level organization of knowledge obtained from data in which resembles thought processes and reasoning. The field of the semantic web has faced a similar challenge that tries to make sense of data from web content using resource description framework (RDF) which is a set of specifications originally designed as a metadata data model [102]. It incorporates machine learning and optimization through so-called web intelligence [103]. They have been implemented in social networks and search engines [104] and also further enhanced by cognitive computing technologies such as Watson [105].

3.2. Affective model with simulation of natural properties

There has not much been done to incorporate emotional states and personality in models of machine consciousness. It was not addressed as in the past due to the limited motivation for software systems and robotics which mostly was aimed to address problems without taking into account of the human feel or touch which is recently being addressed through the field of affective computing. However, affective computing has yet not fully addressed its implications on machine consciousness. Further challenge is to address the hard problem which refers to the explanatory gap of describing conscious experience [106, 107].

We begin with the proposition where we view the human brain as hardware and mind as computational software [108]. The computational software can also be viewed as an operating system that consists of several layers and components that work coherently as a control system [109]. We note that states in consciousnesses are perturbed though emotional experiences [110]. There has been a study on the links between emotion with consciousness where it was suggested that emotional processing is important for maintaining a sense of ownership necessary for any conscious experience [111]. The state or health of the brain has direct implications for consciousness. For instance, in an extreme case, someone being injured with brain damage can become unconscious and enter a vegetative state [112]. Such natural defective states of consciousness resemble damages of a computer hardware components such as memory and storage devices or even one of the processors.

Figure 1 highlights the difference in physical (hardware) and metaphysical components (computational software) that form consciousness. Although the metaphysical features such as creativity and thought processes could be classified as software, simulating them is difficult. For instance, the input for a vision-based robotic system would be information in terms of videos or images. The software would be the machine learning and data processing components that carry out tasks such as face or facial expression recognition. Creativity, on the other hand, would be seen as a philosophical attribute or feature of consciousness. Creativity is not just about artistic expressions such as fine arts or music, but about the ability to tackle problems from “out of the box”. Stimulating creativity would be a very challenging aspect of any models of consciousness and hence we limit our current affective model which views creativity as a black-box.

Moving on, we revisit the natural states of consciousness and incorporate components that fall between physical and metaphysical states in order to address the hard problems such as conscious experience as shown in Figure 1. In our proposed affective model, we view the conscious experience as a state that enables management of all the states. In doing so, it can change states depending on the “present” and “future” goal as shown in Figure 4. Furthermore, the affective model is developed with the following propositions.

- **Proposition 1**: Being conscious and unconscious are states of the whole phenomenon of consciousness. The model views the sleep versus waking states and the major states of consciousness.
- **Proposition 2**: While being conscious, there is awareness. On the other hand, while being unconscious, there is a certain level of awareness and attention which are given or used in dream states.


• Proposition 3: A thinking mind is generation of or information which can be viewed as random walks in a network of information where there is a certain level priority to that information with attention based on certain goals or emotional states. The thinking mind generates different types of thoughts depending on the problem at hand, the level of intelligence, depth of knowledge and experience.

Hence, the difference of wakeful and sleep states (conscious versus unconsciousness) is merely the participation of the body using motor control [113]. In dreaming state, one has a virtual body which exhibits various actions, that are possible and also not possible (walking and flying) [114, 115, 116]. Hence, during dream states, there is conscious awareness. Moreover, the person in a dream state cannot distinguish the difference whether the events are happening in real-life or in a dream. In several levels of dream states, one may think that the situation is real which asks further raises questions of the difference between a dream and awake states. We limit our affective model from such philosophical interpretations, while at the same time, acknowledge them. We note that there is a hypothesis about the simulated universe and whether humans are subject to a grand simulation experiment [117].

The elements of pain and pleasure are central driving and features of consciousness [118]. In any artificial conscious system, their existence would influence in the overall emotional state of the artificial conscious system. The literature has the interest has been largely in trying to replicate a level of consciousness, without much interest in the future of robotics with an affective or emotive features that make robots look and feel more human or natural. The demand of humanoid robotics as services to humans, the needs for the human touch in robots will grow. Personality is an attribute of consciousness that defines the way one expresses their affections or emotions and also handles everyday problems and situations that range in a wide range of settings which includes family, work and community.

It is through one’s personality, that they have a certain view of life that also related to moral behaviour and ethical constructs for behaviour. Current models of machine consciousness are not addressing these aspects even though they may not address the hard problems, some elements of affective behaviour could be replicated.

Personality could be seen as an attribute of consciousness that grows with time and experience. It determines how one approaches a problem as the behaviour and intrinsic qualities of the person. Although the changes in our emotions makes mood that contributes to the state of consciousness, the core identity of consciousness remains the same, i.e we feel the same consciousness as a child or an adult although we have gone through varied learning experiences. This is an important aspect of the hard problem. In developing machine consciousness or implementing in it humanoid robotics, one can acknowledge the hard problem but to solve it is not necessary for attaining systems that have some level of affective consciousness.

Hence, such systems would have similar principle as a parrot trying to replicate the conscious behaviour - which may be just repeating some words without understanding it. In our analogy of humanoid robotic with affective consciousness, it would be carrying out a task and display behaviour that generate some emotion or has the human spirit or touch, but whether it is conscious about it would be a philosophical discussion. Since the proposed model has not addressed the hard problem with any definition or discussion but just acknowledged its presence of conscious experience with an identity - i.e some state that is “the observer” or the “one which experiences”. We are not modelling the observer as its nature has yet not fully been grasped the the respective scientific fields. However, in the section to follow, we will provide a means for management of attributes of consciousness through an artificial qualia which aids the “observer” as the goal is to have future implementations of affective computational model for robotics.

There are some intrinsic and extrinsic motivations that lead to the desire to reach our goals. Once a goal is established, every-
day challenges such as the state of pain, hunger, and tiredness remain. These states could be catered in the affective model of machine consciousness which could be helpful in addressing some of the software and hardware requirements. Currently, there are challenges in mobile computing, where at times, the battery life is running low or too many processes slow down the system. These could be seen analogous to challenges in animal consciousness such as pain and tiredness. Figure 2 provides an illustration of the elements that form a major part in making a close link of animal and machine consciousness. It shows how the challenges could be addressed while making certain actions to achieve the goal.

We present the following definitions for developing the affective computational model of machine consciousness.

- **Definition 1**: Any phenomenal observation is viewed as information. Computational software processes the information with knowledge which is either inbuilt or gained through learning from experience or a combination of them.
- **Definition 2**: Consciousness is based on attributes that have qualities, states, and instincts.
- **Definition 3**: The quality of consciousness are those that are in-built, inherited or born qualities such as personality, intelligence and creativity.
- **Definition 4**: The states of consciousness are those that mostly change with phenomenal experience such as emotions, expressions and motor control.
- **Definition 5**: The instinctive property of consciousness are those that have minimum conscious control such as body processes such as ageing, hunger and pain.

With the above definitions, we address affective notions that include emotional states, behaviour, and expressions [110] while taking into account the personality, knowledge and instincts as shown in Table 1. Note that the table forms basis for propositions based on observations only. Moreover, some of the identified qualities such as personality is a more rigid quality which may or may not change over time depending on its influence from birth. The property that make the quality are merely those that we are born with or gained naturally, although some may change over time such as knowledge and creativity.

### 3.3. Problem scenarios

Based on the prepositions in previous section 3.2, we provide the details of the affective model and then present few problem scenarios that are intended to demonstrate its effectiveness. Figure 3 shows a general view of state-based information processing based on experience which acts as input or action while the response acts as the reaction given by behavior or expression. Depending on the experience, there is an expression which would be involuntarily stored as either long or short-term memory depending on the nature of the experience. Moreover, there is also conceptual understanding of implications to the observer and how it changes their long and short-time goals. The output in terms of action or expression could also be either voluntary or involuntary. In some situations, one reacts without controlling their emotions while in others, one does not react in haste. A conscious decision is made depending on the type of personality, depth of knowledge (machine learning models) from past experience (audio, visual and other data).

Figure 4 shows an overview of the affective model of consciousness that is inter-related with Figure 3. The states in Figure 4 shown in blue represent the metaphysical while those in black are the physical states. Note that by physical, it implies that they do have metaphysical (computational software) properties but the physical nature influences these states.

We provide accounts of situations that require problem-solving skills which feature different states of consciousness. We first give the description of the scenario and then show how it will be tackled by the proposed affective model. We provide three distinct scenarios as follows.

**Scenario 1**: Raman is traveling on a flight from India to Japan and has a connecting flight from Shanghai, China. His flight lands in Shanghai and he is required to make it to the connecting flight gate. Raman’s boarding pass has gate information missing and since his flight landed about an hour late, he needs to rush to the connecting gate. Raman is not sure if he will pass through the immigration authority. His major goal is to reach a connecting flight gate. In doing so, he is required to gather information about his gate and whether he will go through the immigration processing counter. He encounters a series of emotions which includes fear of losing the connecting flight and hence exhibits a number of actions that show his emotive psycho-physical states which include sweating, exaggerating while speaking and even shivering due to fear.

In order for Raman to successfully make it to the connecting flight on time, he will undergo a series of states in consciousness which is described in detail with state references from Figure 4 as follows.

1. Exit flight and find the way to transfer desk.
   (a) Search for information regarding “transfers and arrivals” through vision recognition system (State 2 and then State 6).

| Property               | Quality | State | Instinct | Implication     |
|------------------------|---------|-------|----------|-----------------|
| Personality            | -       | -     | -        | D, B, and M     |
| Intelligence           | -       | -     | -        | D, and B        |
| Creativity             | -       | -     | -        | D, and B        |
| Knowledge              | x       | x     | -        | D, B and M      |
| Memory                 | x       | x     | -        | D, B, and M     |
| Extra-Sensory Percep.  | x       | x     | -        | D               |
| Emotions               | -       | x     | -        | D, and B        |
| Expression             | -       | x     | -        | B               |
| Motor Control          | -       | x     | -        | B               |
| Pain                   | -       | -     | x        | M, and B        |
| Hunger                 | -       | -     | x        | M, and B        |
| Bodily functions       | -       | -     | x        | M, and B        |
Figure 3: Output response from input after processing through features that contribute to consciousness

Figure 4: Note that consciousness observer is defined as the root of consciousness. Conscious experience is the core, which can enter different states while also having the property to exist within two states, i.e., it can self-replicate as a process, gather knowledge and update long and short-term memories, and then merge into the root conscious observer. The blue states are metaphysical and black states are physical.
2. Since information that no baggage needs to be collected was already given, check boarding pass for baggage tag sticker.
   (a) Process visual information by checking boarding pass (State 2 and 6)
3. Confirm with the officer at transfer desk if need to go through migration.
   (a) Find and walk to transfer desk (State 2, 6, and 5)
   (b) Communicate with the officer at transfer desk (State 2 and 6)
   (c) Fear and emotions during communication (State 2, 5, 8, and 10)
4. Information was given by the officer that there is a need to go through immigration, hence, prepare boarding pass and passport.
   (a) Rush to the immigration processing section (State 5 and 6).
   (b) Wait in queue and go through a number of emotions such as fear of losing flight and also sweat (State 5, 6, 8, and 10).
5. After immigration processing, find gate information and move to gate and board connecting flight.
   (a) Rush to the gate. In the process breath heavily and also sweat (State 2, 5, and 6).
   (b) Wait at the gate with some random thoughts and then board when called (State 7, 8, 6, 2 and 5).

Scenario 2: Thomas is in a mall in Singapore for his regular Saturday movies and shopping with friends. Suddenly, he realizes that he can't locate his phone. He brainstorms about the last few moments when he used his phone. He goes through a series of intense emotive states that includes fear.
In order for Thomas to successfully find his phone, he will undergo a series of states in consciousness with reference from Figure 4 as follows.
1. Thomas first informed his friends and began checking all his pockets and carry bag.
   (a) Check all pockets (State 5 and 6).
   (b) Inform friends and also check in carry bag (State 6, 8, 10, and 5)
2. Brainstorm where was last time phone was used.
   (a) Ask friends when they last saw him using the phone (State 6, 8, and 10).
   (b) Try to remember when phone was last used (State 2 and 9).
   (c) Finally, take a moment of a deep breath and relax in order to remember (State 2, 9, and 3).
3. Recalled information that phone was last used in cinema and then rush there to check.
   (a) Recalled that phone was last used in cinema (State 1, 3, 7, and 9).
   (b) Inform friends with emotive expression of hope and achievement (State 6 and 8).
   (c) Rush to the cinema and talk to the attendant with emotive state of hope and fear (State 5, 6, and 8).
   (d) Attendant locates the phone and informs (State 6).
   (e) Emotive state of joy and achievement (State 8).

3.4. Artificial Qualia Manager
We have presented affective computational model of machine consciousness with the motivation to replicate elements of human consciousness. This can exhibit characteristics with human touch with emotive states through synergy with affective computing. There is a need for management of components in the affective model which would help the property of consciousness experience. Hence, there is a need for a manager for qualia. This could be seen as a root algorithm that manages the states with features that can assign the states based on the goal and the needs (instincts) and qualities (such as personality and knowledge).
The artificial qualia manager could be modelled with the underlying principle of a security guard that monitors a number of video feedbacks from security cameras and also has radio communication with other security guards and needs to follow a channel of communication strategies if any risks or security impeachment occurs. Figure 5 shows an example that include processing through machine learning for semantic information which is used by the artificial qualia manager to assign the list of states needed for the goal. Similarly, the artificial qualia manager would be overseeing all the status of the states and assigning jobs for reaching the goal through automated reasoning in machine consciousness as given in Algorithm 1.

In Algorithm 1, the goal and data from audio and visual inputs are used to determine and effectively manage the sequence of states of affective model of consciousness presented in Figure 4. Once the goal is reached, a series of states can be used for expression which can include a set of emotions. Note that audio and visual data needs to undergo through processing with machine learning tools which would then output some information. For instance, if the goal is regarding finding date information for a boarding pass, then the task would be to be first
Data: Data from sensory perception (video, audio, and sensor data)

Result: States for consciousness
Initialization (knowledge and personality):
\[ \text{statelist[]} \leftarrow \text{list of states} \; \]
\[ \text{goal} \leftarrow \text{goal to reach} \; \]
\[ \text{means[]} \leftarrow \text{list of actions with reference to statelist[]} \text{required to reach goal} \; \]

while alive do
\[ \text{traversestates(goal, statelist[])}; \]
while goal not reached do
\[ \text{if challenge then} \; \]
\[ \quad \text{nominate a state;} \; \]
\[ \quad \text{attend to challenge (injury, pain, emotion);} \; \]
\[ \quad \text{store short-term and long-term memory;} \; \]
\[ \text{end} \; \]
\[ \text{if goal reached (success) then} \; \]
\[ \quad \text{output through expression (action, gesture, emotion);} \; \]
\[ \quad \text{store short-term and long-term memory;} \; \]
\[ \text{end} \; \]
\[ \text{if goal not reached (failure) then} \; \]
\[ \quad \text{output through expression (action, gesture, emotion);} \; \]
\[ \quad \text{store short-term and long-term memory;} \; \]
\[ \text{end} \; \]
end

Algorithm 1: Artificial Qualia Manager

0. Control (Walk, Raise Hands, Run, Move around, Move Head)
1. Perception (Read, Listen, Focus, Scan, Recognize)
2. Emotion (Anger, Fear, Joy, Trust, Disgust, Sadness, Surprise)
3. Memory (Short term, Long term)
4. Reasoning (Generate series of options and weigh them)
5. Personality (Conscientiousness, Openness, Extraversion, Agreeableness, Neuroticism)
6. Meditative (Complete rest)

Figure 6: Affective computational model states for the Artificial Qualia Manager

to translate this higher level task into a sequence of lower level tasks that would execute machine learning components. After these components are triggered, they would return information which will be used by the algorithm to make further decision of states needed to reach the goal. This is illustrated in Figure 6

There needs to a be a property of states for tasks based on their importance. For instance, we give priority to emergency situations while trying to fill a goal. While fulfilling a goal, we would give priority to aspects such as safety and security. The goal could be similar to those given in Scenario 1 and Scenario 2 where Raman boards connecting flight and Thomas locates his phone, respectively.

3.5. Implementation strategies

The affective computational model can feature multi-task learning for replicating sensory perception through recognition task that includes vision, sensory input for touch and smell and auditory tasks such as speech verification, speech recognition, and speaker verification. Shared knowledge representation would further be used for recognition of objects, faces or facial expression where visual and auditory signals would be used in conjunction to make a decision. Multi-task learning is motivated by cognitive behavior where the underlying knowledge from one task is helpful to one or several other tasks. Hence, multi-task learning employs sharing of fundamental knowledge across tasks [119, 120].

In the identification of objects, we learn through the experience of different senses that can be seen as a modular input to biological neural system [121]. Modular learning would help in decision making in cases where one of the signals is not available [122]. For instance, a humanoid robot is required to recognize someone in the dark when no visual signal is available, it would be able to make a decision based on the auditory signal. Ensemble learning could take advantage of several machine learning models which can also include deep learning for visual or auditory based recognition systems [98]. Ensemble learning can also be used to address multi-label learning where
instances have multiple labels which is different from multi-class learning [123].

The visual recognition process also relies on information from the peripheral vision which is a part of the vision that occurs outside the very center of gaze to make decisions [124, 125, 126]. Mostly, we focus our attention or gaze to the frontal visual system. Similar ways of attention and focus can be used for auditory systems and would be helpful for advanced speech recognition systems. This is especially when one needs to give attention to the specific voice in a noisy and dynamic environment. We naturally adjust our hearing to everyday situations when some parts of sensory inputs are either unavailable or are too noisy as trying to understand what someone is saying in environments with sudden background noise. The feature of modularity will be very helpful in the development of cognitive systems for machine consciousness that need to be dynamic and robust. Figure 7 gives an overview of implementation strategies where machine learning methodologies are used for replicating sensory input through audio and visual recognition systems.

4. Discussion

Although the feature of creativity, reasoning, self-awareness are the essential component of consciousness, modeling them for aspects of machine consciousness will become the greatest challenges in the near future. The absence of these features will highly differentiate artificial systems or humanoid robots from humans and will give special qualities to the human workforce and hence some would argue against simulating them [127]. We note that self-awareness is a critical component of consciousness which has not been fully addressed by the proposed affective model which views conscious experience (observer) as awareness. Howsoever, these could have different philosophical interpretations as in the spiritual literature [39], self-awareness is known to emerge at higher states of consciousness or conscious experience [43]. The spiritual literature views non-thinking or meditative state as the highest state of consciousness [128]. In this state, one can evaluate their own behavior and responses to problems and situations which can also be seen as the ability to have introspection and metacognition [129, 89, 88]. The challenges in machine consciousness is to incorporate features with fundamental models that replicate different states of consciousness which align with information processing from sense organs. Furthermore, intuition and creativity are also major features of consciousness and it could be argued that they form the truly metaphysical properties of consciousness. By metaphysical, we refer to the aspects that transcendental thoughts or notions that cannot be defined through language but have an impact on emotions or a certain sense of perception [130]. It is difficult to determine whether other animals, who are less intelligent have conscious experience. Howsoever, they do have levels of cognitive problem solving, perception, navigation, planning, and affections. All of these attributes are also present in humans, and therefore, any artificial conscious system that exhibits these properties will face the same challenges or philosophical questions if animals have consciousness or conscious experience.

It is important to realise the potential of animal consciousness as it can motivate models for consciousness that full the gaps in models for human consciousness. In simulation or the need to implant certain level of consciousnesses to robotic systems, it would be reasonable to begin with animal level where certain tasks can be achieved. For instance, a robotic system that can replicate cognitive abilities and level of consciousness for rats can be used for some tasks such as burrowing holes, navigation in unconstrained areas for feedback of videos or information, in disasters such as earthquakes and exploration of remote places, and evacuation sites.

Deep learning, data science and analytics can further help in contribution towards certain or very limited areas of machine consciousness. This is primarily to artificially replicate areas of sensory input such as artificial speech recognition and artificial vision or perception. Howsoever, with such advancements in artificially replicating sensory perceptions, one encounters further challenges in developing software systems that oversee or synchronise different aspects of perceptions that lead to a conscious state. Howsoever, to reach a state of natural consciousness will be difficult for machines as creativity and self-awareness is not just biological, but also considered spiritual which is challenging to define.

With the rise of technologies such as IoT, sensors could be used to replicate biological attributes such as pain, emotions, feeling of strength and tiredness. However, modelling these attributes and attaining same behaviour in humans may not necessarily mean that the affective model of consciousness would solve hard problem that enables conscious experience. However, at least the model would be seen to exhibit conscious experience that will be similar to humans and other animals. Such an affective model, with future implementations could give rise to household robotic pets that would have or could develop emotional relationship with humans. We must be careful about affective model when in giving autonomous control or
decision making through simulated emotional behaviour. Humans are well known to be poor decision makers when in emotional states which also resort to level of aggression and violence. Therefore, simulation of affective states need to take into account of safety and security for any future robotic implementations that assist humans.

The proposed affective model has not considered any difference between conscious experience during sleep and waking state from the perspective of awareness [24]. This is due to the difference in the definition of awareness from the sleep and waking state [131]. We note that artificial systems do not need elements such as the sleep state as its a property of a biological nervous system where sleep is required. Moreover, during the sleep state, dreams are persistent and their importance has been an important study in psychology [115], but may not have implications for the affective model of consciousness.

5. Conclusions and Future Work

The paper presented an affective computational model for machine consciousness with the motivation to feature the emotive attributes which give a more human-like experience for artificial systems. The affective model can become the foundation for developing artificial systems that can assist humans while appearing as natural as possible.

The challenges lie in further refining specific features such as personality and creativity which are psycho-physically challenging to study and hence pose limitations to the affective model of consciousness. However, the proposed effective model can be a baseline and motivate the coming decade of simulation and implementation of machine consciousness for artificial systems such as humanoid robots. The simulation for affective model of consciousness with the features of artificial qualia manager can also be implemented with the use of robotics hardware. In their absence, simulation can also be implemented through collection of audiovisual data and definition of certain goals. The affective model is general and does not only apply to humanoid robots, but can be implemented in service application areas of software systems and technology.

Future directions can be in areas of artificial personality and artificially creative systems. These can be done by incorporating advancing technologies such as IoT, semantic web, cognitive computing and machine learning, along with artificial general intelligence.

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