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Review Article

Emergence ex Machina: Correlates of Consciousness

David Josef Herzog[1], Nitsa Herzog[2]

1. Department of Computing, QA Higher Education, United Kingdom; 2. Faculty of Computer Science, Northumbria University, Newcastle upon Tyne, United Kingdom

Consciousness is a phenomenon that justifiably attracts pensive attention. And despite centuries of contemplation and decades of research, consciousness remains an elusive and poorly defined matter. Its nature, composition, and characteristics are hotly debated. The explanatory gap between phenomenal consciousness and the functions of neurobiological correlates is considered a hard problem. However, the so-called "easy" problem, the evolutionary and biological emergence of consciousness from the underlying substrate, is also not easily explainable. The discussion about the essence of consciousness spreads far from neurophysiology and biology into the fields of quantum mechanics and information theory. Old concepts of panpsychism and pre-eminence of information before material substrate have re-emerged in recent decades. Neopanpsychism is an idea of potential consciousness on a physical elemental basis, and it expands into the realm of astrophysical objects and their networks with the potential of complex data production and processing. Information theories of consciousness include possibilities for any non-biological object to harbour proto-mental abilities if they fulfil minimal architectural and informational requirements. The "normal" grasp and "realistic" world perception endure constant criticism from leading physicists and mathematicians. In this atmosphere, it is much easier to claim the platonic pre-eminence of abstract ideas before any substrate and ability of non-physical consciousness objects to exist independently. It is important to re-evaluate the main arguments of the discussion to focus practical efforts on the classical scientific research of consciousness and its underlying elements, with established metrics and clear directions. There are not many arguments which can shift the scientific approach from classical hypothesis proving/disproving towards the more scholastic discussion about the non-physical nature of consciousness and the inability to investigate it. The consciousness phenomenon certainly has emerging stages, as we can see in living nature, and, at the same time, cannot be limited by one person, living or physical object in possession of it. The challenge of consciousness emergence from

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abiological substrate is one of the fundamental questions that require significant scientific efforts to answer.

Corresponding author: David J Herzog, davidjosef.herzog@qa.com

1. Introduction

“Easy problem” or gap between elusive basic forms and fully-fledged consciousness is a perplexing issue. Understanding the emergence of consciousness from non-living matter is an intriguing challenge. Consciousness as a phenomenon is routinely recognized by us on a daily basis. We are self-conscious, we perceive consciousness in others, and we comprehend basic features of levels of consciousness. Still, there is enough lacunae in understanding consciousness as a complex phenomenon based on the underlying processes. Placing this understanding into the time frame allows us to compare stages of acquiring consciousness by Homo sapiens sapiens. The evolutionary approach presents before us a number of principal questions. Does the inanimate world possess not only the possibility to produce life but also a conscious life? The widely debated anthropic principle, in both weak and strong forms, states unequivocally both possibilities[1].

We cannot deny consciousness in ourselves, but we often fail to recognize it in other creatures. Animal consciousness, particularly in mammals, other highly developed vertebrates and mollusca can be understood through levels and states of consciousness, behavioural features and underlying neuro-biological basis[2]. There is a lack of clarity regarding less developed forms of life, such as cellular life or abiologic potential types of consciousness. Suppose consciousness is an emerging phenomenon, progressing through the higher levels with corresponding more developed levels of neuro-biological correlates. What is the first primary unit of it or the least possible natural state, such as initial sentience[3]?

If there is scalability of states and mental and cognitive capabilities, what are the relationships between them in phenomenal consciousness? How important is computational neural or any other power, but also the architecture of elements, to be a source of consciousness as a phenomenon? If the neocortex is not necessary for experiencing pain and neurons or multiple cells are not needed for the reaction of unicellular paramecium, does it allow sentience at the cellular level[4]?

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Is consciousness possible to attribute to an individuum, or is it impossible to separately develop consciousness without social and environmental interactions? How important is the temporal factor when the memory of all previous biological generations is stamped upon any developed consciousness as footprints of evolution or social development? Is unconscious cognition part of consciousness through meta-conscious architectural elements and states? If anoetic primary consciousness and noetic, knowledge-based, are presented in vertebrates, does it mean autonoetic self-consciousness is also presented in them[5]?

We can ask more fundamental questions about the possibility of pre-biological consciousness preliminaries. Did it start from quantum particles, as claimed by some thinkers, from more complex abiologic matter, or biologics from a pre-neuronal cellular or tissue basis? Are there any constructive possibilities for biological and potentially artificial consciousness? If consciousness is possible on the low biological level, how can it have levels of consciousness[6]?

These questions require clear, unequivocal answers, without which we cannot succeed not only in operative abilities but also in explanatory power of our comprehension of consciousness phenomenon. Multiple theoretical models are proposed for the explanation, from abstract logical or informatics structures to purely brain-based, experimentally accessible ones. The focus can shift from structural and architectural descriptions to functional, perceptual and interactive explanations. More complex models include many of these elements, making it multifaceted enough to reflect this subject's complexity[7].

One issue remains constant in all the explanations or frameworks: any theoretical model should be practically accessible for experiments and hypotheses testing. The hard problem of consciousness and qualia being phenomenal states and not objects, given for appropriate scientific assessment, remains outside of any possibilities to resolve it in the traditional way[8]. The dual ontology may deny this option. In order to reconcile the consistency of the scientific world view, with physical categories and metrics and biological and evolutionary laws, there is a necessity to focus attention on objectively accessible correlates of consciousness.

2. Correlates of consciousness

Correlates of consciousness partially help to explain the consciousness phenomena on strictly correlative basis and are relatively open for observation and scientific scrutiny. According to different hypotheses, these correlates range from quantum mechanics to fully developed brain functioning structures. Some of them lean more toward the theoretical end of spectrum, while others have been experimentally and clinically validated.

It is justifiable to cite here the quintessence of Braitenberg's law of 'uphill analysis versus downhill synthesis'[9]: "Complex phenomena that resist direct analysis can be better understood by analysis of less complex alternatives instantiated in simulation."

The mere observation and behaviour registration are not sufficient for the satisfactory understanding of structures, and even less sufficient for replication and simulation. First Person Perspective, "I"-PP, despite important phenomenal positioning, also cannot give a satisfactory, more detailed account not only on the correlational but also "account for" structures. There is a necessity to approach the problem from the other, less complex side: the minimal possibility of consciousness emergency from the lowest informational and physical basis to the human consciousness as a fully-fledged phenomenal state produced on the neural correlative basis. Neural Correlates of Consciousness (NCC) are most considered the foundation, but there are more possible antecedent physical, biological, informational and computational correlates and descendent behavioural correlates.

2.1. Informational and computational correlates

One of the most prominent features of consciousness is cognitive ability. It is impossible to imagine a practical model of consciousness without inherently involved computation processes. Computational Correlates of Consciousness (CCC) serve as a formal, critically important elemental basis for consciousness, regardless of its nature. The brain can be equalled to a complex computational device that processes formal logic, mathematical functions, and information[10].

The formal basis for the minimal inference mode system is proposed to be the Markov blanket: a network of Markov chains operating on the basis of stochastic processes and capable of being in sensory and active states[11]. The Markov blanket, utilizing Bayesian processes, can correlate internal states with intrinsic and extrinsic information geometry. Standard Markov blanket types can be categorized as Pearl blankets and alternative mathematical model Friston blanket, named after researchers who proposed it[12].

There are more complex informational models of consciousness. When compared with stochastic noise, any computation is possible only with information, the structured data. Informational Correlates of Consciousness (ICC) are the most abstract, consistent qualitative/quantitative correlates[13].

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Integrated Information Theory (IIT) comprises five axioms: intrinsic existence, composition, information, integration, and exclusion. Intrinsic existence is IPP reality, independent of other observers, complemented by extrinsic physical postulate of cause-effect upon itself. Composition is a phenomenological distinction, with the ability to comprehend combinations of elements, including vertical, hierarchical orders. Information itself is dissimilar from non-information and cause-effect rules between phenomenological or conscious states. Integration means non-reducibility of phenomenal or formal states to simpler forms or sub-states. Exclusion postulates spatiotemporal grain, where the cause-effect repertoire structure is principally important, not the more/less or faster/slower relationships. Formal logical relationships between elements or states allow IIT to construct more complex information models. The model is supposed to have experimentally supported prediction power: an integrative state of conscious alertness is reflected by changes in EEG patterns by the level of consciousness, as well as spatiotemporal information density is significantly higher in the active state. IIT is compatible with other formal and correlative models and complementary subjective/objective perceptions of reality. Its formality also allows the possibility of non-biological or artificial consciousness. IIT permits a possibility of more than one consciousness within one system, but not aggregated consciousness of the universal type. There is also option for informationally complex, but unconscious systems, which also apply to consciousness simulators.

Computational Theory of Mind (CTM) by Hilary Putnam was developed further by Fodor[14]. Alternatively, to IIT, Jerry Fodor starts from the postulated elimination of mind-body problems via causative effect. The body part is able to perform computations and work with information. In the light of radical behaviourism, it does not require mental causes, and external stimuli are sufficient for internal reactions. There are also complementary perceptive and functional theories, which help him to construct mental state modular theory[15]. Turing Machines, if conceived as the basis for computational consciousness, have to be embedded into a more complex matrix of subsidiary systems in order to react to the environment.

The immediate problem with this approach is the inability of abduction by Turing Machines and the human ability to do it. Perceptive function is universal and hardwired into the biological correlates. This critical difference between abstract computational models and living consciousness perceptive systems is crucial. Input systems are domain-specific and can be seen as modules in the complex with processing capabilities. The perceptive module's function is, in effect, delivering information and providing its fundamental analysis, even in the case of a voluntary desire to comprehend it as stochastic noise. Mental access to this function is limited. These input systems work as computational units with limited flexibility and significant modularity. At the same time, central processes are isotropic, or, in the world of Fodor, Quinean, and, in this way, computations are sensitive to the whole belief system. In this case, the intelligent system, for example, robotic, has not only updated the whole system according to the perceptive data but also holds a plan of action with possible sub-variants. This also means a necessity for the existence of heuristic capabilities, which is supported by experiments[16].

Global Neuronal Workspace (GNW) theory by Stanislas Dehaene is similar in recognising global space for interaction based on impulses sent by different brain areas[17]. It is an extension and rework of Global Workspace Theory (GWT) by Bernard Baars and Stan Franklin. GWT emphasised the concurrent input of unconsciousness processes rather than computational rigour[18]. Dehaene presents GNW more as a workspace, which is taken by the most active processes. Neuronal areas send cascading impulses and ignite the global workspace if they overcome a certain threshold. On an experimental level, the theory is supported by a number of neurophysiological and behavioural studies. Long-distance cortical communications of residual consciousness in patients recovering from coma support the integral nature of the state.

Steven Pinker also regards the mind as a computational system[19]. He is far from basing it on the Turing Machine and regards objections from Putnam and Fodor as irrelevant. While Fodor places abduction at the centre, associating it with cumulative achievements by the scientific community over millennia, producing the gap between observations and models, Pinker claims that it cannot be compared to common sense. Hence, there is no gap. Moreover, evolutionary psychology can explain certain irrationalities in behaviour despite the scientific achievements of humankind, demonstrating a straight approach to the mind. It is an evolved computer, and this description helps to close the illusory gap between mind and biology, nature and society.

At the same time: “The critical act in formulating computational theories for processes capable of constructing these representations is the discovery of valid constraints on the way the world behaves”[20]. Evolutionary constraints of natural selection have a game-theoretic structure[21] and can be reflected in the evolution of the mind[22].

This poses an expected question about the evolution of the mind: why does abstract thinking develop in the realm of pragmatic necessities? It might be a result of the necessity to think formally, step by step and to hold the whole picture at the same time. On a more formal basis, mental reasoning topology includes

Cause-Effect, Change, Time, Part-Whole, Identity, Intentionality and Representation[23]. Rudimentary mathematical and physical reasoning is blended with narrow tasks. The same can be applied to the numerical abilities of animals[24]. The mental model hypothesis proposes creating conscious understanding from unconscious impulses[25]. Humans and animals share quantity representation system with the ability to comprehend cardinality of sets. Does it mean the inherently mathematical world is just reflected in the mind's abilities?

2.2. Physical correlates

Physical correlates of consciousness are usually described as abiological matter with an ability of fundamental proto-mental functions or physical fundamental mechanisms as the basis of biological correlates of consciousness. However, one predicament has to be resolved before discussing physical correlates, especially quantum mechanisms. The objectivity of the world's perception is far from being explicit. The primary fundamentals of reality, whether objective or blended subjective-objective, have been the topic of intensive debate for centuries. The contemporary argumentation of sides reflects the accession and decline of logical positivism, logical empiricism and the later rise of post-positivism[26]. The dispute between realistic post-positivists and constructivists revolves around fundamental division in the explanation of world comprehension: Do we perceive an objective world or reconstruct it with the help of our internal abilities and constraints? Partially, this debate is echoed in the discussions between classical physics interpretation and Copenhagen interpretation, focusing on concepts of locality and non-locality[27].

While classical deterministic requirements can be removed from Bell's theorem through reformulation, requirements for realism remain in place. There can be a difference between physical and metaphysical realism, but it is not easy to draw a clear division between them. Metaphysical realism can take forms resembling neoplatonism or neopythagoreanism. The atemporal nature of science is rooted in Greek mathematical Egiptianism, which is one-sided[28]. The mathematical universe hypothesis, proposed by Mark Tegmark[29], is based on mathematical realism, where the primary ontological point is the existence of structures that are computable and decidable in the Gödelian way. Tegmark hypothesis is an extension of ideas reflected in the seminal paper "The Unreasonable Effectiveness of Mathematics in the Natural Sciences" by Eugene Wigner[30]. Yet critics find the explanation incomplete. Mathematics underwent historical development and cannot be taken as a static body of axioms and theorems[31].

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Science, based on mathematics, answers comparatively few problems. Possibly, basic logical relationships are more fundamental for mathematics itself.

More detailed criticism is provided by Ivor Grattan-Guiness[32]. Mathematics can be applied to certain problems and developed in a theoretical way, where more than one theory is available, and not as a simple reflection of the outside world. A significant part of “pure” math is practically or potentially applicable. The effectiveness of mathematics is increasing with time, even though some physico-mathematical theories are intentionally reductionist and simplified. It is possible to claim the “reasonableness and effectiveness of the natural sciences in mathematics”, and mathematical effectiveness does not apply to all types of science. Mathematics deals more with quantities and relationships than qualities, as reflected in the natural and mathematical language[33]. While real-world knowledge is categorical and ontological, many less-defined factors remain. Mathematics must usually deal with well-defined situations. Literal acceptance of axioms by mathematics does not mean the necessity to do it in science[34].

There is a bridge between mathematics and informatics. Claude Shannon demonstrated that any information can be distinguished from noise mathematically, and channel limit can be seen as the relationship of signal to noise[35]. At the same time, he demonstrated the existence of a physical limit for any information channel. Certain inescapable physical limits exist for any information processes, including mental[36]. And it has to be squarely based on physical processes. There are claims to recognize information itself as a physical phenomenon[37]. The physical basis of consciousness is demonstrated with electromagnetic and thermodynamic calculations and shows a relationship with basic physical constants[38].

Physical basis is also claimed in the quantum phenomenal basis of consciousness. Often, it is related to the assumed failure of classical physics and classical neurobiology to describe consciousness phenomena[39]. The most known mechanism is described by Penrouse-Hameroff theory OrchOr, orchestrated objective reduction caused by the collapse of the wave function in the neuronal microtubules[40]. The alternative theoretical proposal mentions the Grotthuss mechanism for protons[41]. In this way, there is much less noise in the brain tissue environment, which is not really suitable for clean quantum effects, as described by Penrouse and Hameroff. The isolation of the body with this type of mind from the environment as a physically independent system is necessary for the proper functioning of the fundamental substrate: quantum layers of consciousness[42]. And the most radical version of

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physical correlates is presented by micropsychism and panspychism, when primary consciousness is attributed to elementary particles[43].

2.3. Biological correlates

The underlying physical basis is undeniable in the evaluation of consciousness nature. Nonetheless, there is still a wide explanatory hiatus between quantum mechanics or any other physical events and clearly demonstrable correlation with consciousness or mental processes. There is necessary to fill the gap between explanatory demonstrable neuro-biological correlates and proposed quantum or another physical process. Three possible higher-level mechanisms are kinetic, genetic and neurochemical[44].

Proton tunnelling or isomerisation can influence the 3D structure of protein or DNA molecules, teleologically or casually responsible for correlates of consciousness phenomena. Hormones or enzymes can be engaged in certain reactions or stimulate their cascades, resulting in phenomenal changes. Synaptic or cellular activity involves biochemical chain reactions in the case of Hebbian learning. There are also broader views on the biological correlates: neurobiological, -chemical, or even neurocomputational, -topological, or -organizational[45].

An analogous type of data processing in neurons is supposed to be different from the digital non-biologic data flow. But is it a specific feature of data processing in non-neuronal cells? And can they produce minimal consciousness phenomena on that basis? Andrew Adamatzky is a strong proponent of biomolecular computing abilities, demonstrating the ability for effective data processing in slime mould and fungal[46]. Protenoid-based neuromorphic structures or micro-sphere ensembles mimic neural signalling and can serve as minimal models for basic data exchange processes[47].

Before creating networks capable of interactions, cells were not only organisms able to extract abiotic energy from the environment but also existed as minimal autonomic, self-replicative subjective(inside)/objective(outside) systems with antistochastic excitable membranes[48]. Those cellular structures are capable of proto-sentience and are the unitary basis for any potentially sentient, cognitive and conscious abilities. Amoeba-like and ciliated types of cells created symbiotic eukaryotic cells and gave start to lines for similar-types cells in multicellular organisms, fungi, plants and animals. This creates potential, for example, of plant sentience[49]. Sentience means an organism's ability to experience felt states, including external or internal sensory perceptions. There are similarities between animals' nervous systems and plants' non-neural vascular systems. Action potentials in plants resemble similar

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potentials in animal cells. Plants demonstrate minimal observable cognition, decision-making, learning, anticipatory behaviour and very basic numerical abilities. Complex root systems deploy coordinated growing for resource optimization and competition[50].

Nevertheless, it is argued that bound conscious experience is first found on the level of cell and not cell ensemble[51]. This conscious experience may differ from potential artificial, non-biological or non-cellular consciousness[52].

Following this differentiation, consciousness or at least sentience is related to active problem-solving in living organisms. Consciousness may emerge from simple hedonic evaluations in sentient beings[2]. After evaluative capacities gained discriminatory and representational richness, the complexity of sensory experience could influence evolutionary effective subjective states. Gastropodes, for example, are slower than many robots. Do they possess elements of consciousness, developed sentience and cognition? Daniel Dennett stated: "...if cephalopods moved in the clunky way of most existing robots, then inspite of the manifest purposiveness of their motions, it would be quite comfortable to suppose that they were some kind of zombies, marine robots with eight or ten appendages"[53].

There is a necessity to differentiate between sentient adaptive behaviour and statistical mechanisms of natural selection when only a certain part of the population survives, regardless of its sentient power, thanks to certain existing variants capable of living in new conditions. In this case, all less adapted organisms are simply cut off from temporal continuation unless they are using active adaptation, including sentience[54].

We can mark living organisms with the ability for adaptation, where elements of consciousness mean higher resilience if they are epiphenomenal to simple recombination of characteristics. The last feature can be seen in the non-living world. The difference is the purposeful, teleonomic character of life. The dynamic kinetic stability of life is different from the thermodynamic stability of the inanimate world[55].

Despite cells being a basis for any tissue, including neural, the growing consensus among cognitive scientists is representing cognition in wider 4E concepts: embodied, embedded, extended, and enacted[56]. Cells can be the basic structure for fundamental sentient and cognitive phenomena but lack a certain degree of complexity. It can be intelligent but with purely nonconscious processes[57]. The focus has to be on neural structures, especially in animals with developed neural systems.

2.4. Neural correlates

Nervous tissue is most specialized in the data management and active control of multicellular organisms. The simplest diffusive neural system is seen in phylum Cnidaria[58]. More organized neural systems are seen in most other multicellular phylae, with branching neural ganglia, cords or cephalisation, most significant in mammals.

Correlates of consciousness can be seen as neuro-anatomic structures of centralized neural systems, neuro-physiologically active during perceptive and analytical task-solving behaviour[59]. Their activity can be registered observationally as behaviour or instrumentally as a certain level of electromagnetic or neurochemical dynamic processes. Modern methods of activity registration, such as fMRI, PET, AI-empowered EEG, TMS, optogenetics, and metabolite biomarkers analysis of neuronal activity, allow a high level of precision[60]. Correlative markers are obtained through observation and questionnaires.

2.4.1. Neuronal basis

The cellular basis of neural tissue consists of two main types of cells: neurons and supportive glial cells. Neurons are naturally developed from ectodermal embryonic stem cells (ESCs)[61]. There is a specific subtype of neural stem cells that is able to differentiate into fully developed neurons[62], capable of creating effective electromagnetic membrane potential, producing neuromediators, neuromodulators and certain types of hormones. Neurons are subdivided into types in accordance with morphology, physiology and molecular signature[63]. A high level of neuronal specialization is closely connected with function in certain neural or organismic locations. If the cellular basis for sentience is possible, the neuronal cellular basis is even more probable. If there is a specific place for the integration of event experience, it can occur only in neurons[64].

If each of several billion brain neurons is capable of connecting to ten thousand other neurons, it might be seen as excessive for memory or simple functionality. Possibly, they operate on the level of dendritic resonance to produce hologram-type phenomena. There are no well-defined brain fields or specific groups singularly responsible for consciousness – the possible case of a single-neuron basis for it.

However, neural tissue cannot be seen as only neuronal. The close cooperation with different types of glial cells is important[65]. Neuronal functions are result of active neuronal-glial interaction, and focus can be shifted from purely neuronal structures to interactive neuronal-glial complexes in order to

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understand higher level of brain functions. It might be also additional existing force behind neuroplasticity[66].

2.4.2. Fundamental structures and functions

Neuronal tissues are grouping specialized neurons together. There are parts of the brain highly correlated with consciousness phenomena. "A neural correlate of a phenomenal family S is a neural system N such that the state of N directly correlates with the subject's phenomenal property in S"[67]. Any significant anatomic or functional damage in these areas leads to the partial or complete loss of consciousness. The cerebral cortex produces synchronized 40-hertz oscillations, which can be connected not only to temporal visual and audial stimuli recognition but also to underlying integrative cognition[68][69]. Intralaminar thalamic nuclei are responsible for the volition and self-awareness[70]. Another hypothesis of primary conscious awareness is based on synchronized activity in dendrites of dorsal thalamic nuclei neurons[71]. A wider role of thalamic connectivity is proposed in the role of re-entrant loops of thalamocortical systems[72]. Gamma-band 40-hertz activity in thalamocortical systems[73] and extended reticular-thalamic activation systems, especially nucleus reticularis thalami (nRt), are other proposed thalamic NCCs[74].

Several cortical NCCs are proposed. The ventral visual stream links visual cortex V1 to inferior regions of occipito-temporal cortex. Together with top-down information from visual and semantic memory it provides perceptual representations, connected to conscious states[75]. Cortical N-methyl-d-aspartate (NMDA) synapses play a role in instantiated consciousness. Large-scale ensembles produce Higher-Order Representation (HOR)[76].

The internal visual representation and active states are related to neurons in the inferior temporal cortex and visual areas of the cortex of the superior temporal sulcus[77]. Neurons in extrastriate visual cortex V1 projection to prefrontal cortex areas are suggested as important correlates[78]. Asynchronicity and plurality of visual consciousness are believed to play an important role[79]. In wider terms, phenomenal consciousness is supposed to be associated with the activity of multiple synchronized fronto-parietal[80] and temporo-parietal-occipital networks[81]. Formally, the brain of any animal is seen as a symbol-processing organ[82].

2.4.3. Functional architecture

Neural correlate of consciousness is a specific pattern of brain anatomy and related activity that correlates with particular conscious experiences. It is shown that hallucinatory experience correlates with responsible perception area, visual, audial or olfactory[82]. Thalamo-cortical and intra-cortical networks are supposed to be the anatomo-physiological basis of consciousness. Anatomic integrity and functional efficiency of certain network parts can be correlated to consciousness states and phenomena. Still, there is a necessity to clarify the general picture. Integration of functional potential has to be organized on a certain basis with definite rules. For example, the visual consciousness framework is described by Crick and Koch[59].

Baars and Franklin proposed Global Workspace Theory (GWT): access between brain functions that are otherwise separate. The brain is viewed as a massively parallel set of specialized processors which can access frontoparietal and medial temporal regions[83]. Neuronal group selection theory and neural Darwinism are quite similar in the description of concurring neurophysiological processes leading to the phenomenal conscious states[84]. Neuromapping includes the creation of neural fields with similar functions, sometimes with borders of one or two cells wide. Neuroplasticity creates a “salt and pepper” picture of more diffused fields, nevertheless uniting neurons on a functional basis. Higher-level neural integration of functionally segregated maps occurs on the basis of Darwinian-type concurrence.

There is still a gap in the probability of a connection between unconscious processes and phenomenal states of consciousness. As stated by Joseph LeDoux: “. I am not concerned with whether electrons, rocks, or computers are conscious, nor even with whether, and if so how, bees, birds, or cats are conscious”[85].

How unconscious human states become conscious is a question. The proposed schema includes visual and memory/conceptual inputs into the prefrontal cortex. The higher-order cognitive structure of the prefrontal cortex actively re-represents sensory cortex information. Semantic memory stores facts, while episodic memory registers facts and concepts in the context of personal experience. Direct or indirect memory-informed sensory representation can be a mechanism behind consciousness phenomena.

Multiple Drafts Model by Daniel Dennett describes similar remembered perceptual events and concurrence of its perception for the first conscious place. It is not a film of successive perceptual elements demonstrated in Cartesian Theatre to certain virtual homunculus[86]. Higher-order theories (HOT) are more focused on re-representation. Multiple consciousnesses can concur with each other in the first place. However, it is difficult to register the HOT state itself[87]. HOT differs from the Global

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Workspace Theory (GWT) of Baars and Franklin, Global Neuronal Workspace Theory (GNWT) by Dehaene and Changeux and MDM by Dennett. First-order representation in these theories is recognized in HOT as insufficient. A person can be conscious only when he recognises it[88].

Hubert Dreyfus sees the problem here: many tasks are done unconsciously, and the better the task is performed, the more unconscious the performance[89]. At the same time, Damasio and Damasio see the primary role of external stimuli perception analysis, where feelings are the source of consciousness[90].

2.5. Behavioral correlates

Unconscious cognitive states can be a problem for the consciousness description while registering it in accordance with behavioural correlates. Consciousness can be registered based on observation of behaviour. The activity itself is insufficient for the conscious state, especially when we speak about levels of consciousness and self-awareness[91]. A common scale for the behavioural registration of consciousness exists. There are clearly distinguished levels for monkey, ant, tree, thermostat or mineral[92].

While we can speak about levels of active consciousness for organisms on different evolutionary scales or depending on their age, children also have levels of active behaviour or active perceptive state. Local perceptive states, external or internal, have to be different from global conscious states[93]. Global state descriptions are used in medical practice. Glasgow Coma Scale (GCS) and other scales are used. Vegetative state, minimally conscious state or emerging minimal conscious state, confusion and normal awareness state are fundamental and have to be seen differently from sleep, hypocretin-deficiency narcolepsy, somnambulism, general anaesthetic-induced conditions, medication, illness or meditation-induced altered consciousness states. Levels of consciousness can be measured directly in accordance with the activity of brain regions[94].

Intentional behavioural acts are correlated with reported mental states and neurophysiological activity to create formally interdependent correlates[95]. There is probably more than a simple correlation between behavioural and neural mechanisms of consciousness[96]. Studies of crows and macaques demonstrated possible positive and negative interactions between behavioural and neural signs. Specific conditioned behaviour can be a sign of consciousness. The striking similarity in behaviour between humans and rhesus macaques is seen in conscious and unconscious spatial cueing tasks.

There are still discrepancies in the neural correlative substrate and behaviour[13]. The cerebellum has more neurons than the cortex and quite a complex and dense architecture, but it is not directly associated with consciousness. There are also many instances when patients with few remaining islands of functioning cortex, preterm infants, non-mammalian species, and machines outperform people in recognition, driving, or difficult tasks. Table 1 summarizes the different types of correlates of consciousness.

Category	Description	Examples and Key Insights
Informational	Information processing and computation contribute to consciousness	Integrated Information Theory (IIT); Computational Theory of Mind (CTM); Global Neuronal Workspace (GNW)
Physical Correlate	Fundamental physical properties and processes potentially associated with conscious experiences	Penrouse-Hameroff theory OrchOr; Grotthuss mechanism; Emergent properties of complex systems; Micropsychism and Panspychism
Biological Correlates	Biological structures and mechanisms of consciousness	Cellular proto-sentience; Plant sentience, vascular system of higher plants; Neuromorphic structures
Neural Correlate	Specific neural mechanisms and brain regions involved in producing conscious awareness and processes	Activity in the prefrontal cortex, thalamus, and posterior cortex, fMRI-registered; N-methyl-d-aspartate (NMDA) synapses; EEG signatures, e.g. gamma-band oscillations linked to awareness; Synchronized fronto-parietal and parietal-temporal-occipital networks
Behavioral Correlates	Relates observable behaviours and responses to conscious states and processes	Intentional behavioural acts Reaction times and verbal reports in cognitive experiments

Table 1. Consciousness correlates and their main properties

3. Embodiment and extension

The physical information channel limit implies the existence of a physical basis for data processing. Consciousness processes require significant data flow. Physical channel characteristics can be influenced not only by the bandwidth but also by the underlying specificity itself. Autopoietic cellular consciousness described above raises the question about the number of consciousnesses and distributed multiple consciousness possibilities if no overall consciousness agent takes control of events. In more basic terms, neuronal data processing is impossible without a supportive system: glial cells, blood vessels, immune system, cardiovascular system, respiratory system, digestive system, etc. In the case of consciousness, it requires embodiment in a whole sense[97].

Consciousness 'emergence' in complex systems requires two-way or type of reciprocal correspondence between neural events and conscious activity. An extended vision suggests that the processes crucial for consciousness include brain–body–world relationships rather than being brain-bound neural events. Interoceptive and exteroceptive bodily processes produce feelings/experiences that are subjective in relation to their content. Processing of the data results in prospective projections and predictions of possible events. Consciousness appears as a necessity to support homeostasis with a higher level of internal and external information[98].

The data stream from the environment and from inside the perception self-controlling system is similar to the stream of consciousness by William James. Memory function adds an additional temporal dimension, which results in "extension". "Extended consciousness" occurs when objects which are related to the potentially conscious organism are not only "here and now" but in a broader context encompassing the organism's memorized past and its anticipated, projected future[99].

The thalamocortical relationship between the thalamic somatosensory nuclei and the thalamocortical relationship possibly results in the production of second-order maps and proto-self. The first function includes temporal connection and is related to intralaminar nuclei, while the second is related to the hypothalamic nuclei. Diachronic functions are recognized as another important extension function[100].

The extension of the mind is recognized by many researchers, but some of them argue that the bandwidth and speed are not sufficient for the extended consciousness[101]. The brain-in-a-vat thought experiment implies that it is theoretically possible to have a brain separated from the environment and

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obtain only certain types of inputs. What does it say about the brain functions and about the environment? Daniel Dennett claims that the normal brain is a sort of the brain in a vat[102].

The opposing position claims that the embodied brain meets the environment anyway, so the brain-in-a-vat is also embodied. Brain activity is endogenous and spontaneous; this activity requires resources and regulatory processes from the body. Brain activity itself plays a crucial role in the regulation processes of the body. These processes require the maintenance of sensorimotor interaction with the world, presented outside of the body or as internal processes. Connection with the outside world necessitates protective geometry and active inference[103].

Wide embodiment may blur the border between mind, body and environment. There is another spatio-temporal extension of the mind – social. In some respect, this distributed consciousness is similar to swarming intelligence[104]. There is clear communication between humans, synchronic and diachronic. Language, society, and ways of saving and transmitting information influence the brain in direct and indirect ways. Despite the personal experience of self and the environment, there are many modulatory ways to consider when we speak about consciousness. There is a place for the concept of collective consciousness or even collective subject consciousness. Embodiment and extension have social dimensions, such as synchronous and historical ones. More exotic hypotheses about planetary consciousness are certainly more metaphysically conceptual than truly scientific. They probably show the upper limits of our understanding of consciousness.

4. Discussion and conclusion

Emerging consciousness poses several questions that are not readily available to them. The first is what is the basis of any consciousness, regardless of its embodiment. We can speak about mathematically readable properties of reality. To be more precise, we can apply fundamental physical limitations for any data channel and qualitative physical character to any information, with full acceptance of the universal abstract nature of its semantic qualities. Micropsychism and panpsychism can explain the universal ability of the physical world to obtain consciousness, but they give little substrate to comprehend this idea in depth. We can correlate minimal consciousness functions to quantum physical processes, but we do not have enough evidence substrate to support these ideas. Naturally, observable consciousness emerged only in the highest mammals and, in full, only in humans. We have to couple the ascending emerging search for minimal consciousness with the process, going in the opposite direction: descending from the full-fledged active consciousness of alert humans to lesser biological forms. We see elements of cognition, self-awareness, and sentience in lesser brain-possessing creatures or organisms with elements of centralization or cephalization, such as in invertebrates. Attempts are made to contribute minimal consciousness abilities to the living cells, where the internal part and external environment are divided by sensitive semipermeable membranes. The internal part gives the primary basis for the inner self, the outside environment is the source of external data, and the membrane is a minimal sensory organelle. Despite the impressive model of sentience, the singular cell is still supposed to be too simplistic for an explanation of many other consciousness phenomena. Even organismic levels of fungi, plants and some other lowest multicellular life forms without neurons, when certainly processing and exchanging data, are not supposed to be conscious in certain ways. Single neurons are more capable of obtaining, transforming and transmitting data, but single-cell consciousness for neurons is just a hypothesis which requires a certain level of consensus about its nature and features. Nervous tissues, more specialized for sensory sensitivity and regulatory data processing, form the first correlate of consciousness, which still requires levels of complexity and architectural structure, capable of producing neuro-physiological correlates of consciousness phenomena. We can find minimal correlates in insects, but higher forms of life demonstrate steps in developing complex structures connected to sensory perception, motoric outcome and higher regulatory functions. In the developed brain, thalamic nuclei possess alertness, self-awareness, secondary mapping, and temporal synthesis. Together with developed memory structures, reticular formation, visual pathways and cortical fields, they form complex neuronal networks whose activity can be the source of phenomenal consciousness. There are critically important parts of the cortex, such as the prefrontal area, lower temporoparietal area and some others, which can be responsible for the first-order consciousness registration of highest-order meta-conscious structures, able to synthesize underlying consciousness experiences into a full picture. The inability of consciousness to subjectively self-percept all these complex phenomena is explainable in terms of the lack of full power for this level of meta-consciousness. At the same time, with known neuronal correlates of consciousness, it is directly or indirectly open to scientific assessment with observability, sophisticated instrumental access, and reliable metrics. Behavioural correlates of consciousness are important in practical medicine and theoretical research while self-reporting about phenomenal states can be an additional tool when combined with other techniques. Thus, consciousness is open for detailed research despite the claims about explanatory gaps and difficulties in semantically connecting phenomenal qualia with the substrate. We can claim emerging properties of consciousness on the evolutionary scale. The question about the lowest possible substrate for consciousness is still open, and it depends on the research as well as on ontologic consensus regarding consciousness.

Embodiment has a significant connection to autopoietic properties, which raises questions about the possibility of creating Artificial Consciousness. Extended mind also can be seen as an extreme variant of embodiment. However, it includes non-neuronal organs and tissues, as well as non-living external objects in the environment, as a source of continuous information flow. There is a necessity to separate between NCC and external sensory stimulation when discussing consciousness. There are also questions about possibilities of consciousness on the collective level, similar to swarming intelligence. The network of organisms with NCC cannot be denied functional unity and can influence the development and functioning of separate nervous systems. There is an aspect of diachronic connection, which is most prominent in the continuous civilization. More exotic representations of the collective extended mind, such as Gaia or Noosphere, can be seen as not scientifically approachable but instrumentally useful horizons of our understanding.

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