Neuroecology: Modeling Neural Systems and Environments, from the Quantum to the Classical Level and the Question of Consciousness

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Abstract: Perception shifts the surroundings of organism with nervous systems deeply inside the brain, creating an experiential environment from the signatures of physical surroundings. Setting out from these primitives for subjective experience cognitive abilities emerge that deliver a physical description of the self/world boundary as an end-product and allow us to develop a functional relationship with our environment. This view does not give physicality but subjective experience a primacy for the description of our world. However, by a kind of cognitive recursion we can try to physically describe the tight relation between the architecture of the experiencing agent with the phenomenon of conscious experience. In this article I present a sequence of testable relationships between brain dynamics at different scales and conscious perception. I argue that the most convincing physical connection between the information based structure of the brain and the primitives of experience resides in specific electron de-localizations at the quantum scale within ion conducting membrane proteins of electrically excitable cell membranes.

Keywords: Environment-system partitions, Neuro-ecology, Neural correlates of consciousness, Cognition, Neural field models, Neural mass models, Ion channels, Electron-de-localizations, Neural membranes, Quantum-physics, Quantum-biology.

INTRODUCTION

In its canonical version, *i.e*. according to standard physical rules, neuroscience deals with the matching of the brains signalling structure to the variation of physical properties of the world around us. This relation builds on statistical principles behind information contents and transmission and it is solely embedded on physical grounds and physically derived neural strategies (see for example W. Bialek's detailed tutorial outline in [1]). Along this view the intention is to study relations between matter- based systems (the brains molecules and their interactions) and matter-based environments (the physical signals of our surroundings). Due to enormous technological advances studies of this '*type I relation*', as I would like to call it, have made an immense progress reaching into the technical emulation of brain processes, AI and brain-machine interfaces [2]. There is, however, a second type of relation, a much more radical one, with an ancient history and a basically unresolved duality: The relation of the matter-based system composing a brain with the phenomenon of subjectivity, the 'experience of awareness', a highly non-physical, but naturally occurring and hardly deniable property of the agent hosting this brain. This '*type II relation*' between physics and the (natural) occurrence of a mental state, reflects a connection between a state of matter in our brain and how it 'feels' for an observing agent to have this state of matter in his/her brain, a highly intriguing situation reaching far beyond traditional physicalism. I have discussed a possible and testable causal structure of type I and type II relations recently in [3]. Despite the domination of traditional neuralism focusing on the interaction of matter, the study of type II relations has received an increasing attention from the various disciplines of neuroscience more recently *e.g*. [4, 5], and this has led to an impressive list of publications within the studies of consciousness and cognition (*e.g*. the Tucson series on Consciousness studies).

The brain enables and controls perceptive processes. There is a helpful taxonomy behind the variation of these perceptive abilities that ranges from the unconscious and subliminal to preconscious and fully conscious perceptions [6]. And these distinctions map well into relations between systems and environments as suggested here. I think that some of the enduring conflicts to 'explain' subjectivity and conscious experience in brain science may be due to the fact that no or little distinction between type I and type II relations is made. For example, the *un*conscious 'autopilot' in our brain [7] may eventually become completely explained within concepts merely based on type I relations. In terms of explanations type I relations offer an 'easy problem' in the sense of Chalmers [8]. Within type II relations however, the perceived quality of an environment becomes inseparable from the

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perceiving subject (the system). From a modelling perspective, this situation leads to a much more complex system partition, more similar to a ‘Von Neumann tripartite system’ interpretation in quantum mechanics (QM) [9]. In Von Neumann’s view one of the partners in a QM system interaction is the human observer. There are very good reasons why the pioneers of quantum physical conceptions and ontologies such as Von Neumann [9], Schrödinger [10], Wigner [11], Everett [12], Bohm [13] and others were stretching their view far beyond reductive materialistic positions, involving type II relations in the problem of measurement and observations. Today there is a theoretical development that tries to revitalize and unify these ideas within a ‘quantum-like’ interpretation of cognition and perception [14-16].

Environments interacting with neural systems are at the centre of attention in Neuroecology. In the present assay I investigate the question of environment-system interactions in the view of the above defined relations I and II. System partitions that may help to form a basis for a viable theory of adaptive behaviours and involve cognition and (conscious) perception of an experiencing agent will be proposed. Such an ambitious intention naturally entails problems. Conceptions, methods and evidence for these considerations have arisen from fields as diverse as neuro-philosophy and biology, ecology and behavioural sciences, comparative cognition, physics, theoretical and quantum mechanics, coding and information theory. This makes their combined demonstration difficult, if not impossible. The suggested evidence quite often only applies to a particular discipline and appears to be unrelated in the view of a unified approach. In addition, plausible explanations of how experience relates to environments may finally require an exhaustive description at the atomic and molecular level of both, the system and its environment, a task that simply cannot be done. The good news is however, that the derived dynamical principles seem to apply across many scales, ranging from the microscopic to the macroscopic domain. The claim is that the dynamics behind relations I and II has some scale invariant property that allows us to reconcile dimensional differences to a great extent.

Here I will first set out to define and explain some formal background and introduce the way we can present the relational structure between dynamic variables in brain science and relate their ’meaning’ to an environmental context. In what follows I develop a basic conjecture for the brain-environment context of an observing and experiencing agent. As the signalling characteristic (relation I) in nervous systems is given by the cooperative dynamics of ion channels, the focus will be laid on the emergent properties of molecular transitions within channel proteins. There we can identify a *Prigogine-Nicolis type* of dynamic self-assembly [17] at the atomic scale that offers a candidate solution for relation II [3]. In our previous work we have provided evidence that transitions at the quantum scale within ion channel filter regions may have functional significance in shaping and controlling the emerging macroscopic transmembrane signals of excitable membranes [18-20]. Here I extend this view involving the electronic surroundings of conducting ions within membrane proteins and finally propose the underlying electronic conformational change as a core transition in the sense of relation II. Finally I summarize evidence and testability for this conjecture.

ENVIRONMENT -SYSTEM PARTITIONS: GENERAL ASPECTS

System partitions, such as the traditional distinction between an environment and a brain (a surrounding and a system) follow from the Cartesian view of local physical properties. There objects can be delineated, defined, are separate and are outside of each other. This sets the frame for ordinary physical conceptions from classical to quantum physics and it is also largely the result of our naïve perception of the world ‘around us’. In this paper I will however dissolve the system view gradually, inspired by the Bohmian interpretation of quantum- physics [13], ‘biogenic’ information concepts [21], holonomic brain science [22] and complex dynamics [17]. I intend to translate this all into a somehow new view in Neuroecology, where system partitions separating the organism from its environment are less important. Transition dynamics, changes, interactions between systems play the essential role and give rise to experiential properties. Properties are not static attributes of systems but are permanently gained, lost and regained.

Initially we review the canonical systems view: Figure **1** demonstrates two different system partitions as seen from a conventional perspective. The arrows in the figure represent an exchange of information between systems. We use the arrows for very general, uni- or bi-directional interaction terms that symbolize causal relations among system partitions, thereby changing the systems physically. If for example a system A changes a system B we write $\{A \rightarrow B\}$, with vertices denoting the systems and edges the transients. Initially this notation is just a mathematical object, but its interpretation leads to a broad range of algebraic descriptions in physics, describing trajectories of systems in space-time and system interactions in quantum-physics. It is expandable to structural causal modelling (SCM) as developed by Pearl and Scheines [23,24] and described in short previously [3]. In this later situation the vertices would represent (causally-) related variables rather than system partitions.

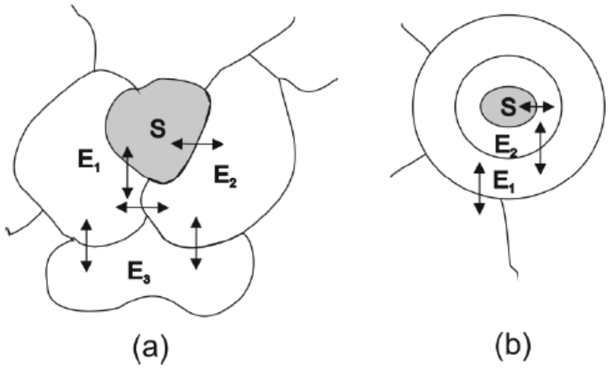

Figure 1: System partitions and their possible interactions between environments (E) and a system (S) under study. In (**a**) a general quantum physical partition is sketched, in (**b**) a partition that is suggested to apply for a resolvable quantum to classical transition as well as for a description of brain processes of an observing agent is shown (compare with figure 2(a)).

Also apparent from Figure **1** are two different types of system partitions. In (a) a partition is shown that is broad enough to cover a general physical interaction situation that may for example underlay a quantum to classical transition. In physics the arrows would represent interaction-Hamiltonians between different (sub-) systems and the delineation of these systems very much depends on the interaction strength with their neighbours. As in physics the universe is generally considered as a huge collection of open and interacting quantum systems the most basic partition between systems and environments sets out from the quantum scale. Let's assume the partition shown in Figure **1**(**a**) is a separation of idealized quantum-systems, a system and its interacting environments that can evolve for a certain but short time in isolation prior to interactions. Classicality and most, but not all, macroscopic partitions in this view appear as emergent properties of quantum observables and systems. However, the understanding of classical emergence seems to be an enduring problem with many aspects still unresolved [25]. The reason is that quantum systems are assumed to evolve into a (linear) combination of arbitrary states ('coherence'), a superposition of possibilities that are never seen to coexist in our 'real world'. If one wants to observe (measure) these states we have to allow for an interaction of one correlated quantum system (say, S in Figure **1**) with a measurement environment or apparatus (say E_1 in Figure **1**) that also constitutes a quantum system with correlated states. Upon interaction the compound system (SE_1) bears non-separable between system correlations, no independencies that would allow us to make predictions about alternatives upon observing a certain outcome of a measurement. This delicate situation was first recognized by von Neumann [9].

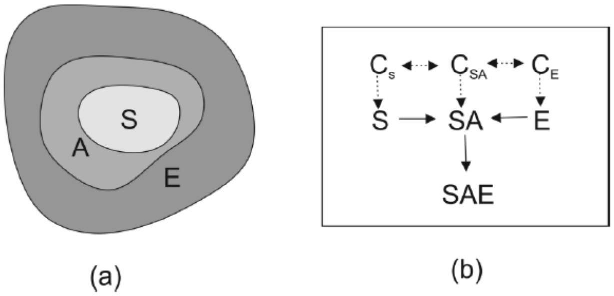

Figure 2: A system partition demonstrating a 'von Neumann tripartite chain' of a system (S), an apparatus or measurement device (A) and an environment (E). The concentric alignment in (**a**) leads to interactions that are modelled in (**b**) by a 'causal graph' of a structural equation model (SEM) that describes the relation of cause and effect by directed acyclic graphs (DAGs, as described in the main text, [23, 24]). The emerging von Neumann chain from the composed system SA is SAE. Correlations (C) are indicated by dashed arrows and causal relations by solid arrows between vertices denoting the systems. The meaning of the causal graph shown in (**b**) is discussed in the main text.

Von Neumann's major contribution to resolve the problem behind a quantum-classical transition was to show how the quantum correlations of composite states (*e.g*. a system and a measurement device, SA in Figure **2**(**b**)) can be transformed into a set of measureable numbers with only classical correlations (the SAE chain in Figure **2**). A deeper discussion of this process is offered by Zurek [25] and a demonstrative calculation employing density-matrix transformations by Tegmark [26]. In von Neumann's view this reduction of a highly correlated state into a 'reduced density matrix' with only classical probabilities is due to a *mental process* performed by the brain of an observing agent. This view opposes the orthodox physicalists interpretation that suggests that a reduction of a quantum state (*e.g*. by von Neumann's 'process 1') is independent of any observing agent, but emerges through the 'selective dynamics' of the engaged system-environment partitions and the brain works solely on classical principles as Zurek and Tegmark suggest. However, I think that physicalism and classical neuralisms are a prejudice of our time as K. Gödel has correctly put it [27] and are now increasingly disapproved by the development of cognitive biology. In line with a long list of high calibre contributions ranging from philosophy to physics such as those from Whitehead, von Neumann, Bohm, Wigner, Stapp and Penrose and many others I advocate the view that 'experience' must be at the centre of our attention. Experience is real and has a primacy for the description of our world and the relation of our brain processes to the perceived qualities around us. The physical aspects of experience (*i.e*. the results of our experience based mental efforts to describe nature) involve a quantum to classical transition and this occurs in the organization of an observing and experiencing subject. In what follows I will try to substantiate this view by reinterpreting the signalling and information based structure of our brain within the concept of 'meaning' and conscious experience.

NEURAL ENVIRONMENTS AT DIFFERENT SCALES

Type I Relations: Structure

Perception shifts environments deeply inside the brain. Remarkably this situation also impressed one of the founders of quantum-physics, Erwin Schrödinger [10] and I will come back to this view for a deeper reason. From the outlines shown in Figure **1b** a concentric organization of environments and systems is apparent that symbolizes some important aspects behind the functional wiring pattern of nerve cells (the 'effective connectome') in the brain. If we consider a single cell activity as the system variable ('S' in Figure **1b**), the graph implies that this property results from a mapping of membrane currents (J) from different environment E_i over a 'time-history' $t < t_0$ into the presence of absence of a spike at time t_0 , *i.e*. $J(t< t_0) \rightarrow S(t_0)$. This is the classical neural coding principle in the view of 'type I relations' as defined above, shaped into a simple and straight forward relation. It also implies that neural systems are 'embedded' into a certain (neural-) environment that determines their activity and 'embeddedness' is the decisive determinant [28]. The environment for brain cells is made of other brain cells and downstream and upstream information exchange between these cells are hierarchically organized, largely separating late stage cells along increasing synaptic distances from the transducing sensory 'surrounding' of an organism.

The question arises whether neural systems and environments are characterized by a specific topology along metrically scaled organizations and to what extent this organization determines the dynamics and the emerging functional character such as cognition and behaviour. Recent progress in neural network simulations [28, 29], together with advances in combined morphological and electro-physiological profiling [30, 31] has substantially improved our understanding in this direction. One of the major conclusions drawn from these studies is that we have to go far beyond statistical correlations in order to understand the structure-function relations in the brain. In Karl Friston's view the major challenge is to explain why one fixed structural organization ('structural and effective embeddedness') can give rise to a huge manifold of functional diversity. Knowing that 'embeddedness' of a neuron within its environment is a key determinant of its function this question becomes even more pressing.

There is a certain topology behind the wiring pattern among nerve cells. However, we do not understand the 'meaning' of this connectivity. From a number of recent comparative studies among vertebrates one finds striking parallels among mammalian and avian forebrains in specific volumes and connectivity patterns. Despite a long lasting evolutionary divergence, these convergent structures seem to correlate with specific cognitive, social and migratory behaviours across very diverse animal species and brain architectures [see for example 32, 33, 34]. What we can learn from the results of these studies might offer an important indication for the connection of type I and type II relations as defined above, for a connection between the signalling structure of the brain and the 'meaning' of these signals from the view of phenomenal consciousness and subjectivity. First, higher cognitive functions and emotions seem to be based on a single und unique principle behind the wiring pattern of brain cells [32, 35]. Further, results from correlations of brain size with cognitive abilities [36,37,38] show that these functions are accompanied by an increasing recruitment of nerve cells into functional 'modules'. The addition of more nerve cells increasing the relative brain volume is associated with an increase in functional 'modularity', the cortical sensory segregation volume [39, 40].

Bridging to Type II Relations: Dynamics Along Multiscale Organizations

First we have to ask the question how the neural connectome produces this enormous range of phenomenal experience behind cognitive, emotional and volitional functions? This question is reminiscent of Karl Friston's 'one to many problem' in brain science

[29]. Intuitively, a given pattern can only give rise to this large variety of functions through its dynamical properties and these properties manifest themselves at different scales of spatial and temporal resolutions. See Figure **3** for a demonstrative (metaphoric) example from the interaction of waves.

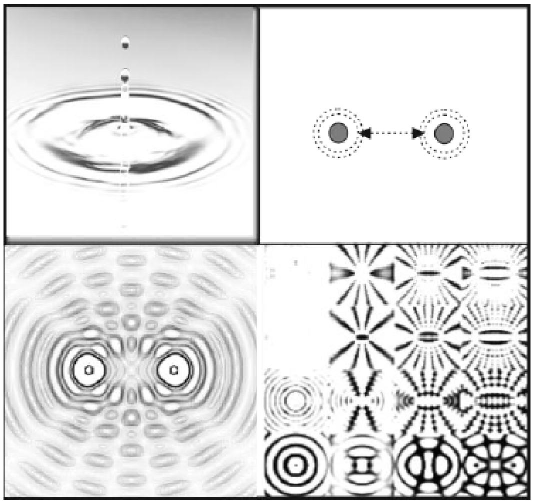

Figure 3: A single-point perturbation produces the spread of a spherical wave on the surface of a medium (*e.g.* water, top left). If two point sources interact (top right) we observe a pattern of phase-differences, an interference pattern spreading out in space-time (bottom left). Changes in just two properties of this perturbation, wave-length and interaction-distance are sufficient to produce a large variety of different interferences (bottom right). This is a demonstration of a 'one to many' relation between structure and function, how dynamics created from two point sources can give rise to a large collection of space-time effects.

If dynamics is the key to understand brain function, we have to look into the organization and critical features behind these processes in the brain. Dynamics is defined by a change of states of some physical entity within space and time. It leads to more or less stable transients, ranging from rather permanent (equilibrated) states as found in non-living matters, to only transiently stable states that are more typical for living systems. However, in the present context I want to add a different and frequently overseen aspect on dynamics that involves a system-environment partition as discussed in the section above.

There are at least two main signatures that determine the realization of a dynamical change: First, local interactions between the smallest constituents of the changing system and second, energy gradients that constrain these changes. The cooperation of these two aspects cause transient assemblies ('self-assemblies') of their constituents that are typical for biological structures at various scales ranging from atomic configurations in molecules to cells and tissues (see Prigogine's seminal work on complexity [41]). Biological dynamics is dissipative at functional scales and requires the permanent supply of energy leading to 'dynamic self-assembly' as for example demonstrated by artificial systems more recently [42]. A system-environment partition would set out from the 'seeds' , the smallest constituents, the atoms and molecules, that give rise to an emergent configuration, in the same way as the interaction of water molecules gives rise to propagating waves by the transfer of energies that entertain these interactions. Assemblies emerging from this dynamics therefore cross multiple physical scales and action orders.

For the transition from quantum to classical descriptions W. Zurek has defined an '*action-distance'*, as the physical action necessary to distinguish between the possible states of an environment (E in Figure **2**) that correspond to different states of a system (S in Figure **2**) [43]. This can give us a first impression about the scaling differences along which system-environment assemblies are realized. I have given some numbers for the estimation of these action orders ranging from the molecular to the cellular level before [44].

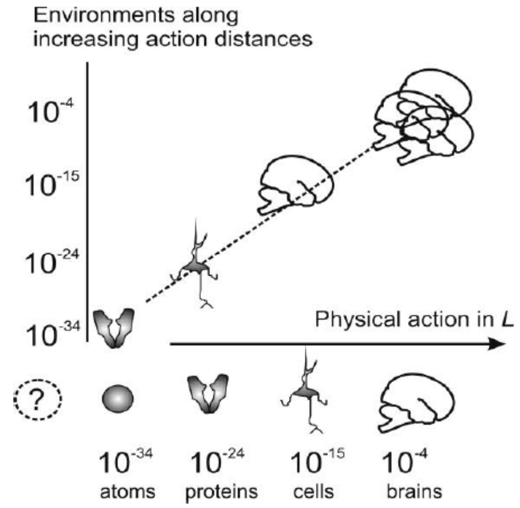

Figure 4: Action distance characterizes neural environments and systems at different scales. Molecules such as channel proteins provide environments for atoms (*e.g.* alkali ions), cells provide the same for molecules and the brains connectome for single cells. Finally the environment for a brain are other brains at the end of the scale. Interestingly there is a linear scaling difference roughly at the order of 10 magnitudes in Lagrangian (L) units.

In Figure **4** the action distances are sketched along different constituents of systems ranging from atoms to social brains. Here these distances Δ are estimated by

$$\Delta\left(\left|\varepsilon_0 \uparrow\right\rangle, \left|\varepsilon_1 \downarrow\right\rangle\right) = N\left(\pi / 2 \cdot \hbar\right)$$

where the ε_l denote two possible states of the environment, corresponding to two opposite states of the system ↑↓, N the number of modes (particles) in the environment and $\hbar$ the reduced Planck's constant. The scales imply that brain dynamics is characterized by a 'spread' of changes setting out from the smallest constituents of a system at the atomic scale up to environments provided by entire and social brains. A highly interesting observation behind the 'environmental scales' as shown in Figure **4** is, that the physical actions that characterize systems from atoms to brains spread out into environments that are very regularly 10 orders of magnitudes larger as estimated by action distances with the above relation. Thus, the brains organization offers a highly ordered and unique path along which dynamics changes from completely dissipative to metastable states of systems. Or, put in other words, the microscopic level with its atomic and molecular dynamics combines to determine the dynamics at the cellular and organ level in a highly ordered and predictable way. With electrically excitable cells, the ion channel proteins that cooperate in the transmission of electrical membrane signals along cells are naturally at the centre of this organization. Within these molecules we must expect the 'seeds' for the overall multiscale dynamics of the brain. In the following I will examine what dynamical characteristic we can expect at the molecular and single atom level and how these changes could build up a bridge between type I and type II relations in the sense mentioned above.

TYPE II Relations: The Atomic Scale

Ion channel proteins regulate the concerted translocation of charges bound to ions across the cells plasma membrane. A very long sequence of atomic resolution studies has revealed the underlying mechanisms in great details and deepened the understanding of impulse propagation in nerve cells [45]. The main focus of these studies has been laid on the channels ability for very fast conduction near the diffusion limit without compromising selectivity for a given ion species. These are important aspects to understand signalling in nerve cells. However, in the view of type II relations there is more behind electrical membrane signals. What has been largely ignored is the functional significance of the changes in the atomic conformation that the ions induce within the protein themselves during the non-conductive stages. The electronic lining of ions from carbonyl oxygen in the filter region (sketched in Figures **5a** and **5b**) has been recognized to serve the coordination of ions by mimicking the electrostatic interactions otherwise provided by the hydration shell of ions in watery environments. An important observation regarding the dynamics of ions in conducting proteins is that during the non-conductive and low-concentration states of the filter, ions move many times between potential minima, *e.g*. the so-called 1,3 and 2,4 configuration [46, 47]. During these trans-locations the metal ion in the filter induces a substantial electron delocalization of its environment and this effect correlates with the Coulomb interaction distance between the ion and the surrounding oxygen atoms (Figure **5c**), as apparent from density functional studies [48].

It is well established that proteins in general, and, in particular, α-helical conformations are particularly susceptible to these induced electron delocalizations, leading to partial covalency in the otherwise non-covalent interaction of atoms [49]. Now, an important observation for the present view is the finding of Bartlett *et al*. about the delocalization of a lone pair of electrons (n) from oxygen atoms to the antibonding orbital ($\pi*$) of neighbouring carbonyls (see Figure **5c**) [50]. The computational and structural studies of the Bartlett group identified a widespread occurence of $n \rightarrow \pi*$ interactions in three quadrants of the Ramachandran plot with their typical signatures: pyramidalization of the acceptor carbonyls and polarization of their π-electrons. These are quantum-mechanical effects within the protein, with energy resources from the dissipation of ion motion in the filter region. This induces specific electronic de-localizations in the α-helical lining of channel proteins. Moreover, the same group found ample evidence for a tight correlation of filter conduction states with $n \rightarrow \pi*$ transitions along the chain oxygens. In the closed, non-conductive and low concentration state of the filter (2 ions) the oxygen lon pairs can participate in $n \rightarrow \pi*$ transitions, whereas in the conductive (high concentration, 4 ions) state these electrons coordinate the translocation of ions through the filter and do not engage in $n \rightarrow \pi*$ transitions.

The above findings show us a route how to combine type I and II relations in the present context. The canonical signature of 'signalling', the exchange of information among nerve cells is realized by selective ion-conduction across membranes that shape propagating (action-) potentials. This is one side of the story. The other side is, that this process leaves behind traces, as it induces electronic de-localizations in parts of the channel proteins. Put into the language of

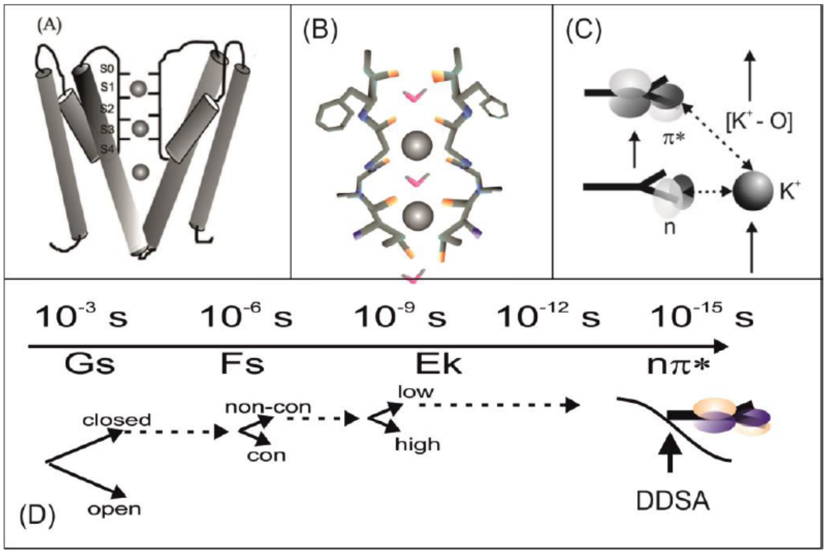

Figure 5: Channel states (**A**), filter states (**B**) and electronic transitions(**C**) during ion conduction in voltage gated membrane channel proteins. In (**D**) the time scales and events that characterize the associated channel dynamics are shown. DDSA denotes a dynamic dissipative self-assembly of electronic configurations. This dynamics involves a n→π* electronic transition of carbonyl-oxygen electrons depending on the Coulomb interaction distance to moving alkali-ions during the closed, non-conductive and low occupancy filter state of the channel as described in the text (C).

environment-system interactions and coming back to the 'von Neumann tripartite chain' as shown in Figure **2**, the ions would represent the system, the proteins represent the 'apparatus' and the collection of ion channels across cells can be seen as the 'environment' of this partition. The highly ordered action distance (Figure **4**) between single channel states and the population of channels cooperating for a given signal enables quantum-mechanical effects in the electronic transitions within the molecular configuration of single filter atoms to spread into a classical correlation of environmental binary states (open and closed channel states).

CONCLUSIONS

Based on a list of empirical evidence I have suggested a route how the brain could combine its information based signalling activity with 'imprints' on the electronic configuration inside conducting membrane proteins. In the view of biophysical modeling, this combination bridges neural field models, *i.e*. the spatial-temporal variation of membrane potentials, to 'neural mass' activity, a 'point-like' property characterizing a global brain state at a given moment of time as Karl Friston's group has reviewed [51] and I have previously discussed in the present context before [3]. Going one step further, it is suggested that the field properties reflect the 'role' of neurons within their effective connectome, their neural environment in the brain, or 'embeddedness' in the view of Vlachos *et al*. [28]. There is a purpose behind this organization that has been largely overseen before. The purpose could be to 'mass-amplify' the configuration of electrons inside the filter-region of channels by recruiting more and more channel-filter configurations with similar electronic configurations. This amplification seems to work by synchronizing the conductance of filter states in ion channels because in the closed, low ion occupancy state there is a run for similar electron de-localizations among carbonyls of the filter lining, likely of the n→π* type.

With an average firing rate of neurons in the order of 10 Hz and a gating time in the order of 10^{-3} secs for voltage gated ion channels, the channels spend most of their time in the closed gating state. During this time the filter states can change many times from permissive to non-permissive [46,47,48] and ion-translocations between the 'oxygen-cages' of the filter will induce electronic reconfigurations of the same type. So propagating membrane potentials among functionally engaged neurons can be expected to synchronize channel, filter and electronic states and thereby amplify a specific electronic configuration around the atomic skeleton of ion-filter regions. Most likely, the closed channel times provide sufficient time to synchronize the population of functionally engaged cell membranes to adopt this electronic property within integrated membrane proteins.

This view makes changes at the atomic scale in special sub-domains of membrane proteins decisive and these changes are basically of quantum-physical nature [20, 50, 52, 53]. The entire process outlined above is highly reminiscent to a quantum-classical transition involving three interacting parties in the sense of von Neumann's and Zurek's tri-partite conjecture [9, 25]. Along these arguments, the systems are provided by the moving charges bound to ions, the proteins act as the 'measurement apparatus' and the environment is represented by all channel proteins that are associated by the specific wiring pattern of functional 'embeddedness'. In addition, this electronic integration may also go beyond ion conduction and involve, membrane fatty acids, lipid rafts, G proteins and the cytoskeleton as suggested recently by Cocchi *et al*. [55].

However, 'type II relations' as defined in the introduction are even more challenging. These relations should causally combine physics with a mental state, a connection between a state of matter (*e.g*. electrons) and how it feels to 'be in' this state of matter. The underlying object/subject dichotomy remains a philosophical conundrum that cannot be resolved by purely associational (statistical) arguments within physics. It requires a premise that grants experiential properties to physical phenomena, a kind of property emergence as claimed by micro-psychistic arguments [54]. While the author of this article can share such a premise, it is left over to the reader to adopt or deny this position. In any case this work describes a chain of physical events from the quantum to the classical level in the brain that builds on recent experimental observations and naturally combines what needs to be combined: The relation between the information based and spatially segregated neural signalling structure on one hand and the convergence of these properties to a whole brain state that characterizes every moment of experience and may provide the 'meaning' of this information. This relation allows for physical interventions and is testable. For example the excellent work of Turin *et al*. demonstrates that the most powerful intervention of conscious experience through general anesthesia works through electronic perturbations along α- helical peptides [56] as suggested here.

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