System-Processual Backgrounds of Consciousness

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The article shows how can associative neural networks, quantum systems and their virtual structures (patterns-qua-attractors having the role of mental representations) realize the system-theoretical or processual backgrounds of consciousness. Although "basic units" of neural and quantum parallel-distributed processes are very different, complex systems of neurons and quantum systems obey analogous collective dynamics which contributes to conscious information processing.

1 Introduction

Science cannot explain *phenomenal qualia*, i.e. qualities of conscious experience (e.g., experience of yellow colour, man's experience of his own body or mental activity, etc.) yet [1, 15, 79]. However, it can provide a lot of important knowledge about the processual backgrounds of consciousness. It seems that not neural networks alone, but coupling of the neural, sub-cellular and quantum levels exhibit the required system-dynamical basis.

Models using parallel-distributed processing are the most relevant for micro-cognition modeling [49]. They are also suitable for understanding intuitive or aconceptual mental processes. Therefore they provide a complementary neuro-processing basis for rational and logical thought-processes which are analyzed by cognitive science based on classical artificial intelligence.

Neural network models are the most well-known ones which process information in parallel and in a collective way through-out the whole network [16]. Associative neural networks of Hopfield type [4, 36] are the simplest model of such a symmetrical complex system. This simplest model includes the system of basic elements (*formal neurons*), and the system of connections (*formal synapses)* which represent strenghts of interaction between two neurons connected, or the correlation of their activities, respectively. Symmetrical means that the same signal-summation-process is going on in every neuron, or that formal neurons are functionally equivalent.

Here we will consider neural networks as a model of a complex system which could be used in various ways *depending on the interpretation of basic elements (formal neurons) and their connections (formal synapses).* In the beginning formal neurons and synapses will be nervous cells and synapses. Later this interpretation will be attributed to some quantum elements (quantum "points", particles or their spins), etc. In the *appendix* it will be shown mathematically that neural as well as quantum complex systems realize similar collective dynamics if we neglect the role of "anatomy" of an individual element (formal neuron) of the network. The hypothesis of similar collective dynamics could be extended, although not yet with a high level of mathematical rigor, also to many other nano-scopical biophysical levels, e.g. to numerous *networks of dendrites, microtubules, biomolecules (proteins, etc.), dimeres* or *dipoles* of various orientation, *particle spins*, etc. [37, 62]. Potential information processing capabilities of cytoplasmatic *microtrabecular networks* [3] and *quantum-field* interaction networks or many-body systems down to the level of *quantum "vacuum" states* [37, 55, 27] are also entering into consideration.

2 Patterns of Formal Neurons Representing the "Objects" of Consciousness, Patterns in Formal Synapses Constituting Memory

Let us first present the model of associative neural networks. This model serves as a description of the *global processual skeleton* capable of information processing which could also be applied for modeling other biophysical complex systems. Of course, this model would be merely the first approximation—useful for finding out whether information processing on these levels is in principle possible. Later it would be necessary to incorporate specific functional details into a more biologically plausible model.

Various versions of the model of associative neural networks [4, 28, 36] have been often successfully simulated on computers by many researchers, including this author.

Activities of many neurons form neuronal configurations. Firing configurations which are especially stable, because they represent free-energy minima, are called neuronal patterns. Specific patterns are correlated with specific external objects: whenever an external object is perceived, its corresponding pattern is reconstructed. Thus, neuronal patterns, which are physiological correlates of mental representations, are carriers of information. They have a specific meaning in context of other possible patterns. Every synapse changes its strength proportionally to the correlation of neurons. Patterns of synaptic transmissions represent memory.

In such a network *neuronal patterns* which act as *attractors* are formed. This means that large groups of neurons constitute a sort of organizations which are distributed all-over the network. Patterns acting as attractors are those dominant neuronal configurations each of which lies at the bottom of its free-energy minimum, and causes the convergence of all the neighbouring configurations (which lie within the "basin of attraction" of an attractor) towards the nearest pattern-qua-attractor.

Such patterns-qua-attractors represent categories or gestalts. Gestalts are some qualitative unities arising from collective system-dynamics which cannot be reduced to the sum of activities of the constituting basic elements alone. In other words, gestalts are emergent structures. Patterns-qua-attractors thus represent some *mind-like representations*, because they are isomorphic to some environmental objects. Such patterns are not only some collective neuronal states, but also encode specific information. Whenever a specific object occurs in the environment, the reconstruction of a specific neuronal pattern-qua-attractor is triggered. Actually, a superposition of the sensory stimulus-pattern and the most similar memory-patterns (coded in the matrix of synapses) is formed in the system of neurons. The system of neurons is a carrier of those information which is currently processed (i.e., which is the most important in that specific context or that circumstances, or which is mostly correlated to the state of environment). It could be said that the pattern of neuronal activities represents the object of consciousness (which has to be, of course, distinguished from the consciousness-in-itself, or the phenomenal qualia, respectively).

The system of synaptic connections represents (long-term) memory. The strengths of these connections between neurons are proportional to the correlation of activities of the two neurons connected. So, the matrix of synaptic connections represents autocorrelations of neuronal patterns (Hebb learning rule). By this matrix (= memory) neuronal patterns (= virtual "objects of consciousness") are transformed into new patterns. This is an association. Such transformations may be connected into associative chains or temporal pattern sequences which are origins of thought processes.

Recall of a memory pattern takes place when an external pattern interacts with the system of synaptic connections. This causes the occurence of the nearest (the most similar) memory pattern in the system of neurons ("in consciousness"). Actually, during the recall process the external pattern triggers selection of all the relevant memory patterns (i.e., expectations, presumptions), and a "compromise" (a new "mixture" of them) is made in the system of neurons. Selective "moving" of patterns from the system of neurons ("consciousness") to the system of synapses (memory), and vice versa, is realized by continuous "interplay" of neurons and their signals through synapses.

To summarize, neural networks can realize the micro-structure of cognition: pattern recognition, associations, adaptation, content-addressable memorization and recall (partial information triggers reconstruction of the whole information), forgetting, categorization, compressed data storage, selection and abstraction of all relevant data, the basis of attention, etc. On the other hand, with neural networks alone we are not able to include consciousness into a general theory of mental processes, although associative neural networks realize many of the characteristics which are essential for the processing basis of consciousness. They realize recurrent, auto-reflexive information processes. Neuronal patterns interact with each other and with themselves, because their constitutive neurons are constantly interacting. This self-interaction of neuronal patterns is a global process encompassing a web of local interactions, where the individual neurons represent each-other's context and content. However, even such self-referential, collective processes seem not to suffice for the unity of consciousness as a global emergent process. Even a very large and complex neural network would not be sufficient for consciousness. There are indications that consciousness arises from quantum systems [25, 27, 47, 52, 72, 73].

3 Why Include Quantum Systems?

The fact that on the one hand neural-network-processes and their virtual processes are very relevant for consciousness, but on the other hand various sub-cellular and quantum-biological processes seem also to be relevant, raises a question of relation between the neural, the virtual, the sub-cellular and the quantum levels.

The main reasons for the quantum hypothesis are the following:

- Neural networks with their rigid neurons and synapses, in spite of their subtle virtual processes, are too mechanistic, too discrete and too deterministic to be able to produce emergent consciousness and phenomenal qualia, i.e. real (perceptual) experiences.

- Characteristics of consciousness often coincide with the phenomena in quantum systems. An example is the uncertainty principle, i.e. inability of simultaneous determination of Fourier-connected variables and information attributed to these variables. Similarly, one cannot be conscious of all information at once, but only of selected portions.

- There are many indications that consciousness-in-itself may be trans-individual, or trans-personal, and thus cannot be limited to the neural brain and to its virtual structures alone. Quantum or sub-quantum systems include several experimentally well-supported phenomena which may be related to consciousness - e.g., non-locality, undividedness, long-range coherence [12, 38, 71]. An important support for the quantum hypothesis are meditational or mystical experiences, the collective (un)conscious, and many hypothetical parapsychological phenomena. Here this author feels necessity of emphasizing that he had a powerful transcendental mystical experience himself. He considers this as the most important and "objective" empirical evidence of the holistic nature of consciousness and of the sub-quantum world, although he is not able to locate the level or "center of weight" of processual background of this clear experience [57].

- Quantum systems are the microscopical basis of all physical processes and of biological or psychophysical processes also: all the classical world arises from the overall quantum background. Quantum dynamics is very fast and multiple, i.e. incorporates many processes simultaneously in a non-local superposition which is even more effective than parallel-distributed processes in neural networks.

- Quantum systems transcend even the division of particles and waves, or interactions, or fields. Quantum systems, or sub-quantum systems especially, are holistic in nature [13]—they cannot be satisfactorily analyzed into interacting fundamental elements. So, quantum wholes such as Bose-Einstein condensates may act as proper candidates for correlates of the phenomenal unity of consciousness.

– Numerous sub-cellular structures do not merely provide a biochemical energetic and material support for activities of neurons and synapses, but some experimental evidence [30, 62] suggests that they act as pre-cognitive processors or "interfaces" between the quantum level and the neural level (the last one being a regulator of organism–environment sensory-motorical interaction).

All information processing, including cognitive processes and consciousness, seems to arise from dynamics of complex systems, although they become virtually differentiated and incorporates newly-emerging virtual constraints (rules, procedures) in higher cognition. The objects of consciousness and the stream of conscious thought seem to be represented in some physical or at least informational (virtual) "medium". This "medium" has to be a complex system which only is enough flexible, fuzzy, adaptive, and has good self-organizing and recurrent abilities.

Because the mathematical formalism of the Hopfield-type neural network theory [23, 36] describes the collective system-dynamics, it remains to a large extend useful also for complex systems of other nano-scale basic elements. The following sub-cellular systems could be modeled using associative neural network models as a global "skeleton" model, i.e. in the approximation of very many basic elements of the system (formal "neurons"). Physiological and functional specificities would have to be incorporated additionally.

– *presynaptic vesicular grid*
is a paracrystalline hexagonal lattice in synapses of the pyramidal neurons. Due to Eccles [62], this lattice is responsible for increasing or decreasing the probability of "random" release of neurotransmitter vesicles (which mediate between neurons). The amount of exocytosis (neurotransmitter release) could be sensitive to quantum effects.

– *dendritic networks*:
A dendrite is usually a presynaptic input-"cable" of a neuron. It has a similar (but linear) summation-task to that of the neuron's soma [63]. Dendritic network consists of entangled dendritic trees of numerous neurons. Dendrito-synaptic networks [61, 62], directly coupled with quantum systems, could be as important for information processing as neural networks are (actually they cannot be separated from each other).

– *cytoskeleton* (interconnected protein polymers constitute cell's skeleton), especially its *microtubular networks* (microtubules connected by MAPs—microtubule associated proteins) and *actin microfilaments*:
Microtubules are, for example, located in neuron's axon and influence the transmission rate of neuron's synapse. "Bits" of a microtubular lattice array are two conformations of tubulin dimeres. Interacting tubulins constitute a molecular "spin glass" or "cellular" automaton inside a microtubule. They may have a role of an interface between the neural and the quantum level [30, 55], because tubulin's conformations are dependent on a variable electron location which is sensitive to quantum effects [65].

– *perimembranous bioplasma*, a special phase of matter consisting of interacting positive and negative ions, located near dendritic membrane [37, 64]

– various *interaction webs of biomolecules (e.g., proteins)* [9, 14], networks of *actin filaments* beneath the cell membrane [37], systems of *magnetic or electric dipoles* [77, 78], *spin glass* and other frustrated systems. Networks of protein filaments extend throughout the cytoplasm as well as outside the cell membrane where they form the extracellular matrix [3, 5, 6]. Superconducting electrical currents or soliton-waves may emerge along the filaments [66].

– *quantum coherent superpositions* (quantum computing [21, 45]) and *conscious events* *as orchestrated space-time selections by self-collapse* of the quantum coherent system: Due to Hameroff and Penrose [31] quantum coherence is established among tubulins in microtubules, or in water ordering within the hollow microtubule core, respectively. This is needed for quantum computing going on until a threshold related to quantum gravity is reached. In such a case the coherent system collapses itself, because the superposed coherent states have their own space-time geometries which get too much separated. The self-collapse corresponds to a conscious event [32].

- *networks of quantum particles* (e.g., *electrons, coherent bosons* such as *phonons*, or *Goldstone bosons)* [6, 76] with their spins [74, 75] and *quantum-optical interaction webs* (i.e., systems of *photons*—quanta of electromagnetic fields) [64]

- networks of *"vacuum" states* (Jibu, Yasue) [37], or sub-quantum *"beables"* (Bell, Hiley), or *"hidden variables"* [12]:
  They emerge as excitations of the sub-quantum "vacuum" or "holomovement" which is an indivisible quantum whole. They can perhaps be considered as conceptual artefacts only, because "particles" lose their autonomy at the level of (sub)quantum field completely, or retain it merely as a result of quantum measurements, i.e. experimental interaction with the undifferentiated sub-quantum "sea" [25].

Bose-Einstein condensate also represents such a unitary, non-local quantum boson field (bosons are particles which can unite into an indistinguishable quantum whole). Bose-Einstein condensates are macroscopic, collective quantum states which can act as lasers, superconductors or superfluids.

In the next section and in the *appendix* a detailed mathematical discussion of quantum "neural"-like networks is given. It presents connections of the neural network formalism and the quantum formalism (detailed presentation in [59]; see also [17]). The only difference is a different interpretation of formal neurons: nervous cells (or artificial neurons) versus quantum "points" (quantum wave-function at a specific location in a specific time).

All these levels and structures are indirectly or even directly (quantum-physically) locally and non-locally connected [38, 15, 13]. They process in a highly cooperative way [35]. The synthesis of all these multi-level processes, including the sub-quantum "sea" [70] in a non-excited and in an excited state, represents the biophysical background of consciousness.

There are several theories which try to make a synthesis of partial approaches: quantum neural holography by Schempp [67, 68, 69], holographic and holonomic brain theory by Pribram [61], ontological interpretation of quantum physics by Bohm and Hiley [12], quantum field biophysical theories by Umezawa, Jibu and Yasue [37].

4 Multi-Level Coherence in Brain

Consciousness is, from the system-processual aspect, a multi-level phenomenon [2, 58, 59]. One extreme is unintentional consciousness which is "consciousness-in-itself" or "pure" consciousness. It can be experienced during transcendental mystic or meditational states [57]. It is probably associated with the quantum field, or better, with the "overall sub-quantum holomovement" [27, 60].

On the other hand, intentional consciousness is a state of consciousness which is bound to some object of consciousness. This "consciousness-about-some-object-of-consciousness" cannot be associated with a specific quantum-informational state only [50, 51], but is multi-level and macroscopical in the sense that it is coupled to a usually classical-physical object (see also [39, 40]).

We cannot totally divide intentional consciousness from the object of consciousness which may be an internal virtual image or a real external object. Actually, the object of consciousness is a phenomenon which is a combination of both [15]. We may take that pure unintentional consciousness is originally of quantum nature, although we cannot reduce it to quantum processes only. Intentional consciousness emerges from the nanoscopical quantum processual background as soon as the system gets correlated with a macroscopical state in the (external) environment which is usually described by classical physics. In order to establish such a connection, neurally-based sensory-motor mediation is needed, and therefore *neuro-quantum coherence* is necessary. Virtual representations are associated with neuronal as well as quantum patterns or neuro-quantum joint conglomerates (see also [41, 42]).

The "wave-function collapse" is a transition of the quantum state from a state described by a linear combination of many quantum eigenstates to a "pure" state which is one eigenstate (one eigen-wave-function) only. A superposition of many "quantum patterns" is transformed into one "quantum pattern" only. The "wave-function collapse" means a selective projection from the subconscious memory to the conscious representation which was explicated from the memory. Each biophysical level can realize its own style of memory and memory-recall [2]. A network is needed—a quantum one or a classical (neural) one. Memory is a parallel-distributed pattern of the complex system of connections or interactions. It may use synaptic or more microscopical sub-cellular connections, or nanoscopical quantum interactions, even very subtle ones where models such as Everett's parallel-worlds interpretation of quantum theory [20] or Bohm's implicate order are used.

Mental representations emerge as neuronal, sub-cellular and/or quantum patterns which act as attractors. An attractor is a contextual gestalt-structure which cannot be reduced to the neuronal / sub-cellular / quantum pattern (which represents attractor's kernel) alone [56]. Virtual structures such as attractors overbuild their constitutive material background and represent a unity with new qualitative characteristics. They represent complex networks of relations [42]. Contextual or relative constellations are thus essential: a pattern acts as an attractor only if it is more stable and more dominant in the system-dynamics than the neighbouring system's configurations are.

5 Explicit versus Implicit Collective States: Patterns versus Attractors

A set of explicit collective states, i.e. configurations or patterns—"mosaics" of formal neurons' activities, is always accompanied by implicit collective states, i.e. virtual states or attractors. We do not experience activities of single neurons and their exchange of signals, but we experience their unities. Thus we experience attractors as global informational unities, not their local, separate, physically-realized constituents. Attractors are an useful explanatory level connecting physical implementation and the highest virtual structure—the conscious I which gives interpretation to underlying physical processes and "transforms" them into information processing. In this article we will not enter into the question of a relative sovereignty of the conscious I. Therefore we will remain in the third person perspective.

Quantum mechanics governed by the Schrödinger equation does not exhibit attractors until they are formed during the "collapse" of the wave-function. In that case, because of the interaction of a classical macroscopical system (measurement apparatus, environment, neural sensory apparatus) with the quantum system, the wave-function "collapses" and a specific quantum eigenstate (a quantum pattern) occurs as an attractor. Similarly to neural attractors, quantum virtual structures exist. They cannot be reduced to a quantum eigenstate alone. They usually emerge as a result of interaction with a classical system. The possibility of the "collapse" is very much higher if the interaction is knowledge-based, i.e. it involves consciousness. Thus quantum virtual structures are (re)constructed as a result of the so-called quantum measurement which can be direct or indirect, i.e. machine-mediated. Thus, the "measurement apparatus" may be our sensory and associative neural system directly or a machine which is then observed by that neural system. In both alternatives the "wave-function collapse" occurs as a result of a specific interaction with a classical system.

Every collective state of a complex system may constitute a specific gestalt (a specific virtual unity) which emerges from the constitutive elements of the system. Formation of a specific isomorphic (e.g., fractal) multi-level coherence is a central problem. Practice in our computer simulations of neural networks shows that we can by explicitly ruling the artificial-neuronal level, govern the artificial-virtual level also—implicitly. If our dynamic equations for neurons and synapses regulate the patterns only, the attractors always accompany this dynamics implicitly. Neuronal dynamic equations (represented in the computer program) are differential equations (with local range of validity), but attractor-structures may be mathematically described by variational calculus (with global range of validity). We can use the first mathematical description (integro-differential equations) or the other (variational calculus), but not both at the same time. Thus, we may reductionistically describe one level only and make influence on its self-organization, but the other levels will automatically, anyway, globally follow the locally-triggered self-organization.

To summarize, virtual structures cannot be reduced to the corresponding state of neural or quantum "medium", although they are tightly connected with it! Virtual states are always non-local, or parallel-distributed, respectively. They cannot be measured, or can be measured only indirectly—through the states of their corresponding neural or quantum "ground". For the sake of modeling and analysis we indeed have to distinguish neural, quantum and virtual levels, and consider environmental influence. Intentional consciousness, however, requires that all these levels are coupled into a multi-level coherence.

6 Mathematical and System-theoretical Analogies in Models of Neural and Quantum Networks

We have presented some reasons why one has to be motivated for research of parallels between quantum processes and neural-network-processes. In this chapter it will be shown that the mathematical formalism of the quantum theory is analogical to that describing associative neural networks. The following text is written for a broad multidisciplinary audience. Experts can jump to the *appendix* where corresponding mathematical formalisms are presented.

A quantum state can be described as a superposition of quantum eigenstates ("quantum patterns"). Analogously, a neural-network-state may be described as a superposition of neuronal patterns. In both cases the coefficients of this linear combination ("mixture") of patterns describe the influence (or mathematically: projection) of the corresponding pattern on the actual state of the system. Each pattern is represented by its own coefficient. The coefficient essentially describes how probable it is that the corresponding pattern will be reconstructed or recalled from memory. In fact, the coefficients (quantum probability coefficients or neural order parameters) represent the meaning of a pattern in a specific context [28]. The meaning is a result of parallel-distributed dynamic relationships of the complex info-physical system.

Feynman's version of the Schrödinger equation [34] has the same structure as the dynamic equation of neurons. The Feynman interpretation shows that the wave-function on a specific location and in a specific time is a result of summed influences from all other space-time points. Similarly, the neural dynamics actually incorporates a spatio-temporal summation of signals from other neurons.

Transformations of the quantum system result from microscopic parallel-distributed interaction webs. They can be described by the Green function which is an autocorrelation function of quantum eigenstates [11]. The Green function or propagator of a quantum system actually describes how the system transforms itself into a new state by exhibiting numerous internal interactions between its constitutive "quantum points" (some mathematical "basic elements" of the system). It is a matrix, which describes such a parallel-distributed transformation of the whole system from an initial state to the final state. Turning to neural nets, this is similar to the Hebb learning rule which is an autocorrelation function of neuronal patterns. A superposition of such (auto)correlation patterns represents memory. If parallel-distributed transformations using Hebb or Green correlation-matrices are interpreted as carriers of information, they are called associations. In the relativistic case the so-called S-matrix has the role of quantum Green function, and our analogy still remains valid.

The *"collapse of the wave-function"* is a transition of a quantum state from the case of a linear combination of eigenstates to the case in which a "non-mixed" eigenstate is individually realized. In Bohm's terminology, it is a transition from the implicate order (which codes inactive, potential information only) to the explicate order (carrying active, manifest information) [13, 34]. The other unrealized eigenstates remain inactive in the implicate order. This is very similar to *neuronal-pattern-reconstruction* from memory. In memory there is a superposition of many stored patterns. One of them is selectively "brought forward from the background" if an external stimulus triggers such a reconstruction. In the quantum case a "wave-function collapse" also takes place as a result of the external influence of the experimenter (quantum measurement). In both cases suitable informational context is necessary for the pattern-reconstruction or the "collapse" to occur. Human knowledge increases probability of such an event enormously, because knowing its part and presenting it to the system triggers the reconstruction of the whole pattern. This is the general characteristics of all homogeneous, symmetric complex systems like neural nets, holograms, (sub)quantum nets, etc. The environment selects those neural/quantum pattern which is the most similar (or is correlated) to the state of environment.

Why are the neural-pattern-reconstruction and the "wave-function collapse", which represent a transformation from the implicate order (latent, potential information) to the explicate order (manifest, realized information) so important? These two processes may represent a basis for *memory-consciousness transitions, or subconsciousness-consciousness transitions.* The implicate order represents a combination of very many possible states or processes. It is analogous to the set of so-called "parallel worlds" or parallel sub-branches of the general wave-function offered by Everett [20, 54]. The explicate order, on the other hand, represents a state or process which is at a moment physically actualized—it is "chosen" from a set of potential (implicate) states, or is a result of their optimal "compromise". In memory, patterns are represented as potential information only (i.e., merely as correlations of these previously gain patterns). The influence from environment explicates these correlations, so that the whole pattern is manifested again. This explicated pattern (neural or quantum one) can then serve as the object of consciousness.

In neural networks the correlations between patterns are important for memory. In quantum mechanics the phase differences between different parts of the wave-function are important. Phase difference is a discrepancy between two oscillatory processes (e.g., time delay of their peaks). Phase differences control the time-evolution of probability distribution involving interference of the contributions of different stationary eigen-wave-functions. Thus, changing the phase relations between eigen-wave-functions is analogical to the learning-process in neural networks where new pattern-correlations are added into the synaptic correlation-matrix. This is also similar to holography [68].

In the neural network theory there are *uncertainty principles* by Gabor, Daugman and MacLennan [18, 62, 59] which are similar to the quantum uncertainty principle: inability of simultaneous determination of two conjugate observables (e.g., position x and momentum p). An interesting neural analogy of this uncertainty principle of Heisenberg is represented by inability of simultaneous determination of patterns in the system of neurons and of patterns in the system of interactions (formal synapses). We are unable to be conscious of a pattern in the system of neurons, and to control a pattern in the system of connections at the same time. Only one pattern, which is temporarily realized in the system of neurons, is explicated. So, we can be aware of this single pattern only which has been extracted from memory. All the others remain implicit in the system of interactions, or in the dynamics itself, respectively.

To summarize the uncertainty analogy, we are not able to control simultaneously a pattern in the system of neurons ("consciousness") and patterns in the system of synaptic connections (memory). This is similar to the quantum situation, where it is not possible to explicate (to unfold) all eigen-wave-functions at the same time.

There is an additional analogy corresponding to the previous one. The duality of the system of neurons and the system of connections reminds one of the double nature of particles and waves, or of the duality between the position (x-) representation and the momentum (p-) representation of quantum mechanics. Thus, the so-called position (x-) representation of quantum theory can be approximated by the system of neurons. The so-called momentum (p-) representation can, on the other hand, be associated with the system of interactions which regulates all transformations of the network-states.

7 Questions Concerning the Fractal-like Nature of Brain

Only some basic mathematical analogies were presented here; numerous other parallels can be found between the neural and the quantum processing. They suggest that there is a subtle "division of labour" and an isomorphic cooperation between the neural and the quantum levels. These levels may be in a sort of fractal-relationship (infinite replicas of each other).

Although these levels are complex systems of various basic elements, their parallel-distributed *collective dynamics* is governed by very *similar* principles! They are mathematically formalized as algebras.

The only essential difference between mathematical formalisms of the quantum theory and the neural network theory (of course, if we forget the internal structure of the basic elements of the system, i.e. formal neurons and synapses) is the *imaginary unit (i)* taking place in the Schrödinger equation. The origin of complex-valued variables in quantum theory can at least to some extend be attributed to the oscillatory nature of quantum phenomena. Generalizations of presented neural network formalism in order to incorporate *oscillatory activities of neurons and their phase-coupling* have already been realized in order to make neural models more biologically plausible [7, 28, 29, 48]. Haken showed [28] that a network of phase-coupled neurons-oscillators also realizes efficient associative memory.

Coupled oscillations are an essential ingredient of classical biophysical and neural systems having information-processing significance [33, 35, 78]. Phase coupling of oscillatory neuronal activities in different neural domains signifies that the information encoded in these spatially-separated patterns has something in common. Using a simplified example, if a neural activity pattern in the auditory cortex oscillates in phase with a neural activity pattern in the visual cortex, subject recognizes that the person just seen is the person just heard, i.e. he recognizes the equivalence of the origin of received visual and auditory stimuli.

Phase coupled oscillatory phenomena (coherence), described by complex-valued equations, are usual in neural as well as sub-cellular and quantum networks. It is suggested that they are responsible for *binding* of multi-modal sensory experiences. It is, however, not clear whether binding is realized by 40 Hz coherent neural oscillations or by coherence at another level (sub-cellular, quantum) [33]. It may be that binding is also a multiple or multi-level phenomenon.

The question remains, whether an underlying "medium" of consciousness is always necessary, and which level codes some specific information [8, 43]. Are various levels carriers of specific mental processes also simultaneously, synthetically? Does even a single conscious mental representation (as far as we can say that it exists as an entity, although virtually, transitionally only) emerge from multi-level processes?

Various associative processes may be realized by attractor neural networks, but in order to be conscious, it seems that they must have quantum correlates. In that case, the neural brain is a classical system, which acts (similarly to a quantum-measurement-apparatus) as a non-linear processing interface connecting our quantum Self with environment.

Informational processes are usual physical processes with an additional *interpretation*. Who gives informational interpretation to some usual physical processes or states? This is consciousness, individual or collective in the sense of a common sense or convention. If a secret agent puts his hand-bag to a special location, this could mean a special sign (give information) to a second secret agent if such a convention was accepted between them previously. *Without* this convention (an act of intersubjective consciousness) hand-bag would just be in a physical state. *With* this intersubjective agreement (an act of collective consciousness) the hand-bag becomes an informational state also.

If consciousness is connected with information dynamics in physical (usually complex) systems, including quantum systems, a question arises why usually very many complex-system-states (classical and quantum) are not considered as conscious information or even being conscious themselves. A difference between the physical and psychical processes is that a complex physical system itself is not intentional (does not carry any mental information), but mind is intentional (carries specific mental contents). Again, the difference arises from the interpretation-giving (intentional) consciousness (whatever it is).

The second reason why not all quantum-physical processes are usually considered as conscious information or even being conscious is that a quantum system itself does not have any relatively independent environment, but mind-brain does. Therefore the mind-brain models its macroscopical environment in a specific and flexible manner by using the biological neural network as a macro-micro-interface and a (subconscious) pre-processor for an unified conscious experience which involves neuro-quantum coherence (see also [39, 40]).

It is a common characteristic of neural networks and sub-quantum systems that their functional processes transcend space-time-structures. Like sub-quantum processes, neural attractors operate in *"pre-space"* [34, 58]. Neurons are, of course, located in space-time, but their *virtual structures cannot be located.* Specifically, if their constitutive neurons are mixed, but the strengths of their connections remain the same, then all the patterns-qua-attractors remain the same. Human perceptual system *encodes the correlated (similar) stimuli into topologically ordered structures*; like elements are encoded close together according to Kohonen model (for a summarized description see [59]). So, spatial order of neural maps emerges as a consequence of correlated stimuli of various types, arriving from various locations. According to the functional analogy between neural and sub-quantum processes, space-time can be treated as a special case of a correlation-network, because it is established as a result of self-organizing processes in the holomovement [1] (or network). To summarize, space-time is a secondary structure, correlated parallel-distributed processes are primary and thus more fundamental.

8 Conclusions

The main problem of the brain-mind-modeling using neural networks and orthodox quantum mechanics is the fact that mind, and especially consciousness, are even more holistic than these models are. Consciousness transcends the necessary analytic division of a system into elements (formal neurons) and interactions (formal synaptic connections). Thus, well-defined basic units of cognitive information cannot be found; processes are more "fundamental". It seems that consciousness, and the sub-quantum "sea" as well, are a superposition of all possible quantum-informational "networks".

For unintentional consciousness the connection with the "vacuum" or holomovement is the most relevant one. For intentional consciousness coherence of the (sub)quantum level with the neural, subcellular and virtual levels (including coupling with some environmental object) is necessary. Without this multi-level coherence, it cannot be imagined how one could be conscious of a macroscopic object detected by sensory neurons. One thus needs neuro-quantum mediators.

Several mathematical neuro-quantum analogies were presented. It was argued that they are a result of a similar collective dynamics in neural and quantum networks (a comprehensive discussion in [59]). The most important analogies were the following: The reconstruction of a neuronal pattern (the recall of a pattern from memory) is analogous to the so-called "wave-function collapse". In the neural case, from a "mixture" of neuronal patterns one pattern alone is made clear in the system of neurons ("consciousness"), all the others remain represented in the system of synaptic connections (in memory) by mutual correlations only. In a quantum system the wave-function "collapses" from a superposition of eigen-wave-functions to a state which can be described by a single eigen-wave-function, all the others are latent, enfolded in the implicate order.

These processes provide a processual background for consciousness and its "flow" (for progression of conscious "now" forward in space-time see [54]), and for bi-directional consciousness–memory transitions as well as for subconsciousness–consciousness transitions. Simultaneously, with conscious contents, the associatively related unconscious contents are excited also (as far as they remained "below the threshold"). It was emphasized that flexible, fuzzy and fractal-like multi-level processes constitute an alternative basis for aconceptual conscious experience. The hard problem of qualia was not discussed here, although it is the kernel of the con-

[1] Bohm's expression for "quantum vacuum".

sciousness question [33, 1, 79].

9 APPENDIX: Mathematical Analogies of Associative Neural Networks and Quantum Mechanics

A set of equations will be presented which, when properly programmed as a *coupled* system, realize efficient information processing (content-addresable memory, pattern recognition and recall, etc.) as indicated by author's computer simulations [57]. Note that equations (3a) and (4a) or (6a) are coupled in a Hopfield way [36], and that equations (3b) and (4b) or (6b) are also coupled in quantum dynamics. Beside these basic dynamic equations, other presented equations provide a complementary or additional description of information processing.

1. $q(\vec{r},t)$ denotes the activity of an individual neuron at time t, located at $\vec{r}$. In quantum mechanics the state of the quantum system at location $\vec{r}$ and time t is described by the wave-function $\Psi(\vec{r},t)$. Neurons and synapses of a single neural network collectively constitute many *neuronal patterns* $\vec{v}_k$ simultaneously. The state of the system of neurons $\vec{q}$ can be treated as a linear combination of p simultaneously-stored patterns $\vec{v}_k$:

$$q(\vec{r},t) = \sum_{k=1}^{p} c_k(t)\ v_k(\vec{r}) \qquad (1a)$$

Similarly, a wave-function Ψ can be described as a series of eigen-wave-functions ψ_k:

$$\Psi(\vec{r},t) = \sum_{k=1}^{p} c_k(t)\ \psi_k(\vec{r}) \qquad (1b)$$

Neuronal patterns $\vec{v}_k(\vec{r},t)$ are mutually orthogonal and are normalized. "Quantum patterns" $\psi_k(\vec{r},t)$ have the same property.

2. The coefficients of given linear combinations are the quantum probability coefficients C_k and the neural order parameters c_k.

$$c_k = \langle\vec{v}_k,\vec{q}\rangle = \int v_k(\vec{r})^*\ q(\vec{r},t)\ d\vec{r}, \qquad (2a)$$

$$C_k = \langle\psi_k,\Psi\rangle = \int \psi_k(\vec{r})^*\ \Psi(\vec{r},t)\ d\vec{r} \qquad (2b)$$

Asterix denotes the operation of complex conjugation. In the case of real variables $\vec{v}_k$ and Ψ_k, the asterix has no meaning and may be erased.

3. The state of a neuron at position $\vec{r}_2$ and time t_2 is given by a spatial and temporal summation of all signals and the whole history of signals from all other neurons (at different locations $\vec{r}_1$ and times t_1) which are connected with it:

$$q(\vec{r}_2,t_2) = \int\int J(\vec{r}_1,t_1,\vec{r}_2,t_2)\ q(\vec{r}_1,t_1)\ d\vec{r}_1\ dt_1 \qquad (3a)$$

Weight $J(\vec{r}_1,t_1,\vec{r}_2,t_2)$ represents the strength of an individual synaptic connection.

The quantum dynamic equation (Feynman's interpretation of the Schrödinger equation) is analogous:

$$\Psi(\vec{r}_2,t_2) = \int\int G(\vec{r}_1,t_1,\vec{r}_2,t_2)\ \Psi(\vec{r}_1,t_1)\ d\vec{r}_1\ dt_1 \qquad (3b)$$

$G(\vec{r}_1,t_1,\vec{r}_2,t_2)$ constitute the Green function or propagator of a quantum system [11]. It describes how the system transforms itself into a new state by exhibiting numerous internal interactions between its constitutive "quantum points" (some mathematical "basic elements" of the system). G is a matrix which describes such a parallel-distributed transformation of the whole system from an initial state to the final state.

4. The transmission of an individual synapse $J(\vec{r}_1,\vec{r}_2)$ is determined by the Hebb's correlation between its two neurons participating in several patterns $\vec{v}_k$:

$$J(\vec{r}_1,\vec{r}_2) = \sum_{k=1}^{p} v_k(\vec{r}_1)\ v_k(\vec{r}_2) \qquad (4a)$$

On the other hand, the Green function [11] is given, similarly, as an "interference of quantum patterns" ψ_k:

$$G(\vec{r}_1,\vec{r}_2) = i\sum_{k=1}^{p} \psi_k(\vec{r}_1)^*\psi_k(\vec{r}_2) \qquad (4b)$$

The essential difference between equations (4a) and (4b) is the imaginary unit i. The role of i is connected with the oscillatory nature of quantum phenomena. Neurons with oscillatory activities need to be introduced in order to incorporate complex-valued formalism into neural-net-theory (see [7, 28]).

5. The last analogy can be extended to relativistic domain, where the role of G is realized by the $S-matrix$ [11]:

$$S(\vec{r}_1,t_1,\vec{r}_2,t_2) = -i \sum_{k=1}^{p}\sum_{j=1}^{2} \psi_k^j(\vec{r}_1,t_1)^* \psi_k^j(\vec{r}_2,t_2)$$

$$S(\vec{r}_1,t_1,\vec{r}_2,t_2) = i \sum_{k=1}^{p}\sum_{j=3}^{4} \psi_k^j(\vec{r}_1,t_1)^* \psi_k^j(\vec{r}_2,t_2) \quad (5)$$

The first equation is valid for $t_2 > t_1$, the second for $t_2 < t_1$.

6. In contrast to the auto-correlation case **4**, a generalized Hebbian learning rule, where synapses $J(\vec{r}_1,\vec{r}_2)$ are given by cross-correlation of patterns

$$J(\vec{r}_1,\vec{r}_2) = \sum_{k=1}^{p}\sum_{h=1}^{p} \lambda_{kh}\, v_k(\vec{r}_1)\, v_h(\vec{r}_2) \quad (6a)$$

is analogous to the quantum density matrix or statistical operator

$$\rho(\vec{r}_1,\vec{r}_2) = \sum_{k=1}^{p}\sum_{h=1}^{p} \rho_{kh}\, v_k(\vec{r}_1)^*\, v_h(\vec{r}_2) \quad (6b)$$

7. The *reconstruction of a neuronal pattern* (the recall of a pattern from memory) is analogous to the so-called *"wave-function collapse"*. In the neural case, from a "mixture" of neuronal patterns one pattern alone is made clear in the system of neurons ("consciousness"), all the others "die out" there and remain stored in the system of synaptic connections (in memory) only:

$$q(\vec{r},t) = \sum_{k=1}^{p} c_k(t)\, v_k(\vec{r}) \Longrightarrow q(\vec{r},t_f) = v_{k_f}(\vec{r}) \quad (7a)$$

In a quantum system, the wave-function "collapses" from a superposition of eigen-wave-functions to a state, which can be described by a single eigen-wave-function, while all the others are latent, enfolded in the implicate order [13, 24]:

$$\Psi(\vec{r},t) = \sum_{k=1}^{p} c_k(t)\, \psi_k(\vec{r}) \Longrightarrow \Psi(\vec{r},t_f) = \psi_{k_f}(\vec{r}) \quad (7b)$$

8. Many additional mathematical analogies may be drawn. For example, the neuro-synergetic equation

$$\dot{q}(\vec{r},t) = \sum_{k=1}^{p} \lambda_k\, c_k\, v_k(\vec{r}) \quad (8a)$$

is similar to the quantum equation

$$\dot{\Psi}(\vec{r},t) = -\frac{i}{\hbar} \sum_{k=1}^{p} E_k\, C_k\, \psi_k(\vec{r}) \quad (8b)$$

λ_k is an eigenvalue of the matrix $\mathbf{J}$ with eigenvectors $\vec{v}_k$. It represents the *attention parameter* of the pattern $\vec{v}_k$ [28]. Energy-eigenvalue E_k plays a similar role in eq. (8b) as λ_k does in eq. (8a).

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