REFLECTION ON SYSTEMIC ASPECTS OF CONSCIOUSNESS

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Abstract: Today's quick development of artificial intelligence (AI) brings us to the questions that have until recently been the domain of philosophy or even science fiction. When can be a system considered an intelligent one? What is a consciousness and where it comes from? Can systems gain consciousness? It is necessary to have in mind, that although the development seems to be a revolutionary one, the progress is successive, today's technologies did not emerge from thin air, they are firmly built on previous findings. As now some wild thoughts and theories where the AI development leads to have arisen, it is time to look back at the background theories and summarize, what do we know on the topics of intelligence, consciousness, where they come from and what are different viewpoints on these topics. This paper combines the findings from different areas and present overview of different attitudes on systems consciousness and emphasizes the role of systems sciences in helping the knowledge in this area.

Key words: *consciousness, intelligence, system sciences, emotional intelligence, measure of intelligence, consciousness formation*

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1. Introduction, motivation

The study of consciousness is the subject of a number of sciences, philosophy, humanities as well as some technical domains. This entails different understandings of basic paradigms, concepts, methodologies and interpretations. Even the evaluation of the actual level of knowledge of consciousness is rather contradictory. There are those who claim that this is a fictitious problem, a problem being basically solved, we can also find opinions that the overall understanding of human consciousness is an impossible task.

System sciences and systems engineering (including computer science) can contribute to understanding the issue of consciousness by, among other things, asking specific questions, solving tasks that require a transdisciplinary approach, constructing models of various types or their ordered sets – multi-models. System (holistic) methodologies, analogies and generalizations (e.g., of the concepts of

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subjectivity, complexity, indeterminacy, emergence, or measurement of intelligence or systems reliability) have the potential to unify till now incommensurable approaches. A systems approach means, e.g., that we solve the pertinent tasks for wholes and their parts regardless of their material nature. With such an approach, we can find that in most fields, with the exceptions of philosophy, neurology, and to some extent psychiatry, the study of consciousness is at an initial level. As a result, a transdisciplinary approach, enriched with a unifying systemic view, is needed.

The concept of consciousness is discussed from various angles and at various levels.

Scientists, medical doctors and technicians understand it as a concept within reality and relate it to human, or to higher animals. In the field of technology, authors theorize about the possibility of assigning consciousness to constructs, such as robots, computers, buildings or networks. Some cosmologists, many philosophers and theologians assign consciousness to the universe, or even to the planet Earth (Lovelock's strong version of the Gaia hypothesis, which claims that the planet Earth is a conscious living super-organism) [32]. Other researchers are skeptical. E.g., computer scientist Y. A. LeCun [1] considers consciousness to be an ill-defined concept, or a fiction. Graziani [2] claims that the scientific aspects of consciousness are already in principle known and further activities in this direction lack a scientific character.

1.1 Consciousness from different viewpoints

Philosophers have been concerned with consciousness since ancient times. For example, in the overview article "Phenomenological Approaches to Self-Consciousness" in the Stanford Philosophical Encyclopedia alone, we can find over a hundred references to just a partial, albeit very important, area of self-consciousness [3].

Systemic approach can contribute to clarifying some aspects of this concept. It can, for example, detach considerations from preliminary, often unspoken (implicit) assumptions that representatives of a specific disciplines bring to typically multidisciplinary discussions. In this case, it is the basic role of systems sciences – helping mutual understanding of different scientific fields, which belong to the very foundations of the systems movement program [4, 5].

Consciousness certainly is not well-defined concept at present. Neurologists, for example, recognize 3 stages of consciousness in mammals (and humans): vigilance (wakefulness), sleep and paradoxical (REM) sleep. Vigilance by itself cannot exist in the long term, all 3 phases must be repeated cyclically. Engineers, policemen and lawyers consider only the vigilant state to be really conscious. Control of machines and appropriate response on the state of environment (as well as the behavior of other people) strictly require it. Non-unified definition of consciousness results in various misunderstandings.

Most frequently cited definitions of consciousness are as follows:

- *Functional Definition* (Baars 1988) [6]: This definition considers consciousness as the ability to process information, engage in reasoning, solve problems, make decisions, and exhibit self-awareness. It focuses on the cognitive and functional aspects of consciousness, often tied to higher-order cognitive processes.

- *Information Integration Definition* (Tononi 2008) [7]: According to this view, consciousness emerges from the integration of information across various brain regions. This definition highlights the interconnectedness of neural activity and claims that consciousness arises when information becomes globally integrated in a way that supports complex cognitive functions.

- *Subjective Awareness Definition (mostly philosophers)*: Consciousness is defined as the state of subjective awareness and experience. It involves being aware of one's thoughts, emotions, sensations, and perceptions. This definition emphasizes the "Ich" – first-person perspective as well as the qualitative nature of consciousness.

- *Phenomenal Awareness Definition* (Nagel, 1974) [8]: Phenomenal awareness refers to the raw, qualitative, and immediate experience of sensory perceptions, emotions, and thoughts. This definition focuses on the 'what it is like' aspect of conscious experience (it is tied with the Nagel's popular phrase "What is it like to be a bat?").

For our considerations, we will use the older definition of the concept of human consciousness according to Vondráček (Faber 2023) [9] defining the "normal consciousness". This illustrative definition structures the complex concept efficiently:

"The state of normal consciousness is a state in which
we perceive correctly and we feel correctly that we perceive,
we think correctly and we feel correctly that we think,
we feel correctly and we are correctly aware that we feel,
we correctly want and correctly feel that we want
and we correctly relate it with one's own self."

Scientists as well as computer scientists and technicians naturally demand precisation of the expressions "we perceive correctly..." etc. However, this is feasible using systemic approaches[1].

For some technical fields, the concept of consciousness is very important. E.g., in the field of transportation, we deal with both occasional lapses of attention and consciousness in human operators (drivers) as well as the issue of whether it is possible/desirable to have something like consciousness in robotic drivers [29–31].

2. System and consciousness

Under the term of system, we understand, in accordance with the system-engineering approach (Vlček 1999), [3] such a model of an object that is almost identical – isomorphic to the original object. More accurately: The deviation from the isomorphism is under the control of (investigating) subject on the pre-specified set of variables and parameters. The surroundings complement the system analogically

[1] For example, we can consider such a perception which makes possible the construction of an image/model of the object that meets the defining characteristic of the system to be a "correct perception".

as an environment complements the object. We intuitively include everything outside the system in the surroundings. The system and the surroundings share a system boundary, containing an interface. Both the system and the surroundings are recognized within the same universe.

The object can be a specified part of the real world or even a system at any level of abstraction. In such a case, system models can be chained. The subject has a significant role in system identification. System sciences and systems engineering emphasize the indispensable role of the subject both in the identification of the system and in the interpretation of the results obtained by solving tasks on the system (i.e., the results of modeling and experiments with models).

Some tasks on the system are specified or significantly influenced by the subject, e.g., the specification of the goals and strategic goals, or control of the resources.

At this point, it is obvious to ask a question: If in the system sciences, or in systems engineering, the subject plays an important (postulated) role, and we assign consciousness to this subject almost by definition[2], does it not follow from this fact that we are trying to analyze the relationship between the system and consciousness, while the concept of system itself is a certain reflection of the subject's consciousness? The answer is yes, the doubt is justified. However, it does not mean that systems approaches are unusable in the study of consciousness. In any case, however, we must constantly be aware of the fact that the concept of a system presupposes the existence of a conscious subject and confront the acquired knowledge with it.

2.1 Complexity

From experience we believe that consciousness cannot occur in simple objects. Consciousness requires, and often even evokes, complex behavior. Complex behavior presupposes the occurrence of alternative processes and feedback loops. Thus, a considerable degree of complexity[3] is intuitively expected, without serious justification.

From already introduced definitions of consciousness, it is clear that an object equipped with consciousness must be able to dynamically generate high-quality models of the environment, sufficiently accurate models of itself, and control the relevant interfaces.

Why? Control theory proved long ago that even a simple control system – regulator have to contain an adequate model of the environment. More complex, multi-parameter regulation in a perpetually changing real environment then requires that such a model be either very complex or that it is a set of models, among which the control system dynamically chooses the currently suitable model. Very complex models are generally not feasible in terms of dynamics, reliability and uncertainty. Often, their eventual construction is made impossible simply by combinatorial unavailability. So, the multi-model option remains. In addition, this requires the existence of a dynamic optimization module for choosing a partial

[2]How else could it identify the system and perform system tasks?

[3]Complexity can be evaluated by: the cardinality/dimension of the state space ((i.) approach); the number and functions of separable parts of the system – elements/automata and the set of their mutual relations, (approach (ii.)); sets of rules (grammars) for translations of partial languages into a system multi-language (approach (iii.)) E.g., [33].

model and controlling the interface (organizer). And so far, we have only considered the tasks of controlling the system in the given environment. More complex system tasks, e.g., creating goals or choosing strategies, have additional requirements.

An object must be able to control the exchange of energy and information (negentropy). For goal oriented and species processes, it must be able to dynamically solve the systemic tasks of evaluation of the distances of processes, homeostasis and identity evolution. In the case of computer sciences approach – ad (iii.), these are tasks of controlling syntax (composition) and to a certain extent also semantics (meaning), tasks of creating sentences[4] and tasks of managing the effectiveness of translations. As a result of the objective tendency towards the growth of disorder in real macro-objects, we can legitimately attribute to this also the control of substance exchange.

As systems grow in complexity, so does their indeterminacy – the fundamental deficit of information about the system. Uncertainty in complex systems is partly unavoidable. It leads to the chaotization of processes, to the "sliding" of cyclical processes into selected areas of the state space, or to the appearance of attractors in the behavior of systems, to the sudden and unexpected appearance of certain states, i.e., to emergencies. There are also mutations – irreversible changes of species, specifically species processes and their genetic code, or degradation or even system crash. Under specific situations (sufficient energy or information flow from the environment), self-organizing processes – self-ordering – can also appear in significantly open systems (Klir 1991; Stonier 1990) [4, 10].

As shown above, we can assume that an object endowed with consciousness must be richly structured. This is because it must provide high-efficiency sensory functions in relation to the external and internal environment, similarly the functions of actors, complex information processing, optimal management of internal processes and optimization of the internal environment, as well as prediction of the development of the object and environment and the creation of scenarios/multi-models.

2.2 Intelligence

Intuitively, we also consider *intelligence* to be a necessary condition for the emergence of consciousness. Here, however, we encounter a similar problem as when defining consciousness. The concept of intelligence was developed independently in the science, humanities and technology. It is difficult to unify a concept that has arisen in so many different ways.

A unified approach can perhaps be based on a measurement-based definition of intelligence. The information/entropy measurement of intelligence is based on the thesis that intelligence is a tool for reduction of the disorder (entropy) of an object and its immediate environment. The decrease in entropy is then a measure of intelligence. A fundamentally simple approach is proposed by Peter Cochrane in 2010 [11].

An object is recognized in the real universe RU.

The recognizing subject simply considers the near surroundings as the system image of the RU, then decomposes the image of the object, as is shown in Fig. 1,

[4] Including communication in incomplete grammars.

into the following information subsystems: S – sensory subsystem; A – subsystem of actors; P – information processing subsystem (processors); M – memory subsystem. For biological intelligent systems, a set of synapses Sy can be considered instead of a subsystem of processors and memories.

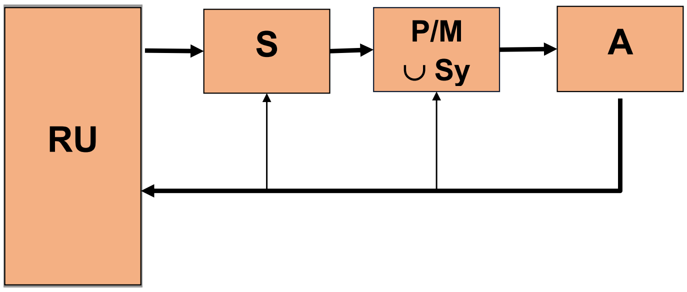

Fig. 1 *Quantitative valuation of intelligence, adopted from Peter Cochrane 2010 [11].*

Subsystem capabilities are expressed in bits for subsystem M, in other cases in bits per second (b/s); K is a constant, depending on the system of units.

ΔEn expresses the entropy reduction of the system and the near surroundings.

$$I_c = K \cdot \log_2[1 + AS \cdot (1 + PM)]; \quad I_c = \Delta En$$

The level of intelligence expressed in this way is logarithmic with the base 2. It is a potential level, i.e., actually an upper limit that may not be, and usually is not, reached. An object that has no inputs or outputs has zero intelligence. Entropy reduction applies to both the object and the immediate surroundings. The mentioned methodology can rightly be criticized as simplistic one, its price is in generalization to objects of different types, e.g., biological or artificial.

We consider the entropy reduction to be the product of intelligence I_c. From the point of view of systems engineering, we consider it natural to suppose that a conscious entity does not intentionally increase chaos, i.e., that the entropy decrease is positive.

2.3 Emotional intelligence

Let's further mention the concept of *emotional intelligence*: Emotional intelligence is not simply related to intelligence. It is understood to be human – centric quality as emotions are mostly related to human beings. However, it significantly affects the success of an individual in society, family and in the intimate area. It is influenced by the activity of the limbic system. D. Goleman [12] introduced the basic types of emotional intelligence abilities:

1. self-awareness

2. self-motivation

3. perseverance
4. impulse control
5. mood regulation
6. empathy
7. hope or optimism.

It is clear from this list that the first component of emotional intelligence is directly also an important component of consciousness. Components 2, 3, 6, 7 have an obvious connection with the formation of processes, the generation of goals, or strategic goals, components 4 and 5 include the projections of the limbic system into the behavior of the whole. Therefore, the knowledge of the nature of consciousness can also significantly help the study of emotional intelligence. However, the level of knowledge of this concept remains at a possibly even lower level, such as the knowledge of consciousness, and therefore we do not consider it effective to deal with it further in this article.

2.4 Agent approach and multi-modelling

As a result, intelligence of an object equipped with consciousness must enable to construct a dynamic and fairly accurate system model including a capture of the internal environment (the system twin of the object), then a dynamic and sufficiently correct model of the environment, the initiation of actions affecting the (near) environment as well as the structure and running of the processes. It is also necessary to control the interface, information, energy and matter exchange, prediction of the states (state trajectory) and the possibility of retrospective monitoring of states, including unrealized alternatives. Complexity and the indeterminacy associated with it give rise to requirements that both the model of the environment and the system twin of the object should actually be multi-models [13, 34]. All these abilities are necessary so that the object – agent can contribute to reducing its uncertainty and the uncertainty of its immediate surroundings in a measurable way. In short, to be intelligent. Sufficient intelligence is a necessary condition for the emergence of consciousness, but not a sufficient condition.

2.5 Problem of identification

Defining an object in a real environment is an exclusive act of a conscious subject. The subject carries out this delineation with the knowledge of a certain goal. An important step is to respect all essential links between the object and the environment, i.e., the system with the environment in the system model. The interface captures these bindings. In general, we require that the interface be regular, that is, that all variables and their ranges (domains) match at the output from the environment and at the subsequent input to the system. This often fails with complex systems. In such a case, possible irregularities must be treated, e.g., using the parallelism of connections or processes. For such cases, we introduce the concept of interoperability. However, we must be aware that in such a case we potentially increase systemic uncertainty [14, 15].

2.6 Synchronicity, time

In order to be able to speak about consciousness and the complex tasks it enables, such as creating goals and strategies, it is necessary to introduce the time.

Time can be introduced as oscillatory, defined by a clock, or relaxing (defined stochastically, e.g., decay). In both systems science and systems engineering, the character of time is determined by the subject. Mostly discrete oscillation time is preferred. In this case, subject also determines the time step (time element). Occasionally, also local system time in the system is introduced, which is specified by the course of events in the system. For the solution of some tasks, the introduction of system time is advantageous. This applies, for example, to the evaluation of the system's response to information [16]. The system environment must also have sufficient system resources. System resources include, for example, resources of matter, energy, information, but also space, finance or knowledge – depending on the nature of the system.

Current experience shows that complex objects, and thus also the systems identified on them, can exist for a long time (measured by system time) only in certain intervals of substance, energy and information densities. This of course also applies to conscious subjects and objects.

We would probably have problems in the study of consciousness if we did not introduce causality. That is, a property of the environment in which no state of the system is affected by future states. Failure to fulfill this condition may result in chaos.

2.7 Intermediate summary of consciousness systemic features

1. Integration of information: Consciousness requires the integration of information from external and internal sources.

2. Complexity: Consciousness is likely to emerge only in complex systems.

3. Functional specialization: Consciousness appears to require the existence of specialized subsystems to perform specific functions such as perception, attention, and memory.

4. Dynamic feedback: Consciousness requires the existence of dynamic feedback between subsystems and the environment, where regulatory processes take place and self-organization arises.

5. Physical correlates: Consciousness in biological entities is associated with specific physical processes in the brain, such as neural activity, which can be measured in different situations and states, e.g., with EEG (e.g., [17–19]). and correlated with conscious experience.

3. Elaboration of considerations, discussion

3.1 Backgrounds of epistemology and control

For the further study of the origin and properties of consciousness, it is useful to focus on how a person perceives and how it affects its surroundings. It means to introduce backgrounds of epistemology and control. A historically informed approach would be based on Aristotle or later on Frege's semantic triangle: object/concept/symbol. For our purposes it is probably better to start with Vlček's enhancement of the original triangle to the semantic square. It is more suitable for the study of human consciousness because it explicitly introduces the level of language [19]. This is important for generation of knowledge, e.g., see Fig. 2.

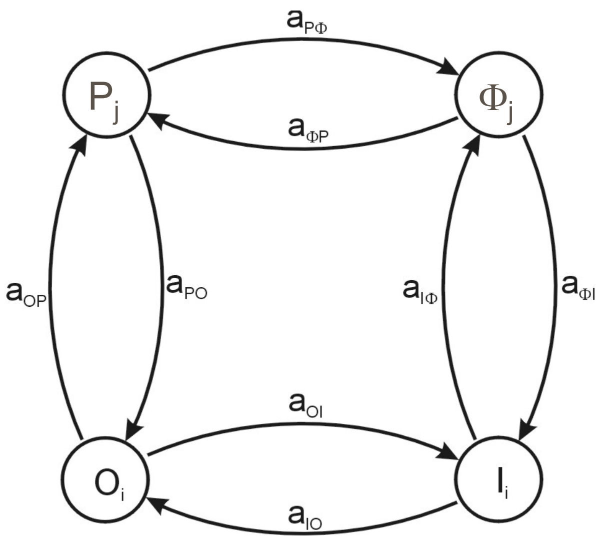

Fig. 2 *Vlček's enhancement of Frege's semantic triangle.*

O_i represents an object of reality existing in a given environment. P_i is the reflection of this object by ith sensor. The set of these reflections through all sensors (including sensors reflecting internal states or memory traces) is processed into an integral model Φ_i in its jth iteration (jth step of thalamo-cortical reverberation). At the same time, there is a significant reduction of information and, perhaps surprisingly, also a reduction of the indeterminacy via iterations of model outputs in their sub-steps. At this level, reflexive behavior is formed. At a higher level, language image I_i is created and further processing takes place in language (concept creation, information expressed in sentences). Information is stored in memory tracks for further use. During further processing using gradually completed and mutually compared models of the object and the environment, knowledge is formed. It is typical for man and human society to act on objects of reality through linguistic constructs.

3.2 Reduction of information

The flow of relevant data from external and internal sensors as well as data retrieved from memory when solving tasks in a real environment and in real time often far exceeds the possibilities of their processing. A model processing too extensive set of inputs and internal states is unusable, as it is often not able to give outputs on time. It also has excessive resources consumption. Therefore, significant intelligent information reduction is a fundamental task. It can be assumed that consciousness effectively helps to carry out this reduction of information. We can express this condition compactly within the framework of systems engineering: Usable models must be system models. Efficient models work with knowledge.

3.3 The role of environment

The environment has a significant impact on the way we infer the intelligence and possibly consciousness of identified objects. Therefore, we must have in mind that our perception of consciousness, intelligence, goals, etc. is always depending on our perception of the real object, its reflection, linguistic description and language we use.

A considerably indefinite real environment, in which existing objects are characterized by physical, chemical, biological and social relationships, forms demands on the intelligence of objects that are far more difficult to express. It is precisely in this environment that consciousness also plays a role.

3.4 Specific features of social or socio-technical systems

For social and socio-technical systems, e.g., of the human-machine or human-society type, the system features of higher order are occasionally constructed. One of them is *systems ethics*.

The first of its components captures the "export" of disorder (entropy) to the environment[5].

Another component is a set of rules for allocating resources to elements, for generating or canceling elements, and for limiting relationships between elements and the system as a whole. System ethics tasks concern both the system and the subject. The second of these high order features is *systems belief*. It refers to the subject, however, during the existence of the system, it can also capture emergent attributes of the system's behavior. Belief postulates some aspects of the subject's activities and the behavior of the system, which are based on long-term human experience, for example:

- An order is better than chaos.
- Too much organization is undesirable, it is unstable and it suppresses free will.

[5]By this we mean: The course of processes in the system is accompanied by the consumption of system resources. Among other things, the degradation of energy into lower-ordered forms (thermalization). The non-zero failure rate of processes also necessitates repairs, which also require material replacement. It means that the surroundings are burdened by changes that cause an increase in entropy there. We express this by the term entropization of the environment.

- The long-term experience of human society must be respected even in socio-technical systems.
- Human life must be protected.
- Short-term benefit must not jeopardize strategic goals.
- Entia non sunt multiplicanda praeter necessitatem – let's not introduce more entities than necessary (Occam's razor).

Belief is closely tied to philosophical and theological principles and captures the fact that conscious beings are closely intertwined with the whole of human society. If, for example, in the role of a system subject, we are followers of the philosophical thesis "esse est percipi" ("to be is to be perceived"), this will affect our activities in identifying the system differently from Cartesians, followers of the thesis "cogito ergo sum" ("I think therefore I am").

The consciousness of the subject is a necessary condition also for the identification of system ethics and system belief. On the other hand, it is not necessary determining them directly, it can be sufficient to define and apply just rules for their identification.

Consciousness is a necessary condition for the emergence of *free will*. In systems engineering, free will is unique quality of subject, it is, among other things, a tool for system identification, for choosing architectures, scenarios or sub-models in multi-modeling. It is also useful in solving system problems with uncertainties, on identity and in the wide area of "soft-methodologies". Free will must not be confused with simply searching the state space. [20] Free will of an object is till now rather a sci-fi stuff.

There is no place for free will in fully deterministic systems, e.g., macro-physical ones. The peculiar problem arises that we are used to identify real universe just as a deterministic system. There are proposals to solve this shortcoming by introducing additional dimensions or fractal dimensions [20]. The possible solution could also be found in the use of quantum models in non-standard interpretations (multiverse). After all, the multiverse concept is close to systems engineering approaches in solving alternative behavior tasks. Particularly interesting is its variant, in which the individual partial universes are not separated, but permeate each other. They do not interact, but can be un-evidently bound by an entanglement from their origin. This limits the variety of their properties.

3.5 Properties of universe

Continuing similar considerations, we can conclude that the very existence of entities (both subjects and objects) equipped with consciousness imposes strict conditions on the properties of the universe. This area of reasoning resulted in the formulation of two versions of the *anthropic principle* hypothesis [21]. The "weak" version of the principle claims that the universe is just so "fine-tuned" that life, and subsequently human being, could have arisen on it. If the fundamental constants of the universe were only slightly different, the real world, and thus life as we know it, would not have come into existence. According to the "strong" version of the anthropic principle, just such information was inserted into the foundations of the universes that intelligent life had to arise in it. The basic constants of the universe are therefore set on purpose – by the creator. A weak version of this principle is based on the analysis of observations and comparison of results with models. In the case of the multiverse model of the world, it does not lead to fundamental contradictions. It is also falsifiable, which is why it can be investigated using scientific methods. A strong version of the anthropic principle is based on faith and the possibility of its falsification is unknown.

Quantum properties of universe have also significant impact on variety of systemic features (e.g., [26]).

3.6 Physiological aspects of consciousness

We can consider the existence of *thalamo-cortical reverberation* as an accompanying phenomenon, or even as a key part of the processes of human consciousness (Faber [9, 22, 31]). It is documented observationally on the basis of electroencephalographic (EEG) or related (NIR; MEG; PET) measuring methods. It shows that characteristic oscillatory processes take place in the human brain as well as in the brains of higher vertebrates, reflexing the extensive information exchange between the thalamus and the cerebral cortex [27]. From a systemic point of view, this is apparently an iterative (gradually refined in a sequence of steps) multimodeling procedure. At the same time, partial models depict the external world – the surroundings – for example according to specific sensory subsystems. At each step of the iteration, the state of these subsystems is compared with the internal states of the system. The individual models are in a resonant relationship. At the same time, iteration effectively eliminates uncertainties (Faber). If we accept the hypothesis that consciousness arises from the integration of sub-models and their association with memory traces, we will arrive at a definition of the concept of the conscious present. This is not a sensorially distinguishable time step (e.g., in the order of a tenth of a second for the human visual subsystem), but a time interval in which sub-models are compared and integrated. This could correspond to the spindle period of the relevant EEG wave (units of seconds).

Various types of brain resonances (not only specifically thalamo-cortical reverberation) have been systematically dealt with by Stephen Grossberg for a long time (e.g., [23]). He decomposes the system generating consciousness to these 6 subsystems:

1. Perceptual Representation System (PRS): It is responsible for processing sensory information and creating a representation of the perceptual world. This system generates a stable and coherent perceptual experience, despite the constantly changing sensory inputs.

2. Cognitive-Emotional Processing System (CEPS): The CEPS processes and evaluates information, and generates emotional and cognitive responses to that information. This system is responsible for forming feelings of pleasure, arousal, and other emotional states, as well as generating higher-level cognitive functions such as decision-making, problem-solving, and planning.

3. Working Memory (WM) System: The WM system is responsible for holding and manipulating information in the short term. This system is responsible

for an attention, switching between tasks, and fusion of multiple cognitive processes.

4. Cognitive Map (CM) System: The CM system is responsible for creating and maintaining a mental representation of the physical world, and using that representation to navigate through space and make predictions of future events.

5. Motor Control System (MCS): The MCS is responsible for planning and executing motor actions, and coordination of the movements of parts of the body.

6. Consciousness System (CS): The CS is responsible for integrating information from the subsystems 1–5, and formation unified experience of consciousness. Thus, it is responsible for creation of a subjective sense of self, and for generation of a coherent stream of conscious experience.

We consider these approaches very inspiring to the understanding of consciousness. They potentially explain the possibilities of the existence of consciousness in living creatures other than humans and do not rule out generalization to inanimate types of objects. The role of other neurological components of consciousness, i.e., sleep and paradoxical sleep has yet to be generally elucidated.

3.7 Emergence of consciousness

The assumption that the advent of *consciousness can be mere an emergent effect of a complex "sufficiently" intelligent system* is developed not only by writers of science fiction literature, but also by some computer scientists, philosophers and theologians. We are of the opinion that such an assumption is for now unfounded. For example, just from the discussed method of measuring intelligence (Cochrane 2010, [11]), it can be seen that the component of intelligence of the sensor/actor type cannot be replaced by even a perfect component of the processor/memory or synapse/neuron type. In order for objects to be conscious, they must be richly equipped with sensors and actuators, both towards the surroundings and inside the object. Contemporary artificial objects do not fulfill this. It seems more likely that evolutionary processes, such as the process of natural selection, are at work in the long term in the emergence of consciousness. After all, evolution shapes life in the long term and permanently. However, we cannot consider it proven, because we cannot prove convincingly (and if possible quantitatively) if/when/what evolutionary advantages the existence of consciousness brings.

Hameroff and Penrose [24] have long developed the hypothesis that *consciousness is made possible by quantum highly parallel processing of information on the microtubules* of neurons in a natural neural network. For now, we have to consider this interesting idea as an unproven hypothesis. However, it is based on the extensive observations and experiments of the first author and the brilliant theoretically grounded modeling of the second author. This assumption has recently been indirectly supported by a work [25], which shows that the behavior of a natural biological neuron is so complex that it is necessary to train an artificial neural network of 6–8 layers, composed of approximately 1000 model neurons (McCulloch-Pitts neuron model), to capture it sufficiently faithfully. Although this finding does not say anything about the principle on which a natural neuron works or whether quantum processing of information takes place in it, it "only" shows that natural neural networks are 2–3 orders of magnitude more complex than we thought until now.

4. Conclusion

The issues of the origin of consciousness and the processes by which consciousness acts are among the most significant challenges of the natural sciences and computer science in the last and upcoming decade. Philosophy and social sciences generally show how important the study of consciousness is. Apparently under the influence of the rapid development of artificial intelligence, including technical applications, an unreasonable expectation arises, in our opinion, that the clarification of the origin and principles of consciousness is "on the horizon". Realistically, however, with the exception of the fields of neurology and psychiatry, the current state of the natural science study of consciousness is rather at the beginning. Fundamental questions remain essentially unsolved and often there is no known strategy for solving them.

Let's name some of them: Under what conditions does consciousness arise? What processes are essential for the existence of consciousness? What benefits does it bring to its holders in a given environment? How do wholes composed of parts endowed with consciousness behave? How can consciousness be strengthened/influenced? To what extent can consciousness be shared? Can constructs be conscious? Does it make sense to pursue it? Is sleep and paradoxical sleep a necessary part of consciousness? This creates space for the construction of diverse hypotheses. Why not make a tips, too? We personally favor a class of hypotheses (Faber 2023 [9] or Grossberg 2017 [23]) that claim that consciousness arises in the human brain as well as in the brains of higher vertebrates during specific oscillatory/resonant processes in which there is a large-scale exchange of information between specific brain areas, notably between the thalamus and the cerebral cortex. From systemic point of view, this is iterative multi-modelling. Partial models depict the external world – the surroundings – for example according to specific sensory subsystems. At each iteration step, the state of these subsystems is compared with the results of the overall model in previous iteration steps. Thus, iteration (sampling) effectively suppresses indeterminacy. Therefore, we would like to focus further research work on the phase-sensitive integration of partial models with consideration of their oscillatory character and the emergence of resonances, which can capture qualitative changes in state trajectories and other unexpected phenomena. A promising alternative is also capturing events using the apparatus of quantum physics. Recommendations on how to attempt consciousness experiments with artifacts can be derived by analogy.

Other "bold" hypotheses are also possible. We have mentioned some of them in this text. In any case, both systems sciences and systems engineering create a possible bridge for the transfer of results between different disciplines and present some framework limits that can limit "wandering down dead ends" or, as LeCun says, grandiose visions.

Systemic approach offers sophisticated modeling methodologies and explicitly emphasize the role of the subject. Systemic view also suggests that the appropriate approach to further study of consciousness is to be broadly based and well-coordinated transdisciplinary research.

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