A Perspective on Machine Consciousness

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***Abstract*—Understanding consciousness and implementing it in manmade machines has interested researchers for a long time. Despite the amount of research efforts, the measurable development in this field is very small. Among various technical, philosophical and ethical reasons, the primary reason is the difficulty in understanding consciousness. Most researchers assume that consciousness is a meta-physical phenomenon. In this paper, we consider various perspectives related to cognitive and information science to conclude that consciousness is a physical phenomenon. We also discuss the role of information in making machines conscious and present our own views on consciousness.**

Keywords — Machine consciousness; models of machine consciousness

I. INTRODUCTION

Many researchers (philosophers, psychologists, cognitive neuroscientists, artificial intelligence (AI) community, etc.) have tried to define consciousness [7], [11], [15], [19], [26], [32], [35]-[38], [49], [51]-[53]. A dogmatic theory of consciousness still evades the researchers and consciousness remains an abstract term (similar to intelligence). Many considered consciousness as causal (or non-causal) [32], [34], [35], accessible (or inaccessible) [33], [34], [38], [53], stateless (or having physical state) [1], [3], [38], [47], [52], [53], representational (or non-representational) [3], [11], [13], [18], [20], [23], [24], [26], [39] and so on. Yet, none of the approaches provides a complete and thorough theory of consciousness. Based on the current research work [1]-[50], one can conclude that consciousness is not merely a physical process but a meta-physical phenomenon which builds upon and is manifest in some physical sense.

In this work, we discuss several approaches and present our view on this topic that "consciousness need not be defined in metaphysical terms". We also address the role of information and information processing mechanisms in realizing machine consciousness. We compare the existing practical models of machines consciousness with our perspective. We conclude that consciousness is a physical phenomenon, and can be realized in machines.

II. MACHINE CONSCIOUSNESS

In order to facilitate further discussion, we introduce the concept of virtual machines and attempts of researchers to link them to consciousness [1], [2], [23], [24], [37], [41]. Virtual machines are biological/non-biological, living/non-living, or physical/non-physical systems (parts of system) that exhibit conscious phenomenon. Such machines are typically expected to:

1. Operate on complex information by acquiring, processing, and using information selectively,
2. Make decisions/selections from available options, and
3. Initiate appropriate actions.

One of the primary perspectives in the definition of machine consciousness is that consciousness is the catalyst of action (consciousness initiates action, or appropriate action as suggested by Sloman [22], [24]). We question whether satisfying the properties of virtual machines listed in (1-3) above are sufficient for consciousness.

In the framework of virtual machines, many day-to-day activities of plants (evident and undeniable examples are pitcher plants and touch-sensitive mimosa pudica) indicate that they are virtual machines too. Yet we do not refer to plants as conscious. Since if plants are conscious, then it can be argued that contemporary AI machines that exhibit some kind of information processing and control should also be referred to as being conscious which, obviously, is an overstatement.

The actions performed by low level animals (like insects) are basically sensory motor skills or results of circadian (sleep/wake) rhythm, and do not require consciousness. These animals are not conscious, though they may partially satisfy (1-3) above.

Another perspective is that consciousness needs to involve a centralized system (unlike plants) as reasoned by Muller [58]. He says that it is someone (I, he, it), a center of being, that is aware or conscious and that experiences. We do partially agree that centralized system is necessary for consciousness. More evolved and conscious animals invariably have a developed central nervous system. It is also notable that the level of consciousness increases with the development of pre-frontal cortex. In our opinion, centralized system is necessary but not sufficient for consciousness and other conditions must be present as well [57].

Different perspective is presented by Blackmore [12] and Velmans [36]. They propose that human-like consciousness is an illusion (it exists but is not what it appears to be). When we try to replicate human/animal behavior, we create this illusion that we are a conscious self having a stream of experiences [11]. We do not agree with this statement. In our

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opinion, consciousness is not an illusion; it does exist and is experienced physically.

A. Levels of machine consciousness

From the perspective of philosophers, 'machine consciousness' is a very complex issue. To make things more tractable, Sloman and Chrisley [13], [15], [22]-[24] suggest that instead of defining and characterizing consciousness, it is better to put down the expected traits of something being conscious (a fly being conscious, a new-born calf being conscious, a file protection system being conscious, etc.). Besides avoiding unnecessary abstraction and unproductive philosophical rigor, it serves another important purpose. It provides a guideline for artificially implementable aspect of consciousness and a manner of defining the requirements for a machine to be conscious.

For instance, for a fly (robot-fly) to be conscious, it needs to be able to identify an impending swat as a threat (something to avoid), the direction of threat, and a possible escape. Its consciousness need not require it to be aware of this action, or to feel happy about escaping the threat. Similarly, a new born calf needs to be aware of mother's presence, and that she can feed him, that he should suckle the mother, and that he needs to reach the mother in order to feed himself. He need not know the exact form of hunger, or what mother exactly is, or that there is a need to traverse the space between him and the mother, and so on. Another example is the requirement of consciousness in a file protection system. Such system needs to be conscious about the types of threats and the actions that it should take in the event of unauthorized access. On the other hand, it does not need to be aware of its capability of doing so. It also need not feel helpful or obliging or enslaved to do a boring job.

The point that is being made is that multiple levels of abstractions may be defined regarding the expected level and form of consciousness. We do not agree with these arguments any more than with the concept of a virtual machine satisfying (1-3) as conscious.

According to us, consciousness is an emerging phenomenon. It involves perception, learning, memory, decision making, and self-awareness. Like intelligence, consciousness may be more or less developed. For instance, social consciousness is less developed in an average 10 years old child than in an adult. The child's frontal area responsible for empathy, responsibility, etc. is still developing. So, we would like to define a scalable concept of consciousness by describing a minimum set of conditions for a conscious mind. We would rather focus on realizing some form of machine consciousness, before delving into the levels and degrees of consciousness.

B. Problems in the implementation of machine consciousness

Many problems are encountered when implementing machine consciousness; some of them are presented next. First, the knowledge of possibilities is usually limited, and may not suffice for implementing the desired effect [1], [18], [23]. Further, virtual machines themselves are not well understood [24]. Another issue is the availability, adequacy and viability of the technology for implementation of consciousness [22], [42], [57], [59].

A more important problem is the problem of formalism and abstraction. As discussed before, consciousness is built upon, concerns, and affects, the physical phenomena occurring in and around the virtual machines. Thus, various important questions arise. Should, to what extent, and which physical phenomena affect the consciousness? How these physical phenomena should be represented? How should they affect the consciousness? In what form should the consciousness be implemented and how can it manifest itself (actions, alarms, emotions, adaptations, etc.)?

This brings us to the importance of qualia, information, architecture, ontology, and information processing. These are discussed individually in the subsequent sections.

III. Qualia, Ontology and their Importance for Machine Consciousness

A. Qualia

Following the difficulties in dealing with consciousness, researchers have come up with 'qualia', which helps us to speak of consciousness in a simplified (though again incomplete) manner. If we think about an experience, we do it (or feel it) in terms of certain phenomenal qualities [15], [24], [52] typically referred to as 'qualia'. Examples of qualia include perceptual experiences, bodily sensations, feelings of reactions/passions/emotions/moods, etc.

Qualia are considered central to the mind-body problem and to the development of a proper understanding of consciousness. They are usually referred to as introspection [60] or awareness, which are different from consciousness [49]. It is notable that Sloman has specifically warned against using just introspection towards the means of knowing (becoming aware of) consciousness [23].

However, if qualia have a functional nature in the form of an intermediate causal occurrence between physical inputs (like body-damage) and outputs (like withdrawal behavior), then qualia should be multiply realizable [61], [62]. In other words, physically very different states may generate the same feeling. From the point of view of functionalism, the internal modeling of physical states becomes an important part of implementing consciousness.

Such functional approach shall involve the capability to derive a connection between the possible sensory inputs, the intentions, and the possible outcomes. Therefore, it must deal with physical information and internal states (which may be in the form of direct or indirect manifestations of previous knowledge, experience, intentions, etc.) to give rise to a physical phenomenon of consciousness.

B. Ontology

Ontology is defined as the characterization of conceptualization. Philosophers and artificial intelligence scientists differ in the definition of ontology. Since our paper pertains to machine consciousness, we use the definition used in the AI community [23], [25], [38]. According to them, ontology is the study of various categories of abstract

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entities, events, processes, matters, etc., and their inter-relationships.

In this sense, ontology is an integral part of machine consciousness, as it formalizes the relationship between physically existing, measurable, decipherable, or deducible information to the abstract mental phenomena that the AI scientists wish to implement. Also, in this sense, it is directly related to the functional nature of qualia.

It is evident that if the chosen ontology is unable to characterize the desired phenomenon, implementation of desired phenomenon may result in failure. Technically, the effect of choosing an unsuitable ontology is called ontological blindness [15], [23], [24]. It refers to the failure of the ontology in visualizing certain abstract characteristics that are pertinent to the understanding and realization of the desired phenomenon.

Information, as used in the machine consciousness, is typically different from Shannon's information and simply means 'content of relevance to something'. The properties of information that are relevant and important for machine consciousness are listed below [15], [23]:

- Information can be false
- Items of information can stand in relations like consequence, contradiction and relevance
- Items of information can be understood or misunderstood.
- Information content is sometimes completely predictable
- Information is non-physical (albeit physically realized), thus, it requires specialized methods for identifying, explaining, and processing.

As agreed by most researchers, the ontology (used to study and link information to consciousness) and the information processing architecture (with consideration of the depth and breadth of information analysis, processing, interpretation, and consequent awareness, learning, planning, action initiation, etc.) are very important for realizing machine consciousness. As mentioned above, if information is picked wrongly, misrepresented, misinterpreted, or wrongly processed, it is expected to at least warp or distort consciousness, and in harsher conditions may lead to failure in the realization of desired phenomenon.

Thus, it is very important to suitably understand, classify, distinguish, and group information. It is also important that information is cast into suitable architectures and processing methodologies so that the pertinent aspects are not neglected.

Sloman [22]-[24] says that for implementation of machine consciousness, it is useful to deal with information in terms of its useful characteristics. Examples are various types of information, the forms it can take, the means of acquiring it, manipulating it, storing it, and communicating it, the purposes for which it can be used, the various ways of using it, etc. It is also important to choose suitable forms of representations, suitable algorithms, and identification of subsystems that process independently and concurrently. Their variations lead to the variation in the resulting consciousness achieved by these choices. For instance, such choices may determine the role of consciousness, in identifying possible events, actions, internal states, internal processes, and causal chain of happenings.

It should be noted that a machine gathers the information from the external signals generated in the sensory units and the internal signals like pains/rewards and machine's motivations. Thus, these physical units of information processing are necessary for consciousness.

IV. Reactive, Deliberative and Reflective Mechanisms of Information Processing

Another impact of the choice of information and information processing is the possibility of reactive [23], [33], [37], [47], [50], deliberative [7], [23], [50], or reflective mechanisms [2], [4], [23], [28], [50]. Of course, the converse also holds, which means, that the type of mechanism desired has an impact on the choice of structural and processing aspects of information.

Reactive mechanism means that the virtual machine always lives in present (never in past or future) and simply reacts or responds to the present stimuli. It is able to make sense of the presently acquired information and choose an action from presently possible options. It never learns from past, nor can it predict future possibilities, and thus it cannot plan, predict, foresee and adapt. It should be noted that if such machines are equipped with internal states they may be capable of influencing the future and may be adaptive.

Deliberative mechanism, on the other hand, is equipped with an advanced ontology that can represent, store, process and relate to the possibilities (of input information, intermediary and internal states, as well as the possible actions). Thus, in some sense (depending upon the richness, depth and breadth, and design of ontology), it has the ability to learn, plan and govern its actions while being aware of the process and having active involvement in it. Though the importance of reactive mechanisms should not be understated, the deliberative mechanism forms the first link between contemporary AI and the desired machine consciousness.

Reflective mechanism enables the virtual machine to reflect on its own actions, to self-monitor, self-examine, and self control. Self-control in reflective mechanism is a result of being aware of one-self and one's own actions. Thus, it is reflective mechanism that shall enable the machine to possess qualia, introspect itself, possess emotions, and relate to itself and its own existence. It also enables a machine to interpolate its self-knowledge in order to understand other machines. Thus, reflective mechanism is very helpful in realizing machine consciousness.

V. Models of Machine Consciousness

We summarize the state of art research in this area by presenting some of the practical achievements in machine consciousness. We mention useful frameworks/architectures and some actually implemented systems for machine consciousness and their models.

We begin with the physical definition of consciousness, its working mechanism and a computational model proposed by us [57]. We define machine consciousness as follows:

"A machine is conscious if besides the required components for perception, action, and associative memory, it has a central executive that controls all the processes (conscious or subconscious) of the machine; the central executive is driven by the machine's motivation and goal selection, attention switching, learning mechanism, etc. and uses cognitive perception and cognitive understanding of motivations, thoughts, or plans. Thus, central executive, by relating cognitive experience to internal motivations and plans, creates self-awareness and conscious state of mind."

A simplified version of our proposed model of the conscious machine similar to the one presented in [57] is shown in Fig. 1.

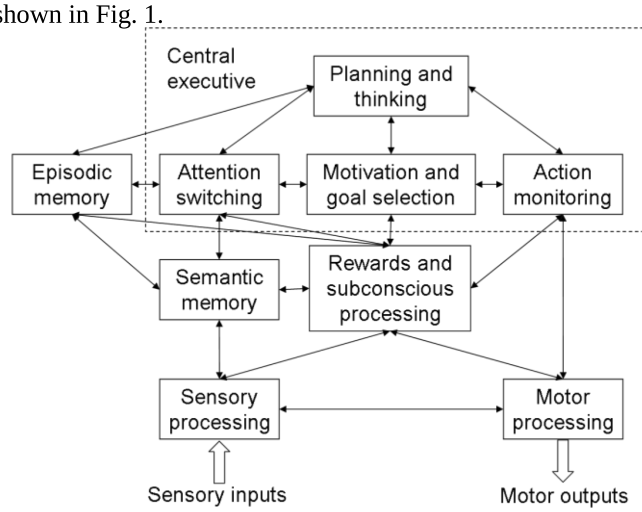

Fig. 1 Proposed computational model of consciousness.

Our current efforts are to build such defined conscious machines, and improve their mental ability and level of intelligence.

Baars and Franklin proposed a model of consciousness called the global workspace theory and developed an agent called Intelligent Distribution Agent (IDA) based on this model [6]-[8]. IDA is an agent that was designed for the U.S. navy for the purpose of collecting information from personnel, assessing the personnel on the basis of their performance and the issues they have had as human beings, and help in new task-allocation and problem identification. The global workspace theory [54] says "Consciousness is accomplished by a distributed society of specialists that is equipped with working memory, called a global workspace, whose contents can be broadcast to the system as a whole" (an argument refuted by Susan Blackmore [11]). Further Baars says [55], "Global workspace theory suggests a fleeting memory capacity in which only one consistent content can be dominant at any given moment". The content of the memory is decided by the consciousness. The exact role of consciousness is to decide the dominant content of the memory. In our model, conscious mechanism that uses planning, thinking, goal creation and goal selection based on machine's motivation, plays a critical role in selecting the dominant content of memory [57].

Rosenthal's Higher Order Thought (HOT) theory [56] says "We don't sense our conscious thoughts and sensations, since there's no distinctive sensory modality or sense organ for doing so. The only alternative is that we are conscious of our conscious thoughts, feelings, and sensations by having thoughts about them. These higher-order thoughts are themselves seldom conscious; so we are typically unaware of them". According to us, there can be only one thought at any moment in the conscious state of a conscious machine. According to us [57], "Conscious machine central executive directs cognitive aspects of machine experiences but its operation is influenced by competing signals representing motivations, desires, and attention switching that are not necessarily cognitive or consciously realized. Central executive does not have any clearly identified decision making center. Instead, its decisions are the result of competition between signals that represent motivations, pains and desires. At any moment, competition between these signals can be interrupted by attention switching signal. Such signals constantly vary in intensity as a result of internal stimuli (e.g., hunger) or externally presented and observed opportunities. Thus, the fundamental mechanism that directs machine in its action is physically distributed as competing signals are generated in various parts of machine's mind. Further, it is not fully cognitive, since, before a winner is selected, machine does not interpret the meaning of competing signals" [57]. Hence, in our opinion, Rosenthal's HOT theory is based on fallacy that multiple thoughts exist in conscious machine simultaneously.

Haikonen has proposed a cognitive architecture based on his theory that if the neural network is large enough and complicated enough, the traits of consciousness will eventually emerge on their own [16], [17], [19], [50]. Thus, he suggests that no algorithm specifically designed for implementing consciousness is necessary. According to us, his claim is vague and too generic. It does not give any concrete direction towards the realization of machine consciousness. According to us, mere presence of large and complicated neural network is not enough to realize machine consciousness. Apart from sufficiently large neural network and suitable cognitive architecture we do require other units such as motivation unit, attention switching unit, action monitoring unit, goal creation system unit, planning and thinking unit [57]. Although these units are fully distributed and are part of large interconnected network, they are functionally different in terms of their role in selecting a cognitive input, governing the planning process, and monitoring the control sequence for motor action.

Sun proposed another architecture called CLARION [27, 29]. CLARION is a two-level architecture in which the lower level concerns things, events, perceptions, reactive information, which cannot be associated with consciousness, and the higher level solely implements consciousness. These two levels are inter-connected with each other in both directions to form complete virtual machine architecture. A similar theory is the supramodular interaction theory proposed by Morsella [48], which models consciousness as integration of high level, specialized, multi-modal systems. Under this model, a distinction between the consciously penetrable and impenetrable modules (systems) is highlighted, and consciousness appears as a cross-talk among these modules. No mechanism is implied how these

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cross-talks between different modules or levels are organized and how a machine reflects its own actions.

Taylor proposed corollary discharge of attention movement (CODAM) model, that emphasizes the role of attention and change in attention for implementing consciousness [31]. We do agree that attention and attention switching mechanism is important to realize machine consciousness. However, other factors also need to be considered [57].

Sloman, Chrisley, and their team have proposed the cognitive and affective (CogAff) schema [22]-[24], which is a generalized schema applicable to a wide range of AI and consciousness architectures. It is able to accommodate multiple hierarchical levels as well as independent lateral modules in its architecture. It is capable of representing reactive, deliberative, as well as reflective (meta-management) systems, thus providing a broad framework for comparison, judgment, and possibilities exploration of AI and consciousness architectures.

Some AI robots or systems have also been made to explore, understand and implement machine consciousness, which include CRONOS (a human like musculoskeletal robot) with the aim of phenomenal consciousness [47], Cyber Child [46] (a test bed for machine consciousness), Khepera models/robots [40], etc. A good overview is provided in [50].

VI. Conclusion

Based on our review of the research done on machine consciousness, we can make the following observations.

Like intelligence, consciousness is a property of a physical mind not a meta-physical phenomenon. It can be alive or not but it requires awareness and intelligence as illustrated in Fig. 2.

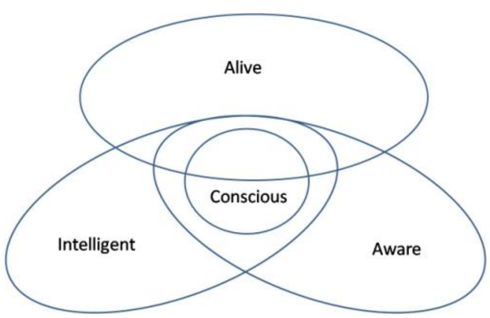

Fig. 2 Consciousness centered view of intelligent systems

Given its complicated nature, a unified explanation of consciousness is difficult. Yet, it is much more difficult to realize it in machines. Thus, in our opinion, though we have to use discretely defined, crisp, and formal theories and architectures, we also have to incorporate the gray area, the possibility for the system to evolve by itself and find its own consciousness. Our work in [57] is a step towards this aim.

Large part of the work in machine consciousness is inspired by biological systems. Our idea is also based on it.

The idea is actually similar to the appearance of consciousness in human beings that we can understand the best. From the conception of a fetus, through its development as a human being, till its death, a human being is taught a lot of things, including moral behavior, importance of social existence, relationship with nature, science, mathematics, sports, art, and so on. But no human being is explicitly taught to be conscious. There might be some intelligence/thinking enhancing exercises. However, these are enhancements only, while the basic mechanism is provided and consciousness develops itself. Furthermore, there is no basic consciousness training, and in its fundamental meaning consciousness is not a thought phenomenon. Higher levels of consciousness (like social awareness) may be trained, but a mechanism for consciousness is a property of the mind and cannot be taught.

In short, a large part of what we think as consciousness emerges through social interactions if a proper architecture, mechanism and functional blocks required for consciousness are available [57]. We conclude that consciousness is a physical phenomenon which can be realized in machines.

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