Original Article

Conscious Image Processing
An Integrated Neural and Quantum Model

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Abstract

An integrated model of conscious image processing in human cortex is proposed based on the Holonomic Brain Theory by Karl Pribram and related models. After optimal delineation of the neural and quantum ingredients, the model combines the predominantly (sub)neuronal image processing and the essentially quantum-based repetitive act of becoming-conscious of the resulting phenomenal image. The model optimally incorporates contemporary limited knowledge starting from a systematic search for fit between existing computational models, and between available experimental data, and between data and models. Since we are not yet able to tackle qualitative conscious experience directly, processes for making an image (or result of image processing, respectively) conscious are discussed.

A quantum implementation of holography-like processing of images in the striate cortex (V1) is proposed using a computational model called quantum associative network. The input to the quantum net could be the Gabor wavelets, together with their coefficients, which are infomax-constrained spectral and sparse neural codes produced in the convolutional cascade along the retino-geniculo-striate visual pathway using the receptive fields as determined by dendritic processes Perceptual projections are used as argument for holography-like and quantum essence of visual phenomena, because classically (neurally) alone they could not be produced in such a quality. Level-invariant image attractors are argued to be representations to become conscious in/by a subject, after a similar stimulus has triggered the wave-function collapse (i.e., recall from memory). Auxiliary representations for simultaneous subconscious processing, based on phase-information, for associative vision-based cognition are proposed to be Gabor wavelets (i.e., spectral codes in V1 receptive fields, or dendritic trees, respectively) and their coefficients (i.e., sparse codes in activities of V1 neurons).

Key Words: Image processing, brain, vision, striate cortex, V1, consciousness, quantum associative net, Pribram

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1. INTRODUCTION

This paper provides an *information-theoretic integrative model of conscious image processing* "having the kernel" in the *striate cortex* (named also the *primary visual cortex* or *V1*). Beside of an attempt to present a model that is an optimal compromise of biologically-plausible ingredients and relevant information-processing features needed for describing image processing in man, this study is interested in the problem how the *result* of image processing (the image representation) becomes conscious, i.e. how we become conscious of the perceived image.

The model is based on several earlier presentations of antecedent and accompanying physiological processes (Peruš, 2000b) and of information transfer and transformation along the visual pathway from the retina over the optic nerve and through the *lateral geniculate nucleus* (LGN) (Weliky & Katz, 1999) to V1 (Peruš, 2001). To provide a ground for the present study, a large body of neurophysiological, psychophysical, biocybernetical, neuropsychological, and other theoretical, experimental and simulation-based literature on vision (incl. reviews in: Kandel et al., 1991; Kosslyn & Andersen, 1992; Arbib, 1995) has been systematically studied, analyzed and compared in search for a synthesis (where possible). These data as well as several relevant models have been considered (Peruš, 2000a) in the context of Karl Pribram's (1991) *Holonomic Brain Theory*. Many informative complementarities were found (Peruš, 2000a, 2001). The present paper thus suggests a new comprehensive model of (conscious) image processing, while all the contextual processes – like visual attention and memory (Crick, 1984; Bickle et al., 1999; Vidyasagar, 1999; Wurtz et al., 1980; Desimone, 1996; Goldman-Raki , 1996), stereopsis (DeAngelis, 2000; Porrill et al., 1999; Poggio et al., 1985), segmentation of figure from background (Sompolinsky & Tsodyks, 1994), perceptual binding (Roelfsema, 1998; Lee & Blake, 1999a,b) and imagery (Kosslyn, 1988) – have been integratively considered in auxiliary literature (Peruš, 2000a,b, 2001).

Early visual processing: Infomax
Along the retino-geniculo-striate pathway (De Yoe & Van Essen, 1988; Livingstone & Hubel, 1988), a cascade of encoding / decoding processes, or convolutional processes, respectively, ensures optimal information pre-processing and encoding of images into various representations needed for visual cognition. Such preprocessing and encoding are realized, as psychophysical evidence (Wainwright, 1999; van Hateren, 1992) shows, so that *information is maximally preserved*, as is also imitated by the so-called *"infomax" models* of artificial neural net (ANN) processing. Many of them generate so-called sparse codes where an oligarchy of units is active in encoding the entire image, but the majority is inactive.

It was realized (Peruš, 2001) that the infomax-models, like the *Independent Component Analysis* (ICA) by Bell & Sejnowski (1995, 1996, 1997) *and sparseness-maximization net* by Olshausen & Field (1996a,b; 1997), outperform the classical Hebbian or Principal Component Analysis (PCA) models (Haken, 1991, 1996), because they incorporate *phase information*, or higher-order statistics, respectively. Infomax-models were shown to give much more biologically-plausible outputs

(receptive-field profile [2]), but a biologically-plausible implementation on the "hardware"-level is possible (for now) only for the Olshausen & Field net, not for the Bell & Sejnowski net. Relations between the Olshausen & Field (1996a,b) net and MacLennan's (1999) dendritic field computation model were found (Peruš, 2001), which indicate a possibility of dendritic implementation of the Olshausen & Field net. However, dendritic processing "following the Olshausen & Field algorithm" would be strongly constrained by sparseness-maximization process which could originate from the lateral inhibition or from top-down (i.e., corticofugal) influences (e.g., Pribram in Dubois, 2000b; Montero, 2000; McIntosh et al., 1999; Moran & Desimone, 1985).

The "sparsification pressure" is imposed on dendritic (and maybe also on neuronal) processing in order to get maximally sparse codes. Biological realization of sparsification is unknown. It might originate in virtual higher-level attractor structures (the "software" level), maybe in a similar way as in Haken (1991). The second hypothesis, i.e. that lateral inhibition forces sparsification, is reflected in Pribram's (1998a) words: *"[…] As the dendritic field can be described in terms of a spacetime constraint on a sinusoid – such as the Gabor elementary function, the constraint is embodied in the inhibitory surround of the field."*

Gabor wavelets

Since the oscillatory-dynamic phase-processing is experimentally supported (Gray et al., 1989; Baird, 1990; Pribram, 1971, 1991; Wang, 1999; Mannion & Taylor, 1992; Schempp, 1993, 1994, 1995; Sompolinsky & Tsodyks, 1994), a question arose whether ICA infomax-processing, or at least the sparsification process, might be realized virtually, i.e. on a "software"-level (higher-order attractor dynamics). ICA-like infomax processing shapes the receptive-field profiles into *Gabor wavelets*, and these are then convoluted with the sensory inputs (Pribram & Carlton, 1986). The infomax processing is thus viewed as an information-saving preprocessing procedure for optimal encoding into Gabor wavelets (also by other ICA models like: Harpur & Prager, 1996; Hyvärinen & Oja, 1998; Lewicki & Olshausen, 1999; cf., van Hateren & Ruderman, 1998).

As will be shown, infomax-based (appropriately weighted) Gabor wavelets are spectral image-representations (van Hateren & van der Schaaf, 1998) which are involved in convolution (during perceptual processing), or in interference, or in other *phase-Hebbian* processes (during pictorial cognitive processing and associations). Phase-Hebb learning rule, i.e. the Hebb correlation-rule with phase-differences (because complex-valued activities are correlated or convoluted) (cf., Sutherland, 1990; Peruš & Dey, 2000; Spencer, 2001), is a name I coined for the following expression for "holography-like" memory-storage into so-called connections (or weights, or interactions, respectively) J_{ij} between "units" i and j:

$$J_{ij} = S_k A_{ik} A_{jk} \exp(i(j_{ik} - j_{jk})).$$

A is the activity-amplitude of a "unit", j is its phase of oscillation; k is the eigenstate which

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[2] A *receptive field* of a neuron is everything (or the whole surrounding space or network, respectively) that influences its output *after* all the inputs have entered it along its own dendritic tree. The receptive-field's *profile* is a mathematical function describing the effect of transformations upon neuron's inputs (the "weights" of inputs) before the axonal output is "calculated".

represents a pattern or image.

Quantum implementation

In Peruš (1996, 1997a, 1998a) mathematical analogies in holographic, associative artificial-neural-net, spin-system and quantum-interference processes which could be harnessed for parallel-distributed information processing were systematically presented. Possible (biological) implementations of these processes were indicated. Furthermore, the *Quantum Associative Network*, an original computational model by Peruš (in Wang et al., 1998), was presented as a possible core-model for holonomic associative image processing in Peruš (2000a). Possibility for such a quantum image processing implies that the image, which is recognized by the quantum associative net, becomes the "object of our conscious experience". This hypothesis results from numerous indications (e.g., Goswami, 1990; Hameroff et al., 1994—1998; Lockwood, 1989; Raki et al., 1997; Stapp, 1993; Peruš, 1997b) that consciousness is essentially related to quantum processes. These indications are faced with skepticism (e.g., Tegmark, 2000), but experimental evidence is missing to decide between the pro- and contra-quantum camps.

The comparative neuro–quantum study, and original derivation of the model of quantum associative net from the simulated neural-net formalism, are presented in detail in Peruš (2000c). Some resulting novel suggestions for flexible image processing (e.g., "fuzzification" harnessing "quasi-orthogonal" structure of data) are described in Peruš & Dey (2000) (cf., Kainen, 1992; Kainen & Kurkova, 1993; Kurkova & Kainen, 1996).

2. ATTEMPT OF AN INTEGRATED MODEL OF IMAGE PROCESSING IN V1, AND BEYOND

Introduction to the model

The holonomic theory (Pribram, 1991) of the retino-geniculo-striate image processing (Pribram & Carlton, 1986; Peruš, 2000a) uses *Gabor wavelets* as "weighting"- or "filtering"-functions while performing convolution with the retinal image. The result of this Gabor transform is a spectral image-representation in V1. This, roughly hologram-like, representation in V1 is then reconstructed by an inverse Gabor-transform into the spatial representation in V2, probably. Thus, the topologically-correct "image" (cf., Tootell, 1998) is recovered in inverted form in V2.

The overlapped Gabor wavelets, which are used in image processing in V1, describe the receptive-field profiles of V1 neurons (Daugman, 1985, 1988) which realize the Gabor transform using their dendritic trees (cf., Berger et al., 1990, 1992; Artun et al., 1998). Gabor wavelets were shaped by an ICA-like process. Peruš (2001, 2000a) stated the reasons why it is good to prefer the Olshausen & Field (1996a,b, 1997) sparseness-maximization process over the ICA-variant of Bell & Sejnowski (1995, 1996, 1997) for the implementation-model of shaping the Gabor wavelets g (i.e., the independent components Y) and especially determining their coefficients s (i.e., the amplitudes or sparse codes of the independent components of input-images). The Gabor coefficients are updated much more rapidly than the Gabor wavelets. Coefficients change with each new input image, but the Gabor receptive fields adapt in a longer term – after a

lot of different images have been presented. In fact, they adapt slowly all the time, but substantial change is seen after a while.

From Gabor receptive fields to wavelets

A Gabor elementary function *g* has two roles in modeling vision which seem to be somewhat different. First, it is used as a description of the receptive-field profile, i.e. of the "weighting" which the synapto-dendritic net imposes on all the inputs to a neuron. Second, it is used as a Gabor wavelet which represents the encoding of an independent component of input-images. Of course, both roles have the same origin (a sort of ICA) and "are two sides of the same coin". However, the consequence of infomax-processing *manifests in different places*: in the receptive-field profile which "lies hidden" in the synapto-dendritic net, *and* in the Gabor wavelet which propagates to other brain areas and gets involved in further holography-like processing there. Namely, if the receptive field is Gabor-shaped, then it gives Gabor-shaped outputs, or at least something similar or generalized, on a later stage. These Gabor wavelets might be of another sort – e.g., time-dependent or spectral.[3]

This effect (i.e., Gabor wavelets produced because/out of Gabor receptive fields) is more clearly evident if the retinal input is made uniform (i.e., "white noise" or Ganzfeld). This is related to well-known observations that an uniform stimulation triggers a system's response which is a sort of internal "expectation" (or a "hallucination", respectively) of the filtering system (e.g., MacLennan in Pribram, 1993, p. 189).

Sorts of representations

In principle, there are two sorts of representations in V1 available for further brain processing: the spectral "compound of images", or equivalently, the sparse assembly of codes (the so-called sparse codes) representing or "weighting" the independent components extracted from a collection of images. The first representation (independent component) is hidden in V1 dendritic fields; the second representation (sparse coding) is encoded in activities of V1-neurons (cf., Pribram et al., 1981). After the spectral representation of V1 has been inverse-Gabor-transformed in the connections between V1 and V2, the retinal image re-emerges in V2. Thus, the usual image, as once originally fallen on the retina, should be reconstructed (turned upside-down, maybe also somewhat "deformed") in V2 or nearby. This "image" is then the third available representation.

Why three representations? (Cf., Kirvelis in Dubois, 2000b.) We could suppose that the spectral (Gabor wavelet) representation is for perceptual image processing in V1. The sparse-code (Gabor coefficient) representation is for robust, rough encoding needed for automatic, immediate, reflex actions — they are unconscious and probably realized by neural circuits alone (dendrites just transmit the signals, do not process them). The "image" representation in V2 is used for the usual phenomenal conscious experience.

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[3] They retain the same form, but with different interpretation of coordinate-axes. The Gabor wavelet in spectral representation see in Daugman & Downing (in Arbib, 1995). This Fourier transform of the original Gabor profile is expressed in the same functional form as the original spatial Gabor "wavelet", but with the spectral (*u*) and spatial (*x*) variables interchanged.

Let me explain. When a person is, say, involved in conversation, (s)he sees another person and at the same time processes a lot of information — e.g., "decodes" the other-person's body-language, not to mention more multi-modal and symbolic cognitive processes like understanding of words and thinking about the topic. The person sees the other one in full phenomenal integrity and quality all the time, without interruptions of the information processing (understanding body-language and spoken language, thoughts, etc.) going on in the background. For the seemingly-direct "realistic" experience of the environmental image, as conscious process offers it, the V2 space-time "image" is needed (more in Pribram, 1998a). For the abundant accompanying apperceptual processing (e.g., Luria, 1983; Stillings et al., 1995), which is unconscious and abstract, the spectral representation is needed (Pribram, 1997b). I will suppose that the "image" is also needed for additional processing, mainly limited to visual cognition, which uses associative processing that is more similar to holography than the perceptual spectral processing is.

From edge- to object-perception

Edges of object-forms are the first level of invariance or perceptual constancy and can be detected by linear transformations, like those in ICA. Incorporation of phase processing essentially improves results, as the Bell & Sejnowski and Olshausen & Field simulations demonstrate. However, finding transformations that are invariant to shifting, scaling and rotation of object-patterns, are mainly an open problem for ICA (Lee after Bell & Sejnowski, 1997). These transformations were with certain success tackled with generalized Hebbian models using Fourier-preprocessing (e.g., Haken, 1991) and by other non-infomax specialized models. ICA seems to be a good model for image (pre)processing, but not necessarily for object perception (which is well distinguished from image processing by the holonomic theory and other models of vision, and this has psycho-physiological reasons) (e.g., see Wallis & Bülthoff, 1999). Object recognition, based on search for perceptual invariances, might need a combination of ICA and associative processing (a successful example is: Bartlett & Sejnowski, 1997; cf. also Gray et al., 1997), probably in attractor-networks which manifest gestalt-like structures (Luccio, 1993; Peruš & Ečimovič, 1998).

Phase-Hebbian associations take over

Peruš (2001) thinks that visual associative processes of V1, after perceptual preprocessing has been finished (ICA has generated Gabor wavelets and Gabor coefficients, and the Gabor transform using convolution has produced spectral responses of V1 simple cells), could be well realized by a Hebbian (e.g., Churchland & Sejnowski, 1992; Gardner, 1993) or phase-Hebbian mechanism. The second one, which is most similar to holography, has much more chances for good performance.

These models may in some respect be less efficient than other phase-processing models, which are not phase-Hebbian, like ICA and MacLennan's (in Pribram, 1993) dendritic model as far as it has similarities with the Olshausen & Field (1996a,b) model. But the phase-Hebbian models have a peculiar symmetry which makes them fundamental and close to physics. So, I believe, there is a division of labor. Other models (ICA, convolution-models, Kohonen's Self-Organizing Maps) "do the hard job" first. After their

processing with nonlinear moments (like sparsification) is finished, the phase-Hebbian associative dynamics start the "fine job". Phase-Hebbian models have an ability to construct rich multi-level attractor-structures. In this, they can go beyond Hebbian models which are already successful in flexible attractor-dynamics (Haken, 1991; Peruš & E imovi , 1998).

Attractor processing

For secondary visual processing (i.e., e.g., object perception, from V1 to V2, and beyond it), processing with attractors is unavoidable (Peruš, 2000b, 2001). Pribram (1971, 1991) also says that cortical processing uses largely parallel-distributed and redundant representations. The model, which realizes this most directly and is also the best ANN embodiment of holography (cf., Psaltis et al., 1990), is sketched as follows. In simple words, the whole network of units with their connections encodes numerous "images" simultaneously: In the weight-matrix (encoded in the array of connections / junctions), there is the content-addressable associative memory. In the configuration-vector (encoded in the set of units), there is the "image" which is currently processed (which "we are *conscious* of"). Each vector of activity-configurations, which represents an "image", acts as an attractor of network's dynamics, because it is at the minimum of its potential well — as in the Hopfield model (details in: Peruš & E imovi , 1998; Peruš, 2000d).

In the matrix of connections (or "hologram"), not the whole patterns or images are stored. Merely pair-wise *(auto)correlations* of all previously-input images are stored. With other words, condensed information about (dis)agreements among all image-parts of all the watched images is encoded so that it is parallelly-distributed across the whole matrix. This is sufficient for reconstruction of an image from the memorized image-traces if a recall-key (i.e., a new, similar input pattern) is presented to the array of connectionist units (formal neurons) of the network. The interaction of these units across the connections is modeled by multiplication of the vector of units' states with the matrix of inter-unit connections (details in: Peruš & E imovi , 1998).

Quantum net as the inner processor

The essential point is that processing of the *Quantum Associative Network* (Peruš in Wang et al., 1998; Peruš & Dey, 2000), as derived from ANN in Peruš (2000c) based on analogies of Peruš (1996, 1997a, 1998), realizes the attractor-dynamics, associative processing and image recognition in a "compact" and effective way. It is progressive that Hebbian processing is enriched with phase-processing. Because this model can be quantum-implemented in a natural way, it is, for now, hard to imagine anything more fundamental, more holographic, more effective, and hypothetically more directly linked to conscious experience, in the sense of associative processing. Processing similar to that of quantum associative net might take place in V1 and partially also maybe in V2.

The quantum associative net can process, by interference, various kinds of eigen-wave-functions (eigen-images). They can be Gabor wavelets. Gabor wavelets are very similar to the natural quantum wave-packets (MacLennan in Pribram, 1993). The Gabor wavelet, originally proposed by the "discoverer" of holography D. Gabor in 1946, is a sequence of waves under a fixed gaussian envelope while the frequency of the wave

inside the envelope varies for different cases. Such a wavelet is *equivalent to a family of Weyl-Heisenberg coherent wave-packets used in quantum physics* (Lee, 1996). This observation allows me to relate infomax image-processing with quantum-implemented holography-like associative processing with attractors – in the quantum associative net. Peruš & Dey (2000) present interference-processing in the quantum associative net using the plane-waves for image-bearing eigen-wave-functions — for simplicity, although efficient. This is the most usual / basic quantum-type holography. *Interfering Gabor wavelets* could enable more sophisticated, maximally information-preserving processing, in accord with the holonomic theory.

Associative basis for visual cognition

The uniformity of (neo)cortical structure (Ebdon, 1993; details in Burnod, 1990) allows the use of phase-Hebbian associative models for a rough (but maybe the best available) approximation of global (neo)cortical processing (cf., however, Ingber, 1998; Körner et al., 1999) which is at roots of visual cognition (cf., Clement et al., 1999; Pribram, 1997a). The proper modeling combination, I suppose, would be: *ICA-constrained convolutional preprocessing up to V1, followed by fractal-based associative processing in (neo)cortical neural, dendritic and quantum attractor networks – one within another inside V1.*

My hypothesis is that the multi-level phase-Hebbian associative processing, having the quantum associative net as the most deep/inner level (for now), is currently the most convenient one for *cognitive manipulations of images or*, rather, *object-forms*, as performed probably in the inferior temporal cortex (ITC) (cf., Miyashita & Chang, 1988; Fuster & Jervey, 1982; Mishkin et al., 1983; Perret & Oram, 1998). ITC is specialized for prototype-converging recognition or *comprehension* of objects, including discriminations and choices resulting from it (Pribram, 1971). Global associations and context-searches are necessary during search of the right prototype. In accord with Rainer & Miller (2000), Riesenhuber & Poggio (2000) argue that the prefrontal cortex finishes the object-recognition started by ITC. They write on p. 1202: "In anterior ITC, invariances to object-based transformations, such as rotation in depth, illumination and so forth, is achieved by pooling together the appropriate view-tuned cells for each object." Then Riesenhuber & Poggio (2000, Fig. 3 caption) continue: "The stages up to the object-centered units probably encompass V1 to anterior ITC. The last stage of task-dependent modules may be located in the prefrontal cortex." These modules are needed for tasks like object-identification, -discrimination and -categorization, they say before.

Experiments of Rainer & Miller (2000) on object recognition in the prefrontal cortex showed that familiar objects activate fewer neurons than novel objects do, but these neurons are more narrowly tuned. Such a sparse representation of a familiar object is also more robust to degradation (made after the learning period) of a newly-posed stimulus-object. Based on ITC inputs (in vision), the prefrontal cortex is the region most important for the so-called working memory used in cognition. Present models use Hopfield-net-produced Hebbian[4] attractors for working-memory representations and attractor dynamics for (visual) cognition. I believe, generalization of these models (which were used in: Peruš & E imovi , 1998; Peruš, 2000d) by incorporating phase-processing (i.e.,

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[4] Details on neurophysiological bases of Hebbian memory-storage see in: Gardner (1993), Abbot & Nelson (2000), Bear (1996).

using the phase-Hebb rule) and implementing it in dendritic or/and quantum networks would be more appropriate.

It should be emphasized once again that image processing and subsequent object recognition could be possible only because of "the hard job done" by ICA and the perceptual convolutional cascade. They provided Gabor wavelets (cf., Pötzsch et al., 1996) and spectral representations of images which are still used in many higher cortical areas for more abstract processing (i.e., processing without the topologically-correct pictorial representation – the usual image). Volition-, "I"-based control- and symbolic processing are examples of abstract processing. On the other hand, operations of visual cognition — like imagery, mental manipulations of objects, visual modeling or planning (e.g., vividly imagining how to drive from A to B) (review in Baars, 1997) — could have cortical implementation based on the quantum associative net, especially if these processes are performed consciously. This fits the Crick and Koch (in Hameroff, 1996) hypothesis that we begin to be conscious of visual processing in V2 and beyond (encompassing visual cognition based on cooperation of ITC and the prefrontal cortex).

3. ADDITION OF CONSCIOUS EXPERIENCE AND QUANTUM PROCESSES INTO CONSIDERATION

From dendrites to conscious experience

The following citate from Pribram (1971, p. 105) summarizes the view which has been later elaborated by the holonomic theory:

> *"Neural impulses and slow potentials are two kinds of processes that could function reciprocally. A simple hypothesis would state that the more efficient the processing of arrival patterns into departure patterns, the shorter the duration of the design formed by the slow potential junctional microstructure. Once habit and habituation have occurred, behavior becomes "reflex" — meanwhile the more or less persistent designs of slow potential patterns are coordinate with awareness. This view carries a corollary, viz. that nerve impulse patterns per se and the behavior they generate are unavailable to immediate awareness. [...]*
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> *In short, nerve impulses arriving at junctions generate a slow potential microstructure. The design of this microstructure interacts with that already present by virtue of the spontaneous activity of the nervous system and its previous "experience". The interaction is enhanced by inhibitory processes and the whole procedure produces effects akin to the interference patterns resulting from the interaction of simultaneously occurring wave fronts. The slow potential microstructures act thus as analogue cross-correlation devices to produce new figures from which the patterns of departure of nerve impulses are iniciated. The rapidly paced changes in awareness could well reflect the duration of the correlation process."*

Discussion on sorts of representation in section 2 seems to fit this citate. Sparse-coding assemblies of neurons (i.e., just few neurons fire, and this is enough for encoding entire images) serve in reflexes without awareness. The second representations of images, the Gabor wavelets, interfere in the (sub)dendritic microstructure. The

correlation process, hidden in subcellular or quantum (as I prefer) interference, could also be accompanied by awareness. The final result of interference processing, the conscious image, would be reconstructed after the collapse of quantum (or at least quantum-like) wave-function.

In support for his hypothesis on junctional electric activity as the substrate for awareness, Pribram (1971, 1995) mentions that using biofeedback subjects can discriminate α-EEG waves in their brain by "feeling them as pleasantly relaxed awareness". He also cites Libet's findings that stimulation-produced awareness occurs in patients 0.5–5 seconds after the relevant brain-area has been stimulated — as if some electrical state would have to be built before the patients can experience anything.

Neural and quantum "sides" of dendrites

Infomax-processing is probably based in dendritic-*fiber* networks or/and neural circuits – on the (sub)cellular level, not quantum. V1 image processing and subsequent visual associations are probably realized by quantum-based dendritic *micro*processes. Dendritic processing thus combines two levels. Its *macroscopic fiber-part* is involved, under some top-down influences probably, in shaping the Gabor receptive-field profiles by specific collective dynamics of dendritic trees of many neurons that criss-cross. Its *microscopic membrane–"bioplasma" part* (in the patches or "holes" in-between the criss-crossed dendritic fibers beneath their membranes) implements the holography-like image-processing, as will be described in section 6, but probably by interfering a sort of Gabor wavelets instead of plane-waves. Wavelets could be naturally rooted in quantum background.

Why fractal-like multi-level processing

Systematic observations show that brain structures repeat roughly on many levels or scales like in a fractal. Why such a (seeming?) redundancy? The answer is probably: flexibility, adaptability and universality.

Pribram (1971, 1991) observes that patterns shaped or learned in one part (area, level) can be transferred to another part (area, level) of the brain. One perceives an image, can recall it, manipulate it in imagination, one can use it to guide and control motor action directed toward its object (the image of achievement). In Pribram's example, one can draw a circle with a pencil on a paper or wall using fingers of a hand or even of a foot, or one can put the pencil in the mouth. *The same pattern* (circle) *can be produced* (drawn) *in different circumstances using different body-actions and different brain areas.* Even different levels of the tissue are needed: microscopic for processing, macroscopic for execution of action. To mobilize a muscle, amplification of (sub)neural signals is necessary – that's why neurons are needed also, not just dendrites and quantum systems. Neurons are cells – like the muscle cells are also. Since Nature is multi-scale, body and brain also have to be multi-scale to handle it. The many levels therefore have to cooperate fluently, so they must be compatible in information exchange. Patterns as global information therefore have to be able to travel from one level to another. This is realizable by *fractal-like* dynamics that is intrinsic to complex (bio)systems anyway. How the *inter-level or inter-scale transfer of patterns* or images is realized is much harder to find out than to

realize that this is indeed happening (J. Anderson).

Attractors are very probably those emergent virtual structures which can "travel across the brain". They are the bioinformational or PDP (parallel-distributed processing) correlate of gestalts — each represents an invariant information-unit (percept). An attractor, a primitive "ghost in the machine", is rooted in a network-state, but *changes its substrate-elements* (Peruš & Ečimovič, 1998) like the electric current changes its underlying crystal structure or like (water) waves change (water) molecules while propagating.

4. QUANTUM ASSOCIATIVE NETWORK MODEL

Essentials
A verbal (partially metaphoric) description of processing in the quantum associative net, in comparison to holography, will now be given (mathematical details in Peruš, 2000a,c). The processing of quantum associative net *is* a sort of holography, if one is allowed to use the term outside classical optics, since the net interferes quantum waves. In fact, the quantum associative net is a quantum-mechanics-based mathematical model which can be computationally simulated (cf., Zak & Williams, 1998). No reasons have up to now been found why the model could not be implemented in a real quantum-physical system. The model also needs *specific input–output transformations*, therefore it is an informational model as much as it is a physical one.

Interpretation of states
The quantum associative net is the core of basic quantum mechanics (in Feynman's interpretation) *which is put into an intelligible interaction* with the environment (visual field). This is new: the input–output dynamics. Another essential new thing is that eigen-wave-functions (i.e., the basic, natural quantum states – they are often particles–waves, but not necessary) are harnessed to encode some information like an image. An intelligent being must be there which interacts with the system in such a way that the input-, output- and internal (memory) states represent some *meaningful information for the being*. His *interpretation "transforms" an ordinary quantum system into an information-processing system* as soon as he is satisfied with the input-to-output transformations. Let us assume so. (It is like in the case of a round piece of wood "becoming" a wheel if put in a proper context – the axis, other wheels, upper plate, etc.)

Inputs
Image processing can be done during the holographic process (Pribram, 1991). It works perfectly and simply, as all physicists and opticians know (Hariharan, 1996). It is natural in holography (as well as photography and any other optics) that the light encodes the 3-dimensional form of an object by specific modulation (i.e., shaping) of amplitudes, frequencies and phases of its waves (rays). So, it is possible to encode complicated object-forms into usual electro-magnetic waves — even with perfect resolution when the code is being reconstructed. We thus have: objects, their codes or representations (in a medium), and we need object-to-code transformations (encoding) and, finally,

code-to-object transformations (decoding or reconstruction).

Because holography works with all sorts of waves, the information-carrying waves can be quantum waves. This might bring new capabilities, but not eliminate the classical ones. Hence, the input-waves can be *plane-waves*, mathematically described by equation

$$y_k(\vec{r},t) = A_k(\vec{r},t)\exp(ij_k(\vec{r},t)) \tag{1}$$

or the input-waves can be *Gabor wavelets* (made of "increasing and decreasing waves under a gaussian envelope"). (y is the wave-function, A is its amplitude, j is its phase – at a specific location r in specific time t; k is the eigenstate index.)

We merely need means for proper manipulations of waves. Even for quantum waves, technology is so far today. Brain might also be able to do it. (Details see in Peruš, 1997a.) We thus "insert the inputs" by illuminating an object so that light-rays (or, in brain's complicated version, ICA-produced wavelets) "fall into" the quantum associative net.

Interference constitutes memory

We do that with different objects and let the waves, each belonging to an object, "mix together" while falling on a medium (the hologram-plate). This is interference of waves (like when two water-waves criss-cross) produced so that it leaves a trace (the hologram) on the medium. The wave-parts add or suppress each other (the constructive or destructive interference), and a criss-cross matrix of their relationships is recorded on the hologram. This hologram is a "frozen" *content-addressable associative memory* which becomes active when light is sent through it!

The quantum interference and quantum holography are when the waves and the hologram (but not necessarily the object) are quantum. The quantum hologram is the interference-pattern of quantum waves which leaves traces *in the quantum medium itself*. In quantum world, "parts are virtually a whole", so the waves and the hologram "inter-penetrate". Matrix G, as given by the phase-Hebbian expression

$$G(\vec{r}_1,t_1,\vec{r}_2,t_2) = \sum_{k=1}^{P} y_k(\vec{r}_1,t_1)^* y_k(\vec{r}_2,t_2) =$$

$$= \sum_{k=1}^{P} A_k(\vec{r}_1,t_1) A_k(\vec{r}_2,t_2)\exp\left(i(j_k(\vec{r}_2,t_2) - j_k(\vec{r}_1,t_1))\right) \tag{2}$$

describes the quantum hologram. Its essential memory-"traces" are phase-differences in the exponent (cf., Ahn et al., 2000). Matrix G is at the same time the carrier and transformer of waves. G is the quantum-holographic memory which is active – performs associations "through itself".

G describes the "self-organizing internal restructuring" of the quantum system by "internal interactions between its (seeming) parts", i.e. by *self*-interference. It should be emphasized here that this is not an interaction in the sense of chemical or quantum-particle (nuclear, subnuclear) reaction, but in the sense of mutual mechanical (or electrodynamic / optical) influence or *re-arrangement* on a quantum level. In the language of quantum informatics, G describes a *compound*. (The "deeper, holistic" quantum fields

incorporate *entanglements*, where parts which have once interacted cannot be really separated any more, but just seemingly. See experiment by Aspect et al., 1982.) Compounds can be "un-mixed" like the images can be reconstructed from the hologram (memory).

Associative processing
The matrix/hologram/propagator G describes phase-relationships between "infinitely"-small parts of the waves which were "mixed". This is associative memory, which also acts like a "turbine" for associative "computing". Each quantum wave y "flows through the G-turbine", and this changes both the G and the wave. In mathematical description:

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

This implies, because equation (2) should be inserted into equation (3) to replace G, that (and how, why) waves y change G and G changes waves y. This is called the coupled dynamics of the quantum system — it is a "self-holography" triggered by our inputs. We call it associative processing, because it is realized by "projecting" the quantum eigen-state or -wave "through the associative memory or hologram" G. Initial quantum-encoded informational state (ψ_{in}) is thus transformed into an *associated* quantum-encoded informational state (ψ_{out}).

Image recognition by wave-function collapse
If we want to recall a memory, or to reconstruct a stored image out of G, respectively, we have to present a part of the image or a similar image (the memory-"key") to the system (ψ_{in}). The similarity activates matching of relations, encoded in phases, and thus *selectively associates* the "key" with the most similar stored image which then "comes out of the mixture" (i.e., G) in a clearly-reconstructed form. This is described by the following sequence of equations:

$$\Psi(\vec{r}_2, t_2 = t_1 + dt) = \int G(\vec{r}_1, \vec{r}_2)\Psi'(\vec{r}_1, t_1)d\vec{r}_1 = \int \left(\sum_{k=1}^{P} y_k(\vec{r}_1)^* y_k(\vec{r}_2) \right)\Psi'(\vec{r}_1, t_1)d\vec{r}_1 =$$

$$= \left(\int y_1(\vec{r}_1)^*\Psi'(\vec{r}_1, t_1)d\vec{r}_1\right)y_1(\vec{r}_2) + ... + \left(\int y_P(\vec{r}_1)^*\Psi'(\vec{r}_1, t_1)d\vec{r}_1\right)y_P(\vec{r}_2) = A y_1(\vec{r}_2) + B$$

$$(4)$$

where $A \approx 1$ ("extracted image") and $B \approx 0$ ("noise").

I can claim that this quantum process, called *"wave-function collapse"*, is *typically holographic* in the framework of quantum associative nets (details in Peruš, 1997a). It is also essential for all quantum measurements, where one "chosen" eigen-state y_k is realized in the quantum state ψ, all the other eigen-states "retreat" (into the implicate order). Thus, the input-triggered wave-function "collapse" is the *memory-to-consciousness transition*. An image is reconstructed from memory and simultaneously "appears in consciousness", because it has been associated with all the relevant contexts during this very process! Therefore, the image is also (consciously) *recognized* at the same time!

Remarks

Memory associations are encoded in correlations of wave-amplitudes A and additionally in differences of wave-phases j. The latter encoding turns out to be more important and more fundamental, although both encodings are complementary (details in Peruš, 2000a; MacLennan, 1999; Sutherland, 1990).

In sum, the significance of the quantum associative net is in the fact that all the elements or aspects of an input-image are compared with all the elements or aspects of all the images, condensely stored in the system (as described by G or, alternatively, by the so-called *probability-density matrix* r; cf., Alicki, 1997). An optimal, "compromise" output-image is then given as the result.

In the following sections, some related quantum or similar models will be presented, and they will be, together with the quantum associative net, discussed in the context of consciousness.

5. HOLOGRAPHIC PERCEPTUAL OUT-TO-SPACE BACK-PROJECTION AND OBJECT—IMAGE MATCH

Mathematical-physical description of holography

A hologram is a complex linear superposition of collective stationary interference fringe patterns. Storage of information (i.e., object-image) is usually made by global interaction (mixing) of a coherent information-bearing object-wave (reflected from the object) and a no-information-bearing coherent reference-wave under a particular angle. Information can be later retrieved by illuminating the hologram (no object needed any more) with the anti-wave of the original reference-wave used at storage. The anti-wave is an original-like information-bearing reference-wave (called phase-conjugate wave) in the opposite direction of the original wave.

Namely, *phase conjugation* refers to the change of sign (direction) of the phase (in exponent) and thus of the wave-vector: k to $-k$. Wave-vectors with opposite signs ($k=2p/1$ and $-k$) indicate wave-propagation in opposite directions, but with the same wavelength 1. The phase-conjugate wave ($-k$) has, in the case of all local fields having the same frequency, an unique property to propagate back, in real or virtual form, along the path of the original wave (k). The advanced wave k and the retarded wave $-k$, which is *as-if* time-reversed, get superposed (giving $e^{2pint} - e^{-2pint} = 2\cos 2pnt$), due to precise timing. Thus, the *phase-conjugate wave (-k) propagates in the direction opposite to that of the original wave (k), similarly to propagation of the original wave backwards in time (as well as in space).*

Hologram's parallel-distributed organization is globally regulated by the local relative-phase variable implemented by the infinite-dimensional irreducible unitary linear representation of the Heisenberg nilpotent Lie group (Schempp, 1993, 1994, 1995; Marcer & Schempp, 1997, 1998, in Dubois, 2000b). The virtual "slices" (pages) of the hologram are frequency-organized, selective by incident angle of the page-oriented retrieval scanning reference-wave. Pattern/page-selection is executed by phase-conjugate adaptive resonance. The fractal self-identity is encoded in a hologram enabling reconstructional resolution proportional to any hologram's fraction where the total information is enfolded from. (Schempp, 1993)

Phase-Hebbian holographic associative memory has many concrete implementations, e.g. in photorefractive media — see Anderson (in Zornetzer, Davis & Lau, 1990, ch. 18).

Implementation of (bio)holograms

Hologram is realizable in fundamental (quantum)-physical media as well as in brain tissue. E.g., O'Keefe (in Oakley, 1985, p. 88-89) gives a concrete proposal of holographic processing in the hippocampus, and Nobili (1985) using damping-constant variations of local oscillators in the cortical glia-tissue. Neural holography could be realized by dendritic transmembrane-potential oscillations characterized by microwave-frequency coherence of the non-thermal excitation-states of biomolecules with high permanent dipole moments. The needed coherent "wave" could be *internally* incident. Holograms can be made also with *partly coherent* waves (Marcer & Schempp in Fedorec & Marcer, 1996; Hariharan, 1996), although usually coherent waves are used. Information between neurons is exchanged also independently of synaptic connections via glia-cells or non-anatomic coherent resonance coupling. Fundamental (sub)quantum holography could be realized with coherent overall wave-functions of dynamic quantum-vacuum (cf., Bohm & Hiley, 1993). A variety of holographic processes including single-state (e.g., single-photon) holograms are possible (why not, at least in a generalized sense, also in the brain?).

The fundamental Berry phase or geometric phase (Anandan, 1992) of the quantum system is promising for quantum memory and holographic (bio)information processing. A quantum system, which evolves so that it returns to its initial state, acquires a "memory" of this trajectory. This quantum "memory" is encoded in the Berry phase which is added to the phase of system's wave-function.

Holographic perceptual projections

We have an impression that an object we see is located "outside". The naive view is as follows: There is an object in the environment. Perception of it is produced in our brains in such a way that we see the object as it "really is – in external space". The perception appears to be somehow projected from the brain out to the original location. Pribram (1998b) mentions several cases of such perceptual or even cognitive projections: For example, one feels the paper, on which one is writing, at the tip of his/her pen, not at the tip of fingers holding the pen. A well-known case are also the so-called phantom-limbs — a patient feels the amputated limb which he has just lost. The pain is felt outside the remaining part of the limb — at the location where the former complete limb was or should be. In experiments, cited by Trstenjak, subjects spontaneously write on their own foreheads a letter (e.g., F) oriented as if they would read it from inside out (with their "mind's eye"), or as if they would write it on the internal side of their own foreheads. Projective nature and use of percepts are thus a part of human performance.

Let us illustrate how we could start to model holography-like perception and memory-recall. First, in stage 1, a subject faces an external, illuminated object. Light-waves reflect from object's surface toward subject's eyes. Image of the object is processed in his visual cortex, and gets memorized in a holography-like manner.

Later, in stage 2, the subject faces a similar object or the same one. Its light-wave indirectly interacts with holographic memory of the (original) object. A memory-image is remembered when the corresponding hologram-page is selectively reconstructed (as detailed in: Peruš, 2000c). By a *phase-conjugate wave*, the perception (a compromise of the

stimulus and memory) is experientially projected back (from brain) into the surrounding space to the location of the original object. *The virtual (holographically back-projected) image of the remembered or perceived object coincidences in space with the original object.* This important and plausible hypothesis originates from: Marcer & Schempp (1998, in Dubois, 2000b). The idea of holographic back-projection by the (quantum) phase-conjugate wave is not yet finally proven, but it fits our *feeling* that the object and its brain-made and out-projected virtual image coincide out-there as if they are one!

The *perceptual* projection has been proven, for example, by the G. von Bekesy experiments (Pribram, 1971, pp. 168-171; 1991, pp. 90-91), but the *quantum-optical* phase-conjugate back-wave remains a question of quantum "reality" (i.e., theoretically it exists and is useful, experimentally there are indications, but there are different interpretations about their "reality"). The hypothetical back-projection waves would be *quantum* – not classical electro-magnetic waves like the input-waves to the retina. They would *not* exist *really* in the ordinary, i.e. classical-physical, sense. (These waves could "propagate backwards in time", "symmetrically" to the original input-wave, as in quantum field theory.)

To repeat: In stage 1, an original object is seen — a representation (a virtual "image") of it is produced in the brain. In stage 2a, a similar or the same object triggers remembering the original object of stage 1. In stage 2b, which follows stage 2a immediately, a joint perceptual image (usually a "compromise" of images of stages 1 and 2a) is projected back to the location of 1 or 2a, respectively. These stages of the dynamic holography-like process usually *iterate* and possibly converge to a maximal agreement of perception with phenomenal reality. Beside pragmatic advantages to the organism, this is also necessary for unambiguous, consistent communication between image-making subjects, since they share the perceived objects in positions relative to one another in the 3-dimensional "Cartesian theatre" they co-create (Marcer & Schempp in Dubois, 2000b).

Iterative matching loop
Thus, the image, which brain/mind creates, is perceptually coincident, maybe also quantumly coincident, i.e. phase-conjugate, in external space with the object imaged. In physical terms, there is a coincidence and annihilation (yy^*) of positive phases of forward-propagating waves (y, having wave-vector k) with negative phases of backward-propagating waves (phase-conjugate y^* with $-k$). Forward waves encode the original object and backward waves its perceptual image. *When they meet and match (yy^*) on the path they share, the perceptual transaction is completed, hence the wave-function collapse occurs* (Cramer, pers. commun.) *and so the image becomes conscious.* This adaptive-resonance hypothesis is best understood with the *transactional interpretation of quantum mechanics* by Cramer (1986).

One can ask: what is (or even: is there any) difference between the perceived object and the back-projected image of it (i.e., the image in the original location in the environment, not the image/code in the brain, say in V1). Disagreements lead to errors or misperceptions. The iterative matching process can also be led to creative generalizations and associations.

In *imagery*, or more plastically in hallucinations, the (possibly modified) back-projected image of the object replaces the non-existent object (which was present

in stage 1, but not in stage 2 when the reconstructed reference-wave has some internal sources). In *perception*, the back-projected image phenomenally fits the real object.

Why (quantum) holography is necessary for spatial perception

Phase-conjugate projection of the image back into the space-location of the original object is an *exclusive characteristic of holography* (or at least of optics, if the image would perhaps be processed in another way, not holographically). Namely, *neural networks or other hard-wired subcellular networks, without having electro-magnetic or quantum embedding, can definitely not back-project their images into the external space on their own*. But we experience that perceptual projection is happening. Because holography (not photography) is involved, it is not directly the object-image that is back-projected (as in photography), but it is the *wave (-k)*, which carries the encoded object-image, that is back-projected by phase-conjugation during/after holographic retrieval (Marcer & Schempp, 1998, in Dubois, 2000b). So, *the external medium must be of the same or at least similar nature than the medium of the brain-hologram*. Hence, the *common medium can only be quantum field!*

Philosophical questions

Actually, there can be no plastic, geometrically-/ topologically-correct 3-dimensional perception of the object, which we experience and call "the real/true perception", without that fitting of the object with the back-projected image of it (which has been a moment earlier reconstructed from the "brain hologram"). This iterative fitting seems to need time, unless the Cramer (1986) transactional interpretation with "quantum waves backward in time" is adopted; but in fact space-time is co-created by ("in") our conscious experience "during" this visual processing. Objects and brain-states seem to be located in space and time, but conscious experience "has been/is/will be there all the time – as long as the Cartesian theatre is in the play". (E.g., Cramer (1986) even says that his interpretation, or a quantum transaction, respectively, is *a*temporal.)

Nothing is perceived outside mind: There are no perceptions, which we are aware of, without consciousness (i.e., conscious experience), and there are no phenomenal unconscious or subconscious sensations or "detections" (i.e., perceptions we are not aware of) without mind. A Kant's *Ding-an-Sich* is not perceived; just the co-created thing is, i.e. a "deformed shadow" of the hypothetical *Ding-an-Sich*. Thus, a perception is a Plato's "shadow" created by consciousness in cooperation with Nature, or "deformed" by brain-processing.

Various back-projections, like visual, tactile, auditory ones, match with the object and with each-other! Our vision "quantum-touches" the object successfully as well as our hands mechanically touch it simultaneously. Indeed a peculiar space-time fit. (But maybe this "resonance", and space-time incorporating objects, and conscious experience including objects, is the *same* thing/process… However, this symmetry or harmony (fit) may be broken, e.g. in hallucinations… The dilemma of reality thus remains.)

6. DENDRITIC HOLOGRAPHY-LIKE IMAGE PROCESSING

Bioplasma dynamics

How can a dendritic network (physiology see in: Pribram, 1991, 1993; Damask & Swenberg, 1984; Koch, 1997; Koch & Segev, 2000) implement holography-like image processing of V1? Stimulus-specific waves of the dendritic field are produced, and these information-encoding waves interfere. A phase-Hebbian PDP is realized.

There are (at least, roughly) two related kinds of collective oscillations accompanying the dendrites cris-crossed in networks: first, the oscillations of dendritic membrane potential, and second, the oscillations of dendritic ionic "bioplasma", or of the electric polarizations within, respectively. The "bioplasma" "flows" and "waves" near the membrane-surface of the dendrite. It depends on the biomolecules (proteins, lipids, etc.) of high dipole moments located on (beneath, in, near, along, respectively) the dendritic membrane, and the ionic charge travels through it.

This membrane–"bioplasma" system of numerous coupled electric dipoles exhibits dynamic ordering which is determined by the distribution of phase-differences in oscillations of the corresponding dendritic potentials. The isophase-contours of oscillations in the polarization-field, extended over dendrites (especially their membranes) and the accompanying "bioplasma", determine the collective wave- and fluid-phenomena that are the *correlates of image processing at the subcellular level of V1* (after Appendix A of Pribram, 1991).

The Jibu, Yasue and Pribram model

The density (or concentration) of the ionic "bioplasma" $r(x,t)$ changes as a result of the dynamic pattern of hyperpolarizations and depolarizations across the space inside and outside dendrites. Yasue, Jibu & Pribram (in Appendix A of Pribram, 1991) defined a wave-function $y = \ddot{O}(r) \, e^{ij}$ (j is the phase). They derived (*ibid.*, pp. 282-286) a wave-equation for the membrane–"bioplasma" system:

$$in \frac{\partial y}{\partial t} = \left(-\frac{n^2}{2} \nabla^2 + U_{ex} \right) y \tag{5}$$

which has the same mathematical form as the Schrödinger quantum wave-equation (cf., Bonnell & Papini, 1997), but with different interpretations of variables. U_{ex} is the external static energy / potential, i.e. the external electric influence (stimulus). n is a constant (a "relative" of the quantum Planck constant) equal to a quotient of "flow"-velocity v and the length of the so-called wave-vector k which is equivalent to spatial frequency, related to the change of phase: $k = \tilde{N}j$.

Successful derivation of such an equation, having a characteristic form for wave phenomena, for an idealized dendritic network / field shows that global polarization-waves, described here by y, emerge in the subcellular medium. As a consequence of these waves, "flows" and interference are also produced in the dendritic net. There are, of course, many variations of oscillations / waves / interferences in that complex medium. y (with different interpretations) could be chosen to approximate (m)any of them.

Phase-Hebb-like memory-storage in bioplasma

Wave-equation (5) is alone not enough for image processing. From wavelets

$$y(x,t) = \sum_n c_n \left(\frac{1}{L}\right) \exp\left[\frac{i}{n}\left(\frac{2p}{L}nx - I_n t\right)\right] \tag{6}$$

we obtain (details in Pribram, 1991, A, pp. 288-291) the density $r(x,t)$ of charge-distribution in "bioplasma":

$$r(x,t) = |y(x,t)|^2 = y(x,t)^* y(x,t) =$$
$$= \sum_n |c_n(t)|^2 \left(\frac{1}{L}\right)^2 + \sum_{n \neq n'} c_{n'}^*(t) c_n(t) \left(\frac{1}{L}\right)^2 \exp\left[i\frac{2p}{L}(n-n')x\right] \tag{7}$$

c_n are the Fourier coefficients; L is a characteristic spatial extent of the dendritic system along the spatial axis x; I_n is a constant; n, n' are integer numbers. The last term manifests interference, which is essential for holographic memory, since it has a phase-Hebb-like structure: $c_{n'}^*(t)c_n(t)$ represents "interference of amplitudes" and $exp[(2pi/L)(n-n')x]$ "interference of oscillations" – in the exponent one finds the phase-differences.

The flow of dendritic perimembranous "bioplasma" is driven by the phase-differences among isophase-contours (i.e., curves connecting all synchronized oscillations). The "density-based flow" toward an attractor at the centre of the concentric contour-family is regulated by the gradient (i.e., maximal change-rate) of phase ($\tilde{N}j$). Exactly:

$$\frac{\partial r}{\partial t} = -n \nabla \cdot (r \nabla j) \tag{8}$$

The wave-equation (5) and equation (8) describe the subcellular "fluid-dynamical" correlate of associative image processing in the V1 dendritic net.

Papers like Berg et al. (1996), Bray (1995), and those in Fedorec & Marcer (1996) support the possibility of biomolecular realization of holographic processing at the subcellular level (cf., Nobili, 1985; Psaltis et al., 1990; Sutherland, 1990; Snider et al., 1999). These dendritic dynamics (Yasue, Jibu & Pribram in: Pribram, 1991, Appendix A) are in general principles equivalent to processing of the quantum associative net, but incorporate some sophisticated constraints imposed by characteristics of the subcellular tissue. The difference also is that the dendritic wave dynamics are quantum-like, but quantum associative nets are purely-quantum. Namely, Yasue *et al.* give a different interpretation of the wave-function y than the Peruš, Bohm and Copenhagen quantum interpretations. In the Yasue *et al.* "quasi-quantum" case, y corresponds to the "bioplasma-density" r, i.e. $y = \ddot{O}(r) \, e^{ij}$. Thus, the "bioplasma-density" r does not exactly correspond to the quantum density matrix r, because the amplitude of the "bioplasma"-y is defined as $\ddot{O}(r)$ (not quantum!) to get the "quantum" $y^* y = r$.

7. MICROTUBULES, COHERENT SUBCELLULAR AND QUANTUM PROCESSES, AND CONSCIOUSNESS

Microtubules

Microtubules, cilindric/filamentary tubes, are the most important ingredient of the *cytoskeleton* which is a protein-made intracellular network. Microtubules extend along dendrites, come together at soma, and extend further along axons. They consist of oriented assemblies of electrical dipoles, or permanent electric polarization systems (electrets), respectively, which globally act as mega-dipoles.

A hypothesis (by Hameroff, 1994) with increasing support has been presented that cytoskeletal microtubules, constituting a network in cooperation with MAP (microtubule associated proteins), realize sub-cellular information processing based on coupled oscillatory collective dynamics. Since Hameroff & Penrose (1995) emphasize that mainly *dendritic* microtubules act such a role, this hypothesis might not be entirely incompatible with the holonomic theory, but complementary. Such dynamics emerges from conformational transitions of tubulin electric-dipolar molecules, which act as "bit flips", and from soliton-based, almost loss-less transfer of energy and information (phase!) along the paracrystalline microtubules. Tubulin states might encode the pixels of patterns which are processed (Hameroff, 1994; Nanopoulos, 1995). Globally, the processing is manifested in changes of concentration of electric polarization (polarization density), and moving of the concentration peaks from one side of the tubulin-web to another.

Long-range quantum coherence and related laser-like, thermal-noise-free (and information-loss-free) ordering phenomena, like super-radiance and self-induced transparency may take place in microtubules. The hypothesis that quantum coherence subserves binding of conscious perceptions is supported by an increasing number of authors (e.g., Hameroff et al., 1996). Microtubules are viewed by Jibu & Yasue (1997) as information-encoders into a coherent subcellular optical PDP network. Fröhlich (1968) has shown the first signatures of interdependence of biological and quantum oscillatory dynamics.

Fröhlich coherence

As proposed by Fröhlich (1968) and succesors, the so-called Fröhlich (long-range, microwave) coherence emerges from interacting oscillating (10^{11}-10^{12} Hz) dipoles of biomolecules. Electric polarization density serves as the biological order-parameter. Fröhlich coherent oscillations may lead to two sorts of extreme collective states: to the Bose-Einstein condensate, where all dipole-elements act as if they are one, or to loss-less solitonic polarization-waves (proposed by the Davydov model), where the dipole order propagates as one traveling condensate (Denschlag et al., 2000). This is analogous to superconductivity. Indeed, it was proposed by Jibu & Yasue (1995, 1996, 1997) that the experimentally-supported Fröhlich waves along the protein filaments can propagate without resistance, thermal loss and damping. Such superconductivity hypothetically occurs even at body temperature.

Subcellular automata

Many nanobiological systems could be represented as assemblies of dipoles: 1. cell membrane as a double sheet full of dipoles; 2. cytoplasmatic and extracellular water; 3. microtubules as systems of tubulins; etc. Systems of dipoles or spins can be arranged: 1. randomly; 2. ferroelectrically (i.e., aligned in parallel); 3. as spin-glass (i.e., in domains of frozen (dis)order, each with its own parallel alignment) (Mezard et al., 1987). The membrane bi-layer of dipoles might incorporate sandwich-like *Josephson junctions*, over which superconducting electrical currents with special effects would flow. They might be connected into a peculiar PDP "Josephson net-computer" (Rein in Pribram, 1993; Jibu & Yasue, 1995).

Quantum effects in synapse

Eccles (e.g., in Pribram, 1993) pioneered the idea that conscious mind, using attention, could influence the probability of discrete (quantal) release (*exocytosis*) of vesicles full with neurotransmitter-molecules at the hexagonal-paracrystalline presynaptic vesicular grid. Conscious mind would impose effect on probabilistic quantum processes (e.g., the wave-function collapse) underlying the probabilistic exocytosis in synapses. So, conscious process would selectively modulate, through quantum fields, the essential ingredients of memory-storage and associative processes – synaptic efficiacies (Rein in Pribram, 1993). To be precise, quantum influences should trigger electronic rearrangements resulting in movement of hydrogen-bridges which would effect vesicle-release from the presynaptic hexagonal grid (Hameroff, 1994).

Collapse and consciousess

The hypothesis of Hameroff & Penrose (1995, 1996, 1997) advocates microtubules and their nets as the main subneuronal substrate of consciousness. They are flexible, fast-changing and might allow retrograde signaling, thus mediating bi-directional subneuronal links between synapses. Hameroff (1994) argues, based on observations, that general anaesthetics cancel conscious experience by operating mainly on specific microtubular ingredients. He writes that an anaesthetized brain usually remains quite active (as persistent EEG, evoked potentials and autonomic functions show), but this activity is neural, not microscopic quantum. So, quantum coherence, which gets disrupted by anaesthetics, should be essential for conscious experience.

In contrast to the environment-induced wave-function collapse of quantum theory (and of the quantum associative net), the wave-function collapse in microtubules is supposed by Hameroff & Penrose (1995, 1996) to depend on quantum gravity: Condensates which become larger than a threshold-size should cause their common wave-function to collapse "under their own mass". This would be thus a self-collapse called *orchestrated objective* collapse. Each such collapse is considered by Penrose and Hameroff to be a single conscious event. A temporal sequence of such conscious "nows" would constitute the "flow" of conscious experience, by this hypothesis.

According to the Hameroff & Penrose (1995, 1996) sketch, preconscious net-computing, when the classical (sub)neuronal PDP (parallel-distributed processing) is gradually replaced / complemented with quantum PDP, leads to emergence of a quantum

coherent superposition. Each of its superposed alternative states has its own "competing" space-time geometry. When an instability-threshold is exceeded, the time-irreversible orchestrated objective self-collapse occurs, and this *is* the conscious experience (the "now"). This moment of maximal coherence "illuminates" the (results of) preconscious network-processing of images etc. (executed till the collapse) "by making it conscious" at the very moment of collapse which "chooses" one from many alternatives. The selected information-state (e.g., a recognized image) is further-on processed unconsciously in a classical way — until a new quantum coherence "consciously illuminates" the new mental state to make a qualitative experience of it, says the hypothesis.

Subcellular "holography"

A number of oscillatory network-structures were mentioned: electric-dipole systems, microtubular nets, "bioplasma", extracellular matrix, protein nets, Josephson-junction nets, etc. They individually or in cooperation (as is usual) are able to exhibit holography-like interference processing (Pribram, 1993). However, molecular vibrational fields in these nets are just a sort of *interface between quantum networks and neural networks*. They all are very probably influencing, directly or indirectly, the synaptic efficiacies (e.g., whether they are inhibitory or excitatory, and how much) (e.g., Nanopoulos, 1995).

Subcellular coherence

What follows, is based on speculations by Jibu & Yasue (1995, 1996, 1997), derived from quantum field theory of Umezawa.

Beneath many levels of cell's biomolecular structure, many levels of sub-atomic or inter-atomic quantum particles, and their ensembles or condensates, can manifest collective dynamics capable of coherence and interference processing of holography-like sorts (reviews in Pylkkänen & Pylkkö, 1995; Pribram, 1993). They should mainly "live" in the intra- and inter-cellular *water* which composes more than 70% of the material composition of brain-cells like neurons and glia. These particles should collectively take part in water's rotational fields (or spinor-fields, emerging from spins of particles or from molecular spinning dipoles) and their interactions with the electro-magnetic field (i.e., with its quanta – photons).

Of special importance is supposed to be the Nambu-Goldstone boson (a sort of dipole phonon) which is a mass-less quantum of a long-range correlation-wave of the water rotational field created in an ordered vacuum-state.

Quantum binding

Macroscopic condensates of Nambu-Goldstone bosons are, after the hypothesis of Jibu & Yasue (1995, 1996, 1997), the fundamental carriers of perceptual memory and cues for reconstruction of the original stimulus-perception. Since they depend on the interaction of radiation (photons) and dipoles, they lead to evanescent (i.e., virtual, tunneling) photons which may collectively produce *Bose-Einstein condensates*. In such a condensate, many particles merge into a collective, unified, macrosopic quantum state. Particles (e.g., photons), which are able to unite into such a coherent condensate, are called bosons; particles (e.g., electrons), which never occupy the same quantum state, are called fermions. A Bose-Einstein condensate of evanescent photons is proposed to be the ultimate

neurophysical correlate of an *unified conscious experience*. In Hameroff (1998, Box 1) and Jibu & Yasue (1995, 1996, 1997) suggestions are given how the Bose-Einstein condensates could be shielded enough by special biomolecular structures against the destroying thermal fluctuations.

The coherent dipole-field (i.e., having dipoles oriented in the same direction) of water might extend over the whole brain tissue or even whole body, not just over several cells. The coherence-length, i.e. a "diameter" of the region of coherent oscillations of all net-elements like dipoles, is calculated to be in the case of outer perimembraneous water about 20 to 50 μm (Jibu & Yasue, 1997) (more than cell-dimensions). Such ordered water with presumably laser-type processes is assumed to enable photonic holography in and around microtubules and in extracellular matrices (Jibu & Yasue, 1995; Hameroff, 1994).

Qualia unexplained

I can agree (Peruš, 1996-2000) with Hameroff and Penrose that the wave-function collapse seems essential for transitions from subconsciousness (or preconsciousness, or unconscious memory) to conscious experience. It also illustrates the classical–quantum (neuro–quantum, macro–micro) transitions. But saying (Hameroff & Penrose, 1996) that only and merely the "orchestrated collapse" (not any usual stimulus-induced collapse) provides the non-computable element necessary for consciousness, does not give any explanation of the qualitative experience.

Namely, the central characteristics of consciousness are *qualia* which are subjective, qualitative, phenomenal experiences ("how things seem to be to us") (Flanagan, 1992; Davies & Humphreys, 1993; Marcel & Bisiach, 1988). Examples of qualia are experiencing yellowness of a lemon, feeling pain in own elbow, and in general also *what it is like to be* a person, etc. Qualia are felt in first person only, not in third person. A blind person cannot imagine precisely how it is to see; person A does not know precisely how person B feels. Qualia cannot be identified with their neural correlates — these are discussed, for example, in: Newman (1997), Frith et al. (1999); for color in: De Valois & Jacobs (1968), Schiller & Logothetis (1990).

Anyway, one might speculate that the usual stimulus-induced collapse is related to conscious perception of the stimulus, and that the orchestrated objective (if indeed induced by quantum gravity) collapse is rather related to (introspective) awareness. Although this hypothesis provides relations of conscious process to the origin of space-time, the problem of qualia remains. Qualia are only (with justice, I think) transferred to the most fundamental level (also). This could be concluded also for the suggestions of Jibu and Yasue: They might "explain" the origin of the unity of conscious experience, but not its qualitative phenomenal character.

8. CONCLUSIONS

This sketched integrated model based in the abundant literature of cognitive neuroscience (review in Kosslyn & Andersen, 1992), but transcended it by introducing fundamental informational (bio)physics. The latter seems to be needed (e.g., Bob & Faber, 1999) and promising (e.g., Dubois, 2000a,b; Pessa & Vitiello, 1999) for modeling quantum background of conscious processing (cf., Ezhov et al., 2000, 2001; Weinacht et al., 1999; Rabitz et al.,

2000; Snider et al., 1999; Spencer, 2001; Wheeler & Zurek, 1983; Jones et al., 2000 – for hints from frontier technology).

According to the holonomic theory (Pribram, 1991), holography-like parallel-distributed processing in dendritic networks of V1 is essential for image processing. To be more specific, electric polarization fields or quantum fields and their wave phenomena are inside dendritic criss-crosses could be the central "medium" for processing. Here, it was proposed that the image-bearing eigen-waves, which interfere in the quantum associative net, are or at least could be infomax-produced, quantum-rooted Gabor wavelets. I thus suggest that the neocortex uses three types of image representations: the Gabor coefficients as sparse neuronal codes for automatic processing, the dendritically-implemented Gabor wavelets as spectral codes for associative visual cognition, and the V2-reconstructed spatial image used in our "direct" conscious experience.

Because the perceptual image seems to match precisely the original object in its external location, holographic back-projections by phase-conjugation have been argued to be necessary. Since neural or dendritic nets alone cannot realize such out-to-space projections, the only medium which is common to holography and to brain networks was declared ultimately responsible for conscious perception — the quantum system.

These ideas have been presented in the context of models by Pribram, Jibu and Yasue, Hameroff and Penrose, among others. Together they constitute, I believe, a view on systems-processing backgrounds of conscious image processing that provides an optimal integration of complementary proposals by the mentioned authors based on current knowledge. In accord with other views, the wave-function collapse was argued to be the physical correlate of becoming conscious of a selected image. The problem of qualia remains unsolved.

Tegmark's (2000) calculation result, which says that the decoherence time-scales ($\sim 10^{-13}$–10^{-20}s) are usually much shorter than the relevant dynamical time-scales ($\sim 10^{-3}$–10^{-1}s) for regular neuron firing as well as for kink-like polarization excitation in microtubules, might have a negative effect on the microtubular hypothesis by Hameroff and Penrose, and also on *some* views of Jibu and Yasue, but *not* also on the more fundamental model of quantum associative net (sec. 4), I suppose.

Concerning the kernel of the presented model, I can assume with much optimism that the quantum associative net, if really quantum implemented (as also, in a way, probably in brain), would realize efficient image recognition and related associative processing. Systematic comparison with extensive cognitive-neuroscientific literature allows me to assume that in cooperation with other brain structures, such an image processing would probably be conscious. A forthcoming paper will discuss results of the present paper in the context of experimental data on neural correlates of conscious visual experience and its impairments such as blindsight (Koch in Hameroff et al., 1996; Davies & Humphreys, 1993).

References

Abbot LF & Nelson SB. Synaptic plasticity: taming the beast. Nature Neurosci (Suppl) 2000;3:1178-1183.

Ahn J, Weinacht TC & Bucksbaum PH. Information storage and retrieval through quantum phase. Science 2000;287:463-465.

Alicki R. Quantum ergodic theory and communication channels. Open Systems & Information Dynamics 1997;4:53-69.

Anandan J. The geometric phase. Nature 1992;360:307-313.

Arbib MA. (Ed.) The Handbook of Brain Theory and Neural Networks. Cambridge (MA): MIT Press. 1995.

Artun ÖB, Shouval HZ & Cooper LN. The effect of dynamic synapses on spatiotemporal receptive fields in visual cortex. Proceedings of the National Academy of Sciences of USA 1998;95:11999-12003.

Aspect A, Dalibard P & Rogier G. Experimental test of Bell's inequalities using time-varying analyzers. Physical Review Letters 1982;49:1804-1807.

Baars BJ. In the Theater of Consciousness. New York: Oxford Univ. Press. 1997.

Baird B. Bifurcation and category learning in network models of oscillating cortex. Physica D 1990;42:365-384.

Bartlett MS & Sejnowski TJ. Viewpoint invariant face recognition using independent component analysis and attractor networks. Advances in Neural Information Processing Systems 1997;9:817-823.

Bear MF. A synaptic basis for memory storage in the cerebral cortex. Proceedings of the National Academy of Sciences of USA 1996;93:13453-13459.

Bell AJ & Sejnowski TJ. An information-maximization approach to blind separation and blind convolution. Neural Computation 1995;7:1129-1159.

Bell AJ & Sejnowski TJ. Learning the higher-order structure of a natural sound. Network: Computation in Neural Systems 1996;7:261-266.

Bell AJ & Sejnowski TJ. The "independent components" of natural scenes are edge filters. Vision Research 1997;37:3327-3338.

Berg RH, Hvilsted S & Ramanujam PS. Nature Lett. 1996;383:505-508.

Berger D, Pribram K, Wild H & Bridges C. An analysis of neural spike-train distributions: determinants of the response of visual cortex neurons to changes in orientation and spatial frequency. Experimental Brain Research 1990;80:129-134.

Berger DH & Pribram KH. The relationship between the Gabor elementary function and a stochastic model of the inter-spike interval distribution in the responses of visual cortex neurons. Biological Cybernetics 1992;67:191-194.

Bickle J, Bernstein M, Heatley M, Worley C & Stiehl S. A functional hypothesis for LGN-V1-TRN connectivities suggested by computer simulation. J Computational Neuroscience 1999;6:251-261.

Bob P & Faber J. Quantum information in brain neural nets and EEG. Neural Network World 1999;9:365-372.

Bohm D & Hiley B. The Undivided Universe (An ontological interpretation of quantum theory). London: Routledge. 1993.

Bonnell G & Papini G. Quantum neural network. Internat. J Theoretical Physics 1997;36:2855-2875.

Bray D. Protein molecules as computational elements in living cells. Nature 1995;376:307-312.

Burnod Y. An Adaptive Neural Network: the Cerebral Cortex. London: Prentice Hall. 1990.

Churchland PS & Sejnowski TJ. The Computational Brain. Cambridge (MA): MIT Press. 1992.

Clement BEP, Coveney PV, Jessel M & Marcer PJ. The brain as a Huygens machine. Informatica 1999;23:389-398.

Cramer JG. The transactional interpretation of quantum mechanics. Reviews of Modern Physics 1986;58:647-687.

Crick F. Function of the thalamic reticular complex: The searchlight hypothesis. Proceedings of the National Academy of Sciences of USA 1984;81:4586-4590.

Damask AC & Swenberg CE. Medical Physics. Orlando: Academic Press. Vol. III: Synapse, Neuron, Brain; ch.4: Chemical and electrical properties of synapses; ch. 5: Neuronal integration and Rall theory. Vol. I: Physiological Physics, Ch.3: The nerve impulse. 1984.

DeAngelis GC. Seeing in 3 dimensions: Neurophysiology of stereopsis. Trends in Cognitive Sciences 2000;4:80-90.

Daugman JG. Uncertainty relation for resolution in space, spatial frequency, and orientation optimized by 2-D visual cortical filters. J Optical Society of America A 1985;2:1160.

Daugman JG. Complete discrete 2-D Gabor transforms by neural networks for image analysis and compression. IEEE Transactions on Acoustics, Speech, and Signal Processing 1988;36:1169.

Davies M & Humphreys GW. (Eds.) Consciousness. Oxford: Blackwell. 1993.

Denschlag J., et al. Generating solitons by phase engineering of a Bose-Einstein condensate. Science 2000;287:97-101.

Desimone R. Neural mechanisms for visual memory and their role in attention. Proceedings of the National Academy of Sciences of USA 1996;93:13494-13499.

De Valois RL & Jacobs GH. Primate color vision. Science 1968;162:533-540.

De Yoe EA & Van Essen DC. Concurrent processing streams in monkey visual cortex. Trends in Neurosciences 1988;11:219-226.

Dubois DM. (Ed.) Proceedings of CASYS'99. Internat. J. Computing Anticipatory Systems 5, 6, 7. Liege: CHAOS. Especially, in vol. 7: Proceedings of the Symposium "Quantum Neural Information Processing: New Technology? New Biology?" (espec. papers by Marcer, Sutherland, Farre, Mitchell, Dubois; also Citko, Luksza & Sienko). 2000a.

Dubois DM. (Ed.) AIP Conference Proceedings, vol. 517: Computing Anticipatory Systems – CASYS'99 in Liege. Melville (NY): American Institute of Physics (especially papers by Marcer & Schempp, Kirvelis, Sienko, Hoekstra & Rouw, Santoli, Pribram, Dubois, Araujo). 2000b.

Ebdon M. Is the cerebral neocortex an uniform cognitive architecture? Mind & Language 1993;8:368-398.

Ezhov AA, Nifanova AV and Ventura D. Quantum associative memory with distributed queries. Information Sciences 2001; In press.

Ezhov AA and Ventura D. Quantum neural networks. Ch. 11 in: N. Kasabov (Ed.): Future Directions for Intelligent Systems and Information Sciences (Series "Studies in Fuzziness and Soft Computing", vol. 45). Heidelberg: Physica-Verlag (Springer), 2000;213-235.

Fedorec AM and Marcer P (Eds.): Living Computers (symposium proceedings). Dartford: Greenwich Univ. Press. 1996

Flanagan O. Consciousness Reconsidered. Cambridge (MA): MIT Press. 1992.

Frith C, Perry R & Lumer E. The neural correlates of conscious experience: an experimental framework. Trends in Cognitive Sciences 1999;3:105-114.

Fröhlich H. Long-range coherence and energy storage in biological systems. Internat. J Quantum Chemistry 1968;2:641-649.

Fuster JM & Jervey JP. Neuronal firing in the inferotemporal cortex of the monkey in a visual memory task. J Neuroscience 1982;2:361-375.

Gardner D. (Ed.) The Neurobiology of Neural Networks. Cambridge (MA): MIT Press. 1993.

Goldman-Raki PS. Memory: Recording experience in cells and circuits. Proceedings of the National Academy of Sciences of USA 1996;93:13435-13437

Goswami A. Consciousness in quantum physics and the mind-body problem. J Mind & Behavior 1992;2:75-96.

Gray CM, König P, Engel AK & Singer W. Oscillatory responses in cat visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. Nature 1989;338, 334-337.

Gray MS, Movellan JR & Sejnowski TJ. Dynamic features for visual speech-reading: A systematic comparison. Advances in Neural Information Processing Systems 1997;9:751-757.

Haken H. Synergetic Computers and Cognition (A Top-Down Approach to Neural Nets). Berlin: Springer. 1991.

Haken H. Principles of Brain Functioning. Berlin, Springer. 1996.

Hameroff SR. Quantum coherence in microtubules: a neural basis for emergent consciousness? J. Consciousness Studies 1994;1:91-118.

Hameroff SR. "Funda-Mentality": Is the conscious mind subtly linked to a basic level of the Universe? Trends in Cognitive Science 1998;2:119-127.

Hameroff SR, Kaszniak AW & Scott AC. Towards a Science of Consciousness: Tucson I. Cambridge (MA): MIT Press. 1992.

Hameroff SR & Penrose R. Orchestrated reduction of quantum coherence in brain microtubules: A model for consciousness. In: J. King, K. Pribram (Eds.): Scale in Conscious Experience: Is the Brain Too Important To Be Left to Specialists to Study? Mahwah (NJ): Lawrence Erlbaum Assoc., 1995;243-275.

Hameroff SR & Penrose R. Conscious events as orchestrated space-time selections. J Consciousness Studies 1996;3:36-53.

Hariharan P. Optical Holography. Cambridge: Cambridge Univ. Press. 1996.

Harpur GF & Prager RW. Development of low entropy coding in a recurrent network. Network: Computation in Neural Systems 1996;7:277-284.

Hyvärinen A & Oja E. A fast fixed-point algorithm for independent comp. anal. Neural Computation 1997;9:1483-1492.

Ingber L. Statistical mechanics of neocortical interactions: Training and testing canonical momenta indicators of EEG. Mathematical & Comput Modelling 1998;27: 33-64.

Jibu M, Pribram K & Yasue K. From conscious experience to memory storage and retrieval: The role of quantum brain dynamics and boson condensation of evanescent photons. Internat. J Modern Physics 1996;10:1735-1754.

Jibu M & Yasue K. Quantum Brain Dynamics and Consciousness. Amsterdam / Philadelphia: John Benjamins. 1995.

Jibu M & Yasue K. Quantum field theory of evanescent photons in brain as quantum theory of consciousness. Informatica 1997;21:471-490.

Jones JA, Vedral V, Ekert A & Castagnoli G. Geometric quantum computation using nuclear magnetic resonance. Nature Letters 2000;403:869-871.

Kainen PC. Orthogonal dimension and tolerance. Tech. report IM-061592 (Industrial Math., Washington, DC). 1992.

Kainen PC & Kurková V. Quasiorthogonal dimension of Euclidean spaces. Applied Mathematics Letters 1993;6:7-10.

Kandel ER, Schwartz JH & Jessel TM.Principles of Neural Science. London (UK): Prentice Hall Internat., 3rd ed. 1991.

Koch C. Computation and the single neuron. Nature 1997;385:207-210.

Koch C & Segev I. The role of single neurons in information processing. Nature Neurosci (Suppl) 2000;3:1171-1177.

Kosslyn SM.Aspects of a cognitive neuroscience of mental imagery. Science 1988;240: 1621-1626.

Kosslyn SM & Andersen RA (Eds.) Frontiers in Cognitive Neuroscience. Cambridge (MA): MIT Press. 1992.

Körner E, Gewaltig MO, Körner U, Richter A & Rodemann T. A model of computation in neocortical architecture. Neural Networks 1999;12:989-1005.

Kurková V & Kainen PC. A geometric method to obtain error-correcting classification by neural networks with fewer hidden units. In: Proceedings of Int. Conf. on Neural Networks '96. Washington (DC): IEEE, 1996;127-132.

Lee SH & Blake R. Visual form created solely from temporal structure. Science 1999a;284:1165-1168.

Lee SH & Blake R. Detection of temporal structure depends on spatial structure. Vision Research 1999b;39:3033-3048.

Lee TS. Image representation using 2-dimensional Gabor wavelets. IEEE Transactions on Pattern Analysis and Machine Intelligence 1996;18 (10):1-13.

Lewicki MS & Olshausen BA. A probabilistic framework for the adaptation and comparison of image codes. J. Optical Society of America A: Optics, Image Science, and Vision 1999;16:1587-1601.

Livingstone M & Hubel D. Segregation of form, color, movement, and depth: Anatomy, physiology, and perception. Science 1988;240:740-749.

Lockwood M. Mind, Brain and the Quantum. Oxford: Blackwell. 1989.

Logothetis NK.Vision:A window on consciousness. Scientific American, November 1999;45-51.

Luccio R. Gestalt problems in cognitive psychology: Field theory, invariance, and auto-organisation. In: V. Roberto (Ed.): Advances in Computational Perception. Heidelberg: Springer. 1993.

Luria AR. Fundamentals of Neuropsychology. Beograd: Nolit (Serb Transl). 1983.

MacLennan BJ. Field computation in natural and artificial intelligence. Information Sciences 1999;119: 73-89.

Majewski AW. Separable and entangled states of composite quantum systems – rigorous description. Open Systems and Information Dynamics 1999;6:79-86.

Mannion CLT & Taylor JG. Information processing by oscillating neurons. In: J.G. Taylor & C.L.T. Mannion (Eds.): Coupled Oscillating Neurons. London: Springer, 1992;98-111.

Marcel AJ & Bisiach E (Eds.) Consciousness in Contemporary Science. Oxford: Clarendon Press. 1988.

Marcer P & Schempp W. A model of neuron working by quantum holography. Informatica 1997;21:517-532.

Marcer P & Schempp W. The brain as a conscious system. International Journal General Systems 1998;27: 231-248.

McIntosh AR, Rajah MN & Lobaugh NJ. Interactions of prefrontal cortex in relation to awareness in sensory learning. Science 1999;284:1531-1533.

Mezard M, Parisi G & Virasoro MA. Spin Glass Theory and Beyond. Singapore: World Scientific.1987.

Mishkin M, Ungerleider LG & Macko KA. Object vision and spatial vision: Two cortical pathways. Trends in Neurosciences 1984;6:414-417.

Miyashita Y & Chang HS. Neuronal correlate of pictorial short-term memory in the primate temporal cortex. Nature 1988;331:68-70.

Montero VM. Attentional activation of the visual thalamic reticular nucleus depends on 'top-down' inputs from the primary visual cortex via corticogeniculate pathways. Brain Research 2000;864:95-104.

Moran J & Desimone R. Selective attention gates visual processing in the extrastriate cortex. Science 1985;229:782-784.

Nanopoulos DV. Tech Rep. ACT-08/95 – http://xxx.lanl.gov/abs/hep-ph/9505374, 1995

Newman J. Toward a general theory of the neural correlates of consciousness. J. Consciousness Studies 1997;4:47-66.

Nobili R. Schrödinger wave holography and brain cortex. Physical Review A 1985;32: 3618-3626.

Oakley DA. (Ed.) Brain and Mind. London / New York: Methuen. 1985.

Olshausen BA & Field DJ. Natural image statistics and efficient coding. Network: Computation in Neural Systems 1996a;7:333-339.

Olshausen BA & Field DJ. Emergence of simple-cell receptive field properties by learning a sparse code for natural images. Nature Letters 1996b;381: 607-609.

Olshausen BA & Field DJ. Sparse coding with an overcomplete basis set: A strategy employed by V1? Vision Research 1997;37:3311-3325.

Perret DI & Oram MW. Visual recognition based on temporal cortex cells: Viewer- centered processing of pattern configuration. Zeitschr für Naturforschung 1998;53:518-541.

Peruš M. Synergetic approach to cognition-modeling with neural networks. In: K. Sachs-Hombach (Ed.): Bilder im Geiste. Amsterdam/Atlanta: Rodopi, 1995b; 183-194.

Peruš M. Neuro-quantum parallelism in mind-brain and computers. Informatica 1996;20:173-183.

Peruš M. Mind: neural computing plus quantum consciousness. In: M. Gams, M. Paprzycki & X. Wu (Eds.): Mind Versus Computer. Amsterdam: IOS Press & Ohmsha, 1997a;156-170.

Peruš M. System-processual backgrounds of consciousness. Informatica 1997;21: 491-506.

Peruš M. Common mathematical foundations of neural and quantum informatics. Zeitschr. für angewandte Mathematik & Mechanik 1998a;78:23-26.

Peruš M. Tracing quantum background processing in visual cortex. In: A.V. Bataev (Ed.): Proceedings 2nd All-Russian Sci. Conf. "Neuroinformatika 2000", Part 1, Moscow: MIFI, 2000; 208-226.

Peruš M. Neural correlates of vision and attention (pp. 17-20) & Neuropsychology of vision (pp. 25-28). Proceedings 3rd Int. Multi-Conf. "Information Society 2000" – volume "Cognitive Science / New Science of Cosnciousness" (Ed.: I. Kononenko). Ljubljana: Institut Jo ef

Stefan, 2000b;17-20 & 25-28.

Peruš M. Neural networks as a basis for quantum associative networks. Neural Network World 2000c;10(6):1001-1013.

Peruš M. Vse v odnom, odno vo vsem (Matemati eskie modeli associativnjih neironnjih setei). St. Petersburg: KARO (originally Slovene book as translated to Russian by A. Ippa). 2000d.

Peruš M. A synthesis of the Pribram holonomic theory of vision with quantum associative nets after pre-processing using ICA and other computational models. Int J Computing Anticipatory Systems, In press. 2001.

Peruš M & Dey SK. Quantum systems can realize content-addressable associative memory. Applied Mathematics Letters 2000;13(8):31-36.

Peruš M & Imovi PE. Memory and pattern recognition in associative neural networks. Internat. J Applied Science & Computations 1998;4:283-310.

Pessa E & G. Vitiello (1999): Quantum dissipation and neural net dynamics. Bioelectrochemistry & Bioenergetics 48, 339-342.

Poggio T, Torre V, Koch C. Computational vision and regularization theory. Nature 1985;317:314-319.

Porrill J, Frisby JP, Adams WJ & Buckley D. Robust and optimal use of information in stereo vision. Nature Letters 1999;397:63-66.

Pötzsch M, Krüger N & von der Malsburg C. Improving object recognition by transforming Gabor filter responses. Network: Computation in Neural Systems 1996;7:341-347.

Pribram KH. Languages of the Brain (Experimental Paradoxes and Principles in Neuropsychology). Orig.: Englewood Cliffs (NJ): Prentice-Hall; 5th publ.: New York: Brandon House. 1971.

Pribram KH, Lassonde MC & Ptito M. Classification of receptive field properties in cat visual cortex. Experimental Brain Research 1981;43:119-130.

Pribram KH & Carlton EH. Holonomic brain theory in imaging and object perception. Acta Psychologica 1986;63:175-210.

Pribram KH. Brain and Perception (Holonomy and Structure in Figural Processing). Hillsdale (NJ): Lawrence Erlbaum Associates. 1981.

Pribram KH. (Ed.) Rethinking Neural Networks: Quantum Fields and Biological Data. Hillsdale (NJ): Lawrence Erlbaum Associates. 1993.

Pribram KH. Brain and perception: From Köhler's fields to Gabor's quanta of information. Proceedings of the 39th Congress of German Society for Psychology, 1995; 53-69.

Pribram KH. What is mind that the brain may order it? Proceedings of Symposia in Applied Mathematics 1997a;52:301-329.

Pribram KH. The deep and surface structure of memory and conscious learning: Toward a 21st century model. In: R.L. Solso (Ed.): Mind and Brain Sciences in the 21st Century. Cambridge (MA): MIT Press, 1997b;127-156.

Pribram KH. Brain and the composition of conscious experience. J. Consciousness Studies 1998a;6(5):19-42.

Pribram KH. Status report: Quantum holography and the brain. In: Proceedings of the ECHO conference, Helsinki or see: Quantum holography: Is it relevant to brain function? Information Sciences 1998b;115:97-102.

Psaltis D, Brady D, Gu XG & Lin S. Holography in artificial neural networks. Nature 1990;343:325-330.

Pylkkänen P & Pyllkö P. (Eds.) New Directions in Cognitive Science. Helsinki: Finnish AI Soc. (especially articles by Chrisley, Globus, Gould, Hiley, Peruš, Revonsuo). 1995.

Rabitz H, de Vivie-Riedle R, Motzkus M & Kompa K. Whither the future of controlling quantum phenomena? Science 2000;288:824-828.

Rainer G & Miller EK. Effects of visual experience on the representation of objects in the prefrontal cortex. Neuron 2000;27:179-189.

Raki LJ, Kostopoulos G, Rakovic D & Koruga DJ. (Eds.) Brain and Consciousness — Proceedings of the First ECPD Int. Symposium (vol. I) & Workshop (vol. II) on Scientific Bases of Consciousness, Belgrade: ECPD. 1997.

Riesenhuber M & Poggio T. Models of object recognition. Nature Neurosci (Suppl) 2000;3: 199-1204.

Roelfsema PR. Solutions for the binding problem. Zeitschr. für Naturforschung 1998;53c:691-715.

Schempp W. Bohr's indeterminacy principle in quantum holography, self-adaptive neural network architectures, cortical self-organization, molecular computers, magnetic resonance imaging and solitonic nanotechnology. Nanobiology 1993;2:109-164.

Schempp W. Analog VLSI network models, cortical linking neural network models, and quantum holographic neural technology. In: J.S. Byrnes et al. (Eds.): Wavelets and Their Applications. Amsterdam: Kluwer, 1994;213-260.

Schempp W. Phase coherent wavelets, Fourier transform resonance imaging, and synchronized time-domain neural networks. Procedings of the Steklov Institute of Mathematics 1995;3:323-351.

Schiller PH & Logothetis NK. The color-opponent and broad-band channels of the primate visual system. Trends in Neurosciences 1995;13:392-398.

Snider G, et al. Quantum-dot cellular automata: Review and recent experiments. J Applied Physics 1999;85:4283-4285.

Sompolinsky H & Tsodyks M. Segmentation by a network of oscillators with stored memories. Neural Computation 1994;6:642-657.

Spencer RG. Bipolar spectral associative memories. IEEE Transactions on Neural Networks, to appear in May no. 2001.

Stapp HP. Mind, Brain and Quantum Mechanics. Berlin: Springer. 1993.

Stillings NA, Weisler SE, Chase CH, Feinstein MH, Garfield JL, Rissland EL. Cognitive Science. Cambridge (MA): MIT Press. Ch. 12: Vision. 1995.

Sutherland JG. A holographic model of memory, learning and expression. Internat J Neural Systems 1990;1:259-267.

Tegmark M. Importance of quantum decoherence in brain processes. Physical Review E 2000;61:4194-4206.

Tootell RBH, Hadjikhani NK, Mendola JD, Marrett S, Dale AM. From retinotopy to recognition: fMRI in human visual cortex. Trends in Cognitive Sciences 1998;2:174-183.

van Hateren JH. Real and optimal images in early vision. Nature 1992;360:68-70.

van Hateren JH, Ruderman DL. Independent component analysis of natural image sequences yields spatiotemporal filters similar to simple cells in primary visual cortex. Proceedings of the Royal Society of London B (Biol. Sci.) 1998;265(1412):2315-2320.

van Hateren JH, van der Schaaf A. Independent component filters of natural images compared with simple cells in primary visual cortex. Proceedings of the Royal Society of London B

1998;265:359-366.

Vidyasagar TR. A neuronal model of attentional spotlight: parietal guiding the temporal. Brain Research Review 1999;30:66-76.

Wainwright M J. Visual adaptation as optimal information transmission. Vision Research 1999;39:3960-3974.

Wallis G, Bülthoff H. Learning to recognize objects. Trends in Cognitive Sciences 1999;3:22-31.

Wang DL. Object selection based on oscillatory correlation. Neural Networks 1999;12:579-592.

Wang PP, et al. (Eds.) Proceedings of the 4th Joint Conference on Information Sciences '98. Research Triangle Park (NC, USA): Assoc. Intellig. Machinery. Volume II: Proceedings of the 3rd Internat. Conf. on Computatational Intelligence & Neuroscience (Ed. G. Georgiou); sections on neuro-quantum information processing. 1998;167-224.

Weinacht TC, Ahn J, Bucksbaum PH. Controlling the shape of a quantum wavefunction. Nature Letters 1999;397:233-235.

Weliky M, Katz LC. Correlational structure of spontaneous neuronal activity in the developing lateral geniculate nucleus in vivo. Science 1999;285:599-604.

Wheeler JA, Zurek WH. (Eds.) Quantum Theory and Measurement. Princeton (NJ): Princeton Univ. Press. 1983.

Wurtz RH, Goldberg ME, Robinson DL. Behavioral modulation of visual responses in the monkey: Stimulus selection for attention and movement. Progress in Psychobiology and Physiological Psychology 1980;9:43-83.

Zak M, Williams CP. Quantum neural nets. Internat. J Theoretical Physics 1998;37: 651-684.

Zornetzer SF, Davis JL, Lau C. An Introduction to Neural and Electronic Networks. San Diego: Academic Press. 1990.