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Consciousness as Informational Phenomenalism:

An Informational, Phenomenological, Philosophical, Neural and Quantum-Mechanical View

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Conceptualism of Consciousness

By Anton P. Železnikar

1 Introduction

Three main concepts of consciousness dominate in man's knowledge (science), investigation (research), and story (literature, imagination) nowadays: the *physical* (materialistic), the *informational* (interconnectionistic, transitional), and the *phenomenal* (idealistic, philosophical).

Physicists prepare the ground for the scientific physical understanding of conscious phenomena. The field of quantum physics seems currently to be the best approach to a true breakthrough in the new physical philosophy and possibilities of mathematical formalization. The hope to bridge the gaps between the reality, experiment, and theory remains—as it often happens in hard sciences—positivistic. The physicists are aware that more experiments, innovative measurement and a less reductionistic theory is a necessity on the way to the goal: to entangle the mystery of consciousness in a materialistic and phenomenal spirit.

Informationalism connects and governs the physical and the living systems, is itself a consequence of the physical phenomenalism. In this respect it enables also an arbitrary artificialness, modeling, and prediction—that is characteristically consciousness abilities. Computers and other man-made machines enable the most sophisticated measurements needed for consciousness investigation. In this sense, the informational supervenes on the physical—in the nature as well in the artifact. Informationalism connects not only different phenomenalisms, it builds informational loops in the domain of a phenomenalism itself. Consciousness becomes a paragon for and of the informational phenomenalism, its metaphor, generalization, and informational universalization. Informational principles and formalism fit best consciousness phenomena.

In its historical-philosophical development, phenomenalism is a conceptual broadening (universalization) of phenomenology, and as such belongs to physicalism as well as to informationalism. Maybe, phenomenalism can best be identified by observing of conscious processes, that is, consciousness phenomena. Mentality is one of the best examples of informational phenomenalism, and consciousness can be recognized as the top achievement of the live (and one day, maybe, also of the artificial) mentality.

Conceptualism—as a form of *informational phenomenalism*—particularly concerns the realm of consciousness. Within a living consciousness, conceptualism becomes a conscious informational phenomenon by itself, informing consciousness and being informed by the conscious intentionality when forming a concrete concept. In the last few years, the concept of consciousness excites anew the actors of various scientific disciplines—and brings them together. The Tucson Conference [1] is, beside the others, the most relevant event in this direction and, with this issue, *Informatica* is an additional trial on the way of the literary presentation of such a research activity.

Interdisciplinarity of consciousness seems to be the most natural process by which the scientific thought has to be joined, refined and diversified, to give push to certain scientific breakthroughs, within which the science of consciousness could become a regular and legal field of investigation. Within this perspective, the investigation of consciousness must remain in the domain of epistemological objectivism[1] as, for example, expressed by Ayn Rand (1966) [3]. Rand's objectivist epistemology can be put clearly and efficiently into the context of consciousness, as cognition and measurement, concept-formation, abstraction from abstractions, concepts, definitions and axiomatization of consciousness, and consciousness phenomenalism and identity. Such a program fits the modern philosophy and theory of consciousness, and supports the formal-theoretical development of the abstract (formalistic, mathematics-like, $\mu\alpha\vartheta\epsilon\sigma\iota\varsigma$-like) apparatus. As such it is also on the way to a new machine (technologies, procedures, methodologies)

[1] In contrast to subjectivism, objectivism as a meta-ethical view believes that certain truths remain true whatever anyone or everyone thinks or desires. As a cognitive-theoretical orientation, objectivism stresses the existence of objective truths and values being independent of the subject. Objectivists are also those cognitive theoreticians who believe that contents of experience is given objectively, and as such determines the entire cognition.

development—for instance, the so-called informational machine [6].

Consciousness belongs to the most important universals ever thought and in this sense it comes not only into the focus of the contemporary philosophy but falls also into the domain of the newest information-processing technologies. That what this new direction of investigation and design needs is the validity of innovative consciousness concepts, first of all, in the philosophical structure and methodological organization and, last but not least, in the development of new formalism. Such a formalism should concern a new sort of abstract space conceptualism, in the form of informational space, giving the consciousness studies new possibilities for the pretentious and interdisciplinarily perplexed formalistic and methodological research. In principle, the new formalism must support the multidimensional approach to the *web of informational knots, informational topology* and *informational graph theory*, performing as a complex circularly organized informational system.

2 Existence, Identity, Unit—Consciousness

The primordial existentials is subject of archaic and modern philosophy. In Heidegger [2], Dasein[2] (Being-there, Being-in-the-world, etc.) is one of the most well-recognized "existentiells". Dasein, possessing its own understanding, functions as a consciousness *per se*.

Concept—another existential within consciousness—puts the question of the concept of a concept. According to Rand, the concept "existent" develops in man's mind by three stages. First, there is an awareness of objects, things, and phenomena, which rises an implicit, vague determined (indefinite) concept "*entity*" (in German, das *Seiende*).

Entity possesses a kind of informational envelope—specific attributes—distinguishing it from other entities. The second stage—entity's attributiveness in the realm of perceptual fields—maintains and brings to the surface another implicit concept, called *identity*. Thus, identity of a concrete entity comes into existence.

The third phenomenon of consciousness consists of grasping informational relationships among the distinguished entities and bringing similarities as well as their contrary natures into the foreground. After the entity and identity phenomenon, a firm (implicit) concept "*unit*" can arise informationally. The ability to understand entities as units is consciousness distinctive phenomenon of cognition into arbitrary abstract depths and informational complexity.

So, existence, identity, and unit of consciousness can be grasped as informational entities, that is, units with specific attributes, informational structure, and organization. This issue of *Informatica* is on the way to such a cognition.

3 Consciousness Measurement

What could measurement mean within the consciousness conceptualization? We need a generally suited notion of measurement within conscious phenomena. Measurement would mean, for instance, to introduce a kind of metrics into the informational space, not only the physical measurement (length, velocity, acceleration, mass, energy, time, etc.) but also much more sophisticated informational and consciousness measurement (for instance, different kinds of interpretation, meaning, contents, intention, modus, intelligence, relationship, and the like).

By measurement, we usually evaluate and interpret the results concerning an entity attributiveness (in the form of numerical values, information as data, structure, organizational principles), in more or less reductionistic, categorized, scientific (mainstream-fitted, rationalistic, real, reasonable, "true") and field-narrowed (disciplinarily legal) manner. In such or another way, a measurement fits the observer's intention, his/her goals, feeling, and methodology. In this respect, an observer can be understood as a concrete consciousness situation and attitude, together with possible unconsciousness and exterior phenomena impacting the observing and measuring system.

In a broader sense, mathematics is the science of measurement (Rand). Metric and vector spaces (with the so-called scalar measures as distances, angles, scalar products, arithmetic relationships, numeric functions, etc.) are paragons of mea-

[2] Dasein always understands itself in terms of its existence—in terms of a possibility of itself: to be itself or not itself. ([2], p. 33.)

surement philosophies and axiomatics. Measurement identifies a relationship—the quantitative and the informational—in arbitrarily complex abstract and real circumstances. One of the aims of measurement is to integrate the emerging knowledge to the limited perceptual experience and, thus, to enlarge the man's consciousness capabilities in various abstract domains. Through the study of consciousness, measurement becomes an innovative informational field in which the measures of meaning, contents, and interpretation emerge as expressible and explicit informational entities (identities, units).

4 Formatting the Concept of Consciousness

If one accepts that concept is a mental phenomenon then there is a short step to the conclusion that a concept phenomenon phenomenalizes informationally. Informing in this case is certainly conscious. But, what we need is the conscious concept of consciousness. What can be transparently felt is that the last sentence (the conscious concept of consciousness) hides circularly perplexed possibilities. At the end of this conclusion remains definitely the cognition of the informational nature of consciousness, as it appears in the everyday happening of the conscious experience of man.

As soon as one articulates the question concerning the informational nature of consciousness, the problem of the initial concept of consciousness—in fact a symbolic marker, say $\mathfrak{z}$—comes into the foreground. A decomposition of the initial symbolic situation $\mathfrak{z}$ calls for the search, analysis, and intuitive identification of various reasonable consciousness components, the consciousness characteristic units (informational subentities, subidentities, subunits), by which, in a circular perplexed informational system, consciousness can perform in the characteristic conscious ways. Such a system unites everything imaginable in the realm of consciousness, its entities, identifications, units, attributes, informational generations, qualities, relationships, interpretations—that is various possible appearances of conscious, subconscious, and unconscious phenomena.

We consider that the nowadays concept of consciousness is formatted physicalistically, informationally, and philosophically (phenomenologically). For these views different sorts of phenomenalism are characteristic. All views concern the abstraction being a selective, professional, or disciplinary focus for certain aspects of the consciousness reality. Thus, consciousness becomes a perceptual concrete, measured by the physical, informational, and phenomenal measures—the abstract and the empirical ones. Each of the disciplines develops a specific language for its own consciousness concept, a disciplinarily oriented cognition, fitting the characteristic tradition but being also on the way to a new discipline—its scientific and empirical legacy (truth, experience, methodology). These languages and their transformations to the formalistic expression (formulas) become the domains and tools of the consciousness concepts.

In the described epistemological approach, language transforms the consciousness concept into entity (e.g., into an informational entity of consciousness—a complex informational system). By additional definitions more and more identity is provided to the initial, loosely decomposed consciousness system. Through permanent metaphysicalistic, externalistic, and internalistic decomposition, consciousness becomes more and more identified, that is, determined informationally.

5 Abstraction of Consciousness

Consciousness is a word representing the concept (meaning) of a process which is never completed in regard to its development of components, although it is already a state of cognitive integration (composition). Consciousness is an emergent, informationally arising concept. This concept already possesses the distinguishing characteristics of consciousness and its components in itself. Informational consciousness is a paragon of such an abstraction leading deeper into the research area of consciousness as an informing entity, identity, and unit. In its components, consciousness informs as their conceptual common denominator, keeping them within the horizons of possible consciousness-informational development.

Abstraction of consciousness begins by its informational decomposition in an emerging, spontaneous, also instable and chaotic manner. As in any concept, consciousness components are abstractions per se when decomposed into deeper and greater details. In fact, each abstraction in the domain of consciousness—at least on the linguistic level—is an emerging abstraction of and from abstractions in a circular, also spontaneous way. Thus, different theories (orientations, intentionalities, schools), discussed in the preceding section, can come into existence.

The formation of a wider concept of consciousness requires more knowledge, experience, and components, and better developed and known contents of components and consciousness structure and organization. Because concepts are regularly circular structures and components depend conceptually on other components as well as on themselves and on the title component 'consciousness', they all gradually become more and more complex, when the overall complexity of consciousness rises. In fact, in an informational loop (knot), each component can be expressed informationally by other components and itself, through the so-called principle (axiom) of component rotation in a loop (see, for instance, [9, 11]).

Informational concepts—like consciousness—remain informationally open which means that the process of identifying new concretes and their emerging in the future is completely open for the development in unforeseeable circumstances and possibilities. In this way the concept of consciousness—like a concrete living consciousness—is never developed to an end. As any informational entity, consciousness with its components phenomenalizes conceptually, saying traditionally, inductively, deductively, and abductively, and in this way remaining within a scientific terminology. Through its informing and observing, it remains within the fundamental postulates (principles, axioms) of informational phenomenalism.

6 Concepts of Consciousness

Informational concept of consciousness considers (can consider) any other possible (imaginable) concepts of various scientific and philosophical disciplines and, in this respect, offers the way especially directed to the formalism of an integral theory of consciousness. Wilber (1997 [4]) discusses a frame overview of consciousness concept in regard to various scientific disciplines without the informational view. Let us see and comment the particularities.

1. *Informational theory* comprehends consciousness (as any other informational entity) in terms of a spontaneously and circularly arising informational phenomenon where consciousness phenomenalism is a system of consciousness externalism, internalism, and metaphysicalism. Consciousness components emerge dynamically in accordance with the interior and exterior situations and between them certain informational transitions (operator connections) [10] come into existence, change, and vanish. In fact, consciousness represents a case of the top complexity in which the most pretentious possibilities of an informational entity are imaged. Any hierarchical[3], intentionalistic, interpretative, circular, spontaneous, etc. structure and organization can exist in an implicit or explicit form. For a concrete component of consciousness, it can be expressed in an implicit form within a loop, or in an explicit form where the component figures as a title operand of a loop [9].

2. *Cognitive science* prefers functional schemas of the brain/mind with complex emergent/connectionist models, integrated hierarchically.

3. *Introspectionism* argues that consciousness is best understood in terms of intentionality (first-person models, immediate awareness, lived experience). Introspectionism concerns philosophical and psychological intentionality, existentialism, and phenomenology.

4. *Extrospectionism* concerns processes of cognition directed outward, apprehending existents of the external world. Introspectionism is a form of consciousness internalism and metaphysicalism [5]; extrospectionism is a form of consciousness externalism and metaphysicalism. Both views—

[3] It has to be studied carefully what a hierarchy within the informational could mean. Informational organization of an entity is circular, and the hierarchy of operand components could be determined upon the distinguished intentional impacts of components, for instance, by the intention of a title operand of a loop. However, the informational hierarchy could also be determined by the most influential informational impact of a component upon other informational components.

internalism and externalism—are decompositionally connected via informational metaphysicalism within the informational phenomenalism of consciousness. Action of consciousness regards the informational impact of its environment and of itself. Contents, meaning, and reference of consciousness are embedded in its structure and organization (e.g., observation, reasoning, learning, perception, evaluation, interpretation, feeling, emotion, reminiscence, conception, imagination, understanding, etc.).

5. *Quantum consciousness* stresses that consciousness is capable to interact with and alter the physical world. Quantum interactions take place at the intracellular level and in the material world.

6. Neural systems, neurotransmitters, and other brain mechanisms are subject of *neuropsychology* in the sense of biologically based approach. Consciousness resides in organic neural system of sufficient complexity.

7. For *Eastern and contemplative traditions* consciousness is a deeper or higher mode of awareness, evoked by specific injunctions (yoga, meditation). On the other side, in Vedanta philosophy, Brahman is grasped as the most general principle of consciousness pervading the universe (being present everywhere and anytime).

8. *Developmental psychology* views consciousness as a distributed entity in the form of a developmentally unfolding process. It includes higher stages of exceptional development and wellbeing, and the study of gifted, extraordinary capacities as higher developmental potentials latent in humans.

9. *Subtle energy* is a form of bioenergy appearing beyond the strong and weak nuclear, electromagnetic, and gravitational forces of physics. This energy plays an intrinsic role in consciousness (prana, chi) and should be the 'missing link' between intentional mind and physical body, acting as two-way conveyor belt, transferring the impact of matter to the mind and imposing the intentionality of the mind on matter.

10. *Social psychology* sees consciousness embedded in webs of cultural meaning, being a byproduct of the social system itself. Its objects are, for instance the collective, mass, common, totalitarian consciousness, etc. (for instance, ideology, cynicism, postcommunism).

11. *Individual psychotherapy* treats distressing symptoms and emotional problems by introspective and interpretive methods. It views consciousness appearing in adaptive capacities of an individual organism. Jungian approach postulates collective structures of intentionality (consciousness), the fragmentation of which contributes to psychopathology.

12. *Clinical psychiatry* tends to view consciousness in strictly neurophysiological and biological terms: consciousness is the neuronal system correctable with medication. The Freudian metapsychology is being more and more abandoned.

13. For *psychosomatic medicine* consciousness is strongly and intrinsically interactive with organic processes (e.g., psychoneuroimmunology, biofeedback). This approach includes consciousness and miraculous healing, spontaneous remission, effects of intentionality on healing, art therapy, etc.

14. *Nonordinary states of consciousness* embrace dreams and psychedelics with the belief that consciousness could be grasped in general. In this context 'toxic side-effects' can act as a 'nonspecific amplifier of experience'.

The theory of informational consciousness tends to integrate all these views into a unique formal model of consciousness with the possibility of its own conscious emerging and development. For this purpose it unfolds and reveals a new (disciplinarily common) formalistic apparatus being capable to follow natural, artificial and research problems by the accompanying informational formalism (see, for example, [5, 7, 11]).

7 Definitions of Consciousness and Its Components

Definitions are statements or informational formulas[4] representing or describing concepts. The-

[4]A defining informational formula uses an informationally particularized operator of the form $\rightleftharpoons_{\mathsf{def}}$ meaning *means definitionally.* Thus, $\alpha \rightleftharpoons_{\mathsf{def}} \beta$ reads α means β in a definitional way, where α and β can represent arbitrary informational formula or formula system.

ory of consciousness uses different sorts of definitions, e.g., the verbal, intuitive, and strictly formalistic. A definition clearly distinguishes a concept from the other concepts. Higher sorts of definitions can use the lower definitions in a hierarchical manner. Quite in the beginning of a consciousness theory definitions concern the basic operand and operator symbols and the adequate terminology. Axioms are in the beginning of a theory and are taken (given) as epistemologically objective, commonsense, true statements (as a kind of axiomatic definitions).

Informationally, every concept can be defined and communicated by other concepts. In general, an informational concept is a structure of other informational concepts (a kind of supervenience) and, at a sufficiently deep level, also of itself (an unavoidable informational circularity). Informational phenomenalism uses definitions which are concepts of informational metaphysicalism, serialism, parallelism, circularism, spontaneousism, gestaltism [8], graphicalism [11], etc.

Definitions of informational entities origin in epistemologically objective concept formations. The basic concept formation considers the informational nature of things, processes, phenomena, events, happenings, beings, consciousnesses, etc. and proceeds from axioms of informational externalism, internalism, metaphysicalism, and phenomenalism (EIMP) [5]. Informing as a metaphor for informational arising in a spontaneous, circular, and informationally perplexed way governs informational entities, being conscious, unconscious, materialistic, mental, organizational, etc.

Within the theory of consciousness, a special care is dedicated to the formalistic means, be they mathematical—formalistic (in physics, cognitive science, biology, etc.) or informational—introducing a new sort of formalism fitted for descriptive formulas and informational systems which in their nature are emergent, developing, changing during their existence. This kind of formalism fits the problems of consciousness phenomenalism, offering the possibility of a formalistic treatment of phenomena, without the usual reductionism, and with additional and adequate formal interpretation in a system-perplexed way.

Axioms and definitions of consciousness as informational phenomenalism must remain in the framework of the epistemologically objective and possible, and must not contradict the reality as understood by the most advanced scientists. Axioms and definitions must remain in the context of the contemporary consciousness philosophy, cognitive science, and the advanced informational formalism by which verbal and logical concepts in the domain of new formalism can be supported and developed.

When conceptually improved, new formalism can suffice for a long period of pioneering investigations of consciousness in different fields of philosophy, methodology, application, and technology. Such a formalism does not only support the facts of reality, but is on the way to be advanced in certain cases in comparison with the non-formalistic research. A fitted formalism opens new ways of informal (verbal) cognition and can extend into a deeper and unforeseeable revealment, complexity, structural and organizational views.

Usually, informational definitions are verbal and formal series of words, sentences, and formulas when establishing informational concepts. They are as true as possible close to the realistic, commonsensical, and non-reductionistic situations; they are, in a scientific-investigational sense, objectively epistemological and, in this respect, do not violate the principle of scientific cognition. On the other side, informational concepts remain free in that part of a concept formation where informational artificialness and constructivism are relevant for a further development of informational and particularly consciousness theory. Thus, new informational theories are not exceptions: they are rather innovations and conceptual extensions of existing and related concepts.

8 Concepts of Informational and Consciousness Axiomatism

Evidently, axioms identify fundamental and self-evident truths. The truth and falsehood of a theory rests on the truth and falsehood of the initial axioms, definitions, and rules of a theory decomposition (deduction, induction, abduction, revealment). In this view, informational theory fits in the best possible way the informational theory of consciousness, following the informational axioms, definitions, and decomposition.

Axioms of informing (EIMP—externalism, internalism, metaphysicalism, phenomenalism) [5] as informational axiomatic concepts identify the primary facts of informational reality (informing of things, entities, processes) and can be analyzed objectively, logically, and commonsensically (by linguistic means), although they cannot be reduced (this is primordially true for EI—externalism, internalism). They can be broken merely in their operand and operator constituents, but perform (inform) together as a compact, unbreakable formulas. However, these axioms serve as the starting formulas for informational decomposition when situations of a more detailed identification occur.

In general, the primary informational axiomatic concepts proceed from various concepts of existence (Being), identity, and consciousness. Informational concepts cover the existential, the identificational, and the conscious in the best possible manner. Namely, the verbal forms *be, identify,* and *be conscious* are comprehended as a unique verbal form *inform.* What exists and what is identified informs consciousness, and consciousness informs exteriorly (for others), interiorly (for itself in the sense of input and feedback), and metaphysically (intrinsically, in itself, self-consciously). Informational axioms satisfy the most rigorous requirements of objectivistic epistemology and, simultaneously, cannot be simplified or reduced to something more fundamental [7], physicalistic, or phenomenalistic. They function as irreducible informational primaries.

Existence, identity, and consciousness are informational phenomena which can be experienced in a direct informational way and grasped through the unique and common axioms by their informingness and informedness. Existence and identity are informational existents and, as such, they inform (impact) consciousness. In this sense, consciousness is an informational process of awareness. All these concepts are conscious abstractions being metaphysically isolated and identified informational fundamentals. They are components of a widest possible consciousness integration and embrace and pervade the entire conscious experience. To resume: existence is informational being, identity is informational identification, and consciousness is informational consciousness. In this way the informational becomes the fundamental of consciousness too.

One can recognize and agree that informational axioms EIMP build up a circular spontaneous informational realm and that every recognized existent, attribute, and entity can be—through them—grasped informationally. At the same time, informational axioms function as basic consciousness axioms when a general informational entity α (an existent, event, thing, phenomenon, process) is replaced by the distinguished entity $\mathfrak{z}$, representing (marking) consciousness in all its possible variance and modes of informational decomposition (see the article of the author in this issue). Thus, informational axiomatic concepts EIMP become constants (invariance) of informational consciousness, the cognitive common determinators which identify the informational and, within it, the conscious in the widest possible way. By axiomatic concepts, the informationally (and consciously) implicit is identified explicitly. It can be said that, so far, informational axioms constitute the foundation of the physical, phenomenal and informational *objectivity.* On the other side, these axiomatic concepts appear also as a foundation of the emerging and promising informational formalism—a new sort of logical and mathematical approach.

9 Formalistic Informational Concepts

Formalism becomes one of the most important and effective approaches in understanding and constructing complex, circularly structured (knotted) and spontaneously informing systems. The new formalism seeks for innovative formal means in the form of informational formulas which can integrate the traditional mathematical convenience and the informationally emerging phenomenal nature. In this respect, the new formalism is phenomenalistic by itself in the framework of informational formulas. This means that informational formulas as formalistic expressions arise, change and vanish structurally during their existence and behave as informational entities of entities which they describe, simulate, represent, or express. In a given moment, a system of informational formulas is the instantaneous description of something. Such a formalistic situation essentially differs from a mathematical system consisting of firmly (unchangeable) determined mathematical formulas (functions, equations, relations, statements, etc.) depending upon space, time, and other kinds of variables.

Also different kinds of circular situations which in mathematics are structured in such or another implicit form, in informational theory appear explicitly as circular formula systems, being structured serially and parallel. To some extent, circular informational formulas can be compared with mathematical equations (with one and the same variable appearing on several places) which can be 'solved' upon certain variables.

Informationally, consciousness is an entity, formally denoted by $\mathfrak{z}$. Consciousness $\mathfrak{z}$ follows the general informational principles (e.g., fundamental axioms of informational EIMP)

$$\mathfrak{z}\models;\ \models\mathfrak{z};\ \mathfrak{z}\models\mathfrak{z};\ \begin{pmatrix}\mathfrak{z}\models;\\ \models\mathfrak{z}\end{pmatrix}$$

Operator $\models$ functions as an informational joker, with the general meaning *informs* or *is informed consciously*. It represents any kind of impactingness or impactedness which can be physical, informational and/or phenomenal. Both constituents, operand $\mathfrak{z}$ and operator $\models$, can be particularized, that is, decomposed in a particular way, keeping the well-formedness of the emerging formula. A decomposition procedure of an informational transition $\alpha\models\beta$ [10] (when in the circular formula $\alpha\models\alpha$ the right operand α is replaced by β) can follow the axioms called informational modi (modi informationis [?, 42, 48]). In this way, from an initial situation $\mathfrak{z}$ (being an informational marker) (in fact, $\mathfrak{z}\models\mathfrak{z}$) circularly (e.g., metaphysically) structured formulas can be obtained by spontaneous, instable, and chaotic decomposition, building up an informational system of $\mathfrak{z}$.

10 Editors' and an Author's Comments and Views

At the editing of the special issue of *Informatica* different views came into the foreground, which may be interesting for the authors and readers of this issue.

Suhrit Kumar Dey:
A Comment on Consciousness in Indian Philosophy.
From time immemorial, philosophers in India looked into the topic of consciousness from very different angles. They are sometimes diametrically opposite. Charvak (1500 B.C.) developed the most materialistic view on consciousness. According to him, consciousness is just a property of human mind. When this material body was formed, mind was formed and consciousness was formed. When this material body disintegrates, mind disintegrates and consciousness disintegrates. Consciousness exists only when mind exists. Thus inanimate objects which have no mind, have no consciousness. The phenomenal universe is self-created and it contains both animate and inanimate objects.

Vedantists find contradictions in these assumptions. They say that if nature is self-created then all objects of nature are self-created which implies that energy must transform itself. This is a gross violation of the law of physics. Thus Vedanta admits that there must exist an operator—which is also a function in mathematics—which must cause all the changes being totally detached from them. This operator is consciousness—the central theme of all science and philosophy. It is also called the "Self" or "Brahman " in Vedanta.

There are myriads of objects in nature and each is continuously going through changes. Consciousness is the mathematical operator which is doing all the changes. When a person is completely detached from everything, mind becomes thoroughly focused, all thoughts subside and the state of consciousness becomes manifest. Although all objects of nature seem to have different selves or consciousness, Vedantists claim that this is an illusion. All individual selves are really manifestations of one sublime cosmic consciousness, which is the Absolute and Divine.

Once a person realizes his/her own "Self"—own identity—he/she sees divinity everywhere—one cosmic consciousness embodied by all—one sun having many reflections. The school of Sankhya admits that "Self" and "consciousness" are the same but claims that nature presents a vivid, colorful variations of many individual consciousness. Vedantists find a contradiction here. They claim that if the limiting point of all of our thoughts and deeds is one cosmic consciousness (as proved mathematically by Dey) how could qualitatively individual consciousness differ from Cosmic Consciousness? The most prevailing doctrine of consciousness, accepted by most Hindu philosophers is the Vedantists' view: *Consciousness is the "Self". It is birthless and deathless. It transcends nature and as such it is beyond time, space and causation. It is the omnipotent, the omnipresent and the omniscient. It is that in which all exists. It is that which exists in all.*

Vladimir A. Fomichov:
It is possible to distinguish, in particular, the following actual directions of studying consciousness as informational phenomenalism.
— A number of specific properties of consciousness (such as continuous receiving and processing information from the surrounding world, the continuos emerging and evolution of dynamic mental structures) force us to look for non-traditional approaches to formal modelling the work of consciousness. In this connection, the A.P. Železnikar's informational theory of consciousness (published in this issue) and the psynet model of Ben Goertzel (Informatica, 1995, Vol. 19, No. 4, pp. 469–477) seem to indicate new promising ways for formal studies of the consciousness.
— One can observe a considerable growth of the number of works devoted to studying mental representations of information and mental operations with respect to their close ties with emotions, feelings, and motives of people.
— The researches on the theory of natural-language-processing systems (NL-processing systems) carried out in the second half of the 1980s and the first half of the 1990s in Canada, Russia, UK, USA have explicated a number of advantages of using NL-like formal representations of information for conceptual processing of information. The results of these researches provide a new background for formal and computer studying the role of NL in the development and functioning of consciousness as informational phenomenalism. In particular, this applies to the V.A. Fomichov's theory of restricted K-calculuses and K-languages (Informatica, 1996, Vol. 20, No. 1, pp. 5–32) provided a model of a complete collection of mental operations (consisting of only 10 operations) enabling the brains of people to form structured meanings of arbitrary NL-texts.
— An entirely new approach to investigating the role of NL in the development and functioning of consciousness as informational phenomenalism underlies the study of V.A. Fomichov and O.S. Fomichova described in this issue. The authors distinguished a number of information processing abilities being salient features of the "good brains". Then they suggested a new method of effective developing these abilities at language lessons (lessons of a foreign language or of a mother tongue) with young children and teenagers. It appears that this result provides a new precious background for modelling the work of consciousness as informational phenomenalism.

Mitja Peruš:
—*Dey*'s presentation of consciousness in Vedanta philosophy from the point of view of an Indian-American professor of mathematics is something peculiar in consciousness philosophy and formalization.
—*Farre* discusses the stratified virtual structures in physical systems and their informational nature, a topic which is often neglected, but very important.
—In the paper of *Jibu & Yasue* (co-workers of Karl Pribam) the significance of nanoscopical biophysical systems and quantum field theory for descriptions of system-processual backgrounds of consciousness is stressed.
—The original theory of *Marcer & Schempp* combines for the first time a rigorous description of quantum holography and neural processes in order to provide the explanation for an essential feature of consciousness—external phenomenal visual and auditory projections; i.e., according to their theory, quantum-holographic phase-conjugation realizes a back-projection of object's virtual image to the object's original location in space-time, so that the virtual image and the original object coincide giving us impression of external location and form of the perceived object; in the paper they combine their consciousness theory with incorporation of quantum-holographic processes into the neuron's physiology.
—*Raković* gives a rare contribution to the biophysical knowledge of altered states of consciousness with respect to the electromagnetic component of ultra-low frequency "brainwaves", i.e. bioplasmatic ionic currents, and their relativistic ef-

fects.
—Schempp's combination of quantum holography with functional magnetic resonance tomography provides a very promising tool for experimental cognitive neuroscience; his paper is an example of useful application of rigorous mathematical theory for practical purposes in medicine.

Peruš also gives the following comments:
—Qualia cannot be fully explained or even reproduced by physical or/and informational means only.
—Systems-processual backgrounds of consciousness are best described by multi-layer networks of formal neurons (real neural cells, cytoskeletal tubulins, electric and magnetic dipoles, spins, quantum particles, sub-quantum "points" or "beables", etc.
—Every complex system exhibits irreducible collective dynamics, so that specific virtual structures—parallel-distributed patterns-qua-attractors—emerge.
—Neural networks alone, or quantum networks alone, are not enough to explain consciousness; their cooperation, e.g. neuro-quantum coherence, is needed.
—Meditational, mystical and other altered states of consciousness provide an important, direct, introspectively empirical origin of knowledge on pure consciousness; there are good perspectives for consciousness studies in biophysical researches of altered states of consciousness, like neurological disorders which provide important data for cognitive neuroscience.

Dejan Raković:
—Out of physical approaches to consciousness, considered in this issue, the two of them are demonstrating the way the quantum mechanical level is coming into existence at macroscopic brain/consciousness level: via spontaneous symmetry-breaking (Jibu & Yasue) and via quantum holography (Marcer & Schempp).
—The quantum optical networks related to consciousness are essential in both cases, being suggested also in biophysical relativistic approach to consciousness where such an optical network might be related to the ultralowfrequency-modulated-microwave ionic acupuncture system, extremely significant for conscious information processing in altered and transitional states of consciousness (Raković).
—An interesting analogy between the collective dynamics of neurons and quantum systems is demonstrated too, in corresponding complex valued formalism of quantum mechanics and neural-net-theory with oscillatory activities (Peruš), implying that nature is possibly mapping its general patterns of conscious-related phenomena on both quantum mechanical (describing microscopic probabilistic implicate order) and neural-net (describing macroscopic explicate order) physical levels.
—A very good attempt towards formalism of consciousness is given in the informational theory of consciousness (Železnikar), as already has been demonstrated by some experiments of Heideggerian understanding and interpretation.

Walter Schempp:
—The majority of scientists agree that now is the time to think scientifically about consciousness and its relationship to the mind, and most important of all, the time to start the experimental study of consciousness in a serious and deliberate way.
—Among the papers submitted to the special issue, the philosophy of the experimental approach has been clearly described in the contribution by Professor George L. Farre.
—The paper submitted by Mari Jibu and Kunio Yasue provides a quantum theory of consciousness; it is written in the spirit of K.H. Pribram's and S.R. Hameroff's microtubules approach to consciousness.
—The paper by Dr. Marcer and myself describes the role of quantum holography in the field of consciousness research.
—Finally, my paper is concerned with the application of quantum holography to human brain mapping by functional magnetic resonance imaging (MRI); it makes sure that the emergent field of quantumography allows to look into the living human brain and to monitor the neural activities; indeed, the article includes as an illustration the visualization of the motor task activation pattern in the cerebrum; the brain mapping technique performed by functional MRI presents one of the greatest promises in the field of modern brain research.
—The paper by Jibu-Yasue and my paper are

based on a heavy mathematical machinery; however, mathematics is the only lingua franca available in science.

Anton P. Železnikar:
— The paper of Vladimir A. Fomichov & Olga S. Fomichova presents a practical concept of developing the consciousness in the childhood based on ideas of artificial intelligence together with a methodology of emotional and imaginative teaching at lessons of a foreign language. This conception is the main constituent of a new theory of teaching suggested by the authors (developing the personality of the child, conflicts-free teaching, information transfer approach to consciousness), and as such should come into the focus of attention in teaching in general.
—Amy Ione uses a multilevel and multilateral model to explore how information, consciousness and culture interpenetrate. This model demonstrates how information exchange (e.g., informational transition [10]) must be a key component of consciousness studies if we are going to adequately acknowledge that how we build informational bridges connecting personal, cultural, and intergenerational perceptions cannot be separated from our living as individuals and cultures in time and space. Particular attention is given to illustrating that while information itself may be personal or impersonal, our conclusions about the processing of information must address consciousness, experience, exchange, and feedback multidimensionally.
— For Horst Hendriks-Jansen, cognitive science has traditionally assumed that all mental phenomena except consciousness can be explained by an information-processing account. The problem of explaining phenomenal consciousness then reduces to that of getting subjective experiences or "qualia" out of functionally and/or causally defined internal representations that can be "grounded" or "naturalised" through evolution. This paper proposes an alternative approach to explanations of human behavior that draws on ethology, developmental psychology, situated robotics, and dynamical systems theory. An evolutionary explanation of human behavior and mental phenomena implies that there is no specific physical, neurophysiological, or *software* ingredient that human beings inherit through their genes and that makes them conscious. Nor can consciousness be conceived as a virtual architecture that is installed by learning in an exceptionally large and plastic brain.
— In the paper by Alexander D. Linkevich, models of anticipation, perception, language, and mind through the nonlinear dynamics of neural networks are discussed and suggested. Reflection and self are considered as mathematical constructions in the semantic space. Consciousness is interpreted as a process of neural activity structured so that a hierarchy of attractors appears in the activity space.
— The paper by Shigeki Sugiyama shows an initial and technical approach to the simulation of some consciousness functions. Sugiyama divides the consciousness whole into the lower and the higher consciousness, setting up two different primitive, to some extent invariant systems, each of them with its own theory. In the future, many engineering models of consciousness will be examined, especially by the improvement of the computer technology which will enable the most complex symbolic calculations within worldwide information nets.
— Let's presume that emerging of qualia in human mind cannot be explained by physical means; qualia is nothing else than a thought product with specific meaning. But people could agree that thought supervenes on the informational. Is qualia an informational phenomenon of mind or something else? Materialists will agree that the informational supervenes on the physical. At least, qualia supervenes on the physical but there is not knowledge for the explaining of qualia by physical means. On the other hand, the meaning or concept of qualia arises informationally and as such can be formalized in an arbitrary complex way through taking into account all available information concerning qualia. Thus an initial informational concept of qualia already exists.

11 Conclusion

The special issue of *Informatica* is edited upon several groups of topics which are the following:

- Consciousness Phenomenalism:
  (1) Informational Theory of Consciousness (A.P. Železnikar) and

(2) An Informational Conception of Developing the Consciousness of the Child (V.A. Fomichov & O.S. Fomichova).

– Philosophy of Consciousness:
(3) Information and the dynamics of Phenomenal Consciousness (Horst Hendriks-Jansen);
(4) Analysis of consciousness in Vedanta philosophy (Suhrit K. Dey); and
(5) Information: description, cognition, invention (A. Ione).

– Neural Networks Modeling Consciousness:
(6) Anticipation, Perception, Language, Mind and Nonlinear Dynamics of Neural Networks (Alexander D. Linkevich) and
(7) A basic idea of Consciousness (Shigeki Sugiyama).

– Quantum Theory for Consciousness:
(8) What is mind?—Quantum field theory of evanescent photons in brain as quantum theory of consciousness (Mari Jibu and Kunio Yasue);
(9) System-processual Backgrounds of Consciousness (Mitja Peruš);
(10) Prospects of conscious brain-like computers: biophysical arguments (Dejan Raković);
(11) Model of the neuron working by quantum holography (Peter J. Marcer and Walter Schempp); and
(12) Some brief remarks on information and consciousness (George L. Farre);
(13) Quantum holography and magnetic resonance tomography: an ensemble quantum computing approach (Walter Schempp).

Editors for these items are, as seen from titles of the papers, Vladimir A. Fomichov, Mitja Peruš, Dejan Raković, Walter Schempp, and Anton P. Železnikar.

Acknowledgment

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References

[1] Toward a Science of Consciousness 1996. "Tucson II". April 8–13, 1996. A service from the Journal of Consciousness Studies. Tucson, AZ.

[2] HEIDEGGER, M. 1962. Being and Time. Translated by J. Macquarric & E. Robinson. Harper & Row. New York.

[3] RAND, AYN. 1966. Introduction to Objectivist Epistemology. With an additional essay by L. Peikoff. A Mentor Book. New American Library. New York.

[4] WILBER, K. 1997. An integral theory of consciousness. Journal of Consciousness Studies 4:71–92.

[5] ŽELEZNIKAR, A.P. 1995. Principles of a formal axiomatic structure of the informational. Informatica 19:133–158.

[6] ŽELEZNIKAR, A.P. 1995. A concept of informational machine. Cyberentica 38:7–36.

[7] ŽELEZNIKAR, A.P. 1995. Elements of metamathematical and informational calculus. Informatica 19:345–370.

[8] ŽELEZNIKAR, A.P. 1996. Informational frames and gestalts. Informatica 20:65–94.

[9] ŽELEZNIKAR, A.P. 1996. Organization of informational metaphysicalism. Cyberentica 39:135–162.

[10] ŽELEZNIKAR, A.P. 1996. Informational transition of the form $\alpha \models \beta$ and its decomposition. Informatica 20:331–358.

[11] ŽELEZNIKAR, A.P. 1997. Informational graphs. Informatica 21:79–114.

Informational Theory of Consciousness

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Keywords: consciousness: arising, artificialism, causalism, circularism, components, concrete formal structure and organization, decomposition, distributivism, emerging, externalism, gestaltism, informational graph, informing, internalism, metaphysicalism, non-computability, parallelism, serialism, spontaneism, phenomenalism, star-gestaltism, understanding

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What is consciousness from a philosopher's, cognitivist's, physicist's, and informatician's point of view? Physicists attempt to tackle the problem by theoretical means of quantum theory [20, 10, 16, 30, 17, 14], philosophers by a debate on qualia [4, 23], cognitivists claim description and explanation [2, 21], for example. Informaticians develop a theory of the informational based on the new ground of informational arising [33, 34, 36, 37, 40, 42, 43, 44, 45]. This theory together with its formalism seems to meet the requirements for consciousness description, development, emerging, vanishing, modeling, and non-computability, although the principles of informational arising must be thought and elaborated to the new possible and necessary details.

The paper presents two basic metaphisicalistically organized concepts of consciousness: the general (Fig. 2) and the standard one (Fig. 3). On this ground, an initial informational shell of the generalized and standardized metaphysicalism of consciousness system $\mathfrak{z}$ in Fig. 7 is presented. The shell can be filled with concrete consciousness components (e.g., intention, experience, memory, understanding, etc.), functioning as operand markers in the scheme; they can be further and additionally (in parallel) decomposed in the form of their own and arbitrarily complex informational systems.

1 Introduction

Informational theory of consciousness[1] is an attempt towards a structure, organization, and formalism of consciousness from the informational point of view. What does this view concern, which scientific disciplines are involved, and what kind of formalistic approach could be used for description of consciousness phenomena?

In [16] (p. 194), Penrose divides the field of physics in two essential theories: the classical and the quantum one. The classical theory is deterministic, *so the future is always completely fixed by the past.* Principles of quantum theory are, on contrary, uncertainty, indeterminism, and mystery in behavior of physical particles.

In informatics (e.g., in the sense of the German term *die Informatik* or *das Informationelle* [47, 49]) also views of theoretical and practical understanding of objects can be recognized: the computational and the non-computational ones, respectively. Like physics, the field of informatics unites both views, and informational theory introduces (legalizes) uncertainty, indeterminism, and mystery as the unknown-yet in behavior of informational entities, however leaves computability to remain where it is consistent and necessary. More precisely, the theory introduces the principle of non-computability (in its widest meaning) as the most essential property of the informational so that the theoretical treatment of non-computable

[1]This paper is a private author's work and no part of it may be used, reproduced or translated in any manner whatsoever without written permission except in the case of brief quotations embodied in critical articles.

informational phenomena becomes possible. In this way a new theoretical approach is emerging—coming into the scientific discourse.

Phenomenalism of consciousness is a good example upon which the informational theory can be proved. From the cognitivistic point of view, consciousness is an assembly of informational concepts from various disciplines concerning brains and mind as biological and cognitivistic entities, respectively. On the other side, quantum theory is on the way to build a new theory for conscious phenomena in the living organisms [10].

Another push for using informational theory in consciousness research is given in [10] by objective reduction, *which is to be a non-computational process instead of merely a random one* [16, 17], and from the consciousness research in general [1]. It is another question what the contemporary mathematics can offer to the problem of non-computability as such, and how could it incorporate the study of consciousness into its own abstract scientific realm (world).

But because of its non-computability principles (that is, informational nature), informational theory does not fit the standard mathematical axiomatism [13] although trials similar to the traditional axiomatics of mathematics have been studied for the sake of the axiomatic analogy [40, 42]. The new theory allows, for instance, to take into consideration phenomena of spontaneity and circularity of informational entities, as the most basic properties of the entity informing [33, 34, 36, 37]. Within these principles the theory anticipates several other and particular forms of informing of entities like intentionality, coming of new information into existence, and informational embedding of arriving and emerging information into the corpus of informational entity. These preliminary studies call to approve the informational theory in the field of cognitive phenomena [44, 47, 49].

The phenomenon of consciousness concerns several fundamental concepts of spontaneous circular informing of entities which are serialism and parallelism in any complex and perplexed form, and the accompanying theory notions of informational transition, frame, gestalt, star gestalt, and graph [43, 45, 48]. These notions can become powerful tools of informational decomposition of entities for mastering the informational consciousness problems [50], as it will be presented through this paper.

2 Terminology of the Consciousness Hard and Soft Problem

How to face consciousness as an evident physical phenomenon, on the one side, and how to express this phenomenon by informational (also linguistic, symbolic, intentional) means, on the other side?

In quantum theory concerning consciousness, several terms came into the conscious foreground:

— attraction;
— coherence, interference;
— collapse;
— contraction;
— non-computability, uncertainty;
— objective reduction OR; and
— orchestrated space-time selections.

In cognitive science specific consciousness concerning terms are:

— awareness, attention, observing;
— intention, coherence, content;
— qualia, perception;
— experience, learning, memory, recall;
— emotion, understanding;
— sentience, intuition;
— thematic fields, nonconscious effects;
— introspection, the self, mind; and
— uncertainty, subjective aspect.

In the study of the human prefrontal cortical functions [8, 9] several models are presented, based on the theories of:

— attentional control [24, 25, 26]:
  — contention scheduler;
  — supervisory attention system (SAS);
— working memory [7, 31];
— temporal processing model [6];
— behavioral/anatomical theory [29];
— problem solving [15];
— somatic marker theory [5, 32]; and
— action framework [22].

The above models explicate similarities and they all operate over extended time domains and resemble the so-called controlled attentional processes. They suggest information stored elsewhere in the cerebral cortex (manipulating the brain distributively) which constitutes the main function of the prefrontal cortex. For instance, working memory, attention, or serial encoding, each appears as an informational operator coordinating the activation of stored information [9].

In the theory of the informational there are the following general counterterms:

- informational arising as a metaphor for:
  - collapse (ceasing) of informing of informational items (operands as well as operators);
  - emerging of new informational items (e.g., on the basis of counterinforming, coming of information into existence);
  - changing of existing (informing) of informational items;
  - informational spontaneity in the framework of an entity's intentionality;
  - non-computability of operands (entities) and operators (their relations);
- informational embedding as a basic property of informing: connecting the arisen and arrived information to the existing information;
- causalism (possibilities of displacement of parenthesis pairs in formula systems; informational gestalts, especially star gestalts);
- circularity in the form of serialism, parallelism, with perplexed causal loops;
- metaphysicalism as a synonym for individual circular coherence;
- serialism as a synonym for causation;
- parallelism (formula systems, informational graphs);
- spontaneity as arising, non-determinism, accidental events, non-predictiveness, etc.;
- vanishing (dying of informational systems as a consequence of dying of biological organization [18], collapse of physical systems);
- informational transition; and
- informational graph as a representative of the most complex parallelism.

These three disciplinary views—the physical, the cognitive, and the informational—constitute an essential ground for the future scientific investigation of the consciousness phenomenalism. Certainly, several other disciplines are and will be involved, especially those studying the phenomena of the brain and the mind.

3 Basic Formalism for Informational Consciousness Study

3.1 Introduction to the Study of Natural and Artificial Consciousness Phenomenalism

A cognitivist can think about consciousness in terms of his/her own observation of his/her own states of awareness in the form of the consciousness phenomenalism. Consciousness appears as a complex informational entity with a number of components being operationally joined into a system of informing entities.

Informational consciousness is a particular phenomenon of the informational, and informational formalism as studied in some recent papers of the author [33, 34, 36, 37, 40, 42, 43, 44, 45, 48] fits the consciousness phenomenalism in the best possible way. What is more important also in this study is the formalistic approach to the phenomenalism of informational consciousness entities. By this approach a systematic understanding of informational entities on both the abstract and the complex level becomes constructively (modeling-likely) and functionally transparent. Formalization brings to the surface several verbally hidden problems in the domain of informational hardness and softness, which can specifically concern the study of consciousness phenomenalism. The formalism brings also to the view the possibilities of structural and organizational artificialness, that is, conceptualization and modeling of arbitrarily complex conscious systems. In this respect, models of natural consciousness, as understood by the contemporary science, seem to appear below the various and arbitrarily powerful (complex) possibilities of the artificial consciousness systems.

3.2 A Formalism for Expression of Consciousness Phenomenalism

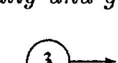
Informational formalism presented in [36, 37, 40, 42, 43, 44, 45, 48] is a visible candidate for the study of the most pretentious problems of consciousness, being a system of coherently and inferentially acting informational components. Both informational operands and informational operators belong, if necessary, to the category of uncertainly and non-computably informing entities. In this respect, they cannot be exactly and efficiently processed and modeled by nowadays computer programs. For this purpose, an informational machine, using informational programs, would be necessary [41], performing as an informing entity (computing device) by itself. This initial comment for the reader is necessary to stay aware that informational operands and operators together with their formulas are, by their nature, informationally arising (changing, emerging, vanishing) entities. This fact cannot be slighted by the fame of the tremendous power of the today computing system nets.

3.2.1 The Most Fundamental Axioms of Consciousness

It is easy to identify how the fundamental axioms of the informational [40] meet the axioms of consciousness. For instance, that consciousness informs out of itself (to the exterior), that it is informed into itself (to its interior) from the exterior, and, its most characteristic feature, that it informs (in) itself and is informed by (in) itself (consciousness circularity). For a consciousness system, marker $\mathfrak{z}$ (or, systematically, $\mathfrak{z}_0$)[2] will be used.

The general informational axiom[3] says that consciousness $\mathfrak{z}$ informs, otherwise it could not be observed by consciousness. This sentence hides three elementary axioms.

Axiom 1 (Consciousness Informing) *Consciousness $\mathfrak{z}$ informs. Formally and graphically,*

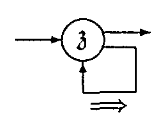
$\mathfrak{z} \models$ *and* 

respectively. Here, $\models$ is an operator of consciousness informing and $\longrightarrow$ (an arrow of an arbitrary length and form) is the graphical representation of operator $\models$, respectively. □

A kind of the consequence of this axiom is an implication which origins in the meaning of the verb 'inform'. Namely, if something informs, there must exist something which is informed by the something's informing. By the first of the classical mathematical axioms[4] it would mean that the following implication is reasonable:

$$(\mathfrak{z} \models) \Longrightarrow ((\models \mathfrak{z}) \Longrightarrow (\mathfrak{z} \models))$$

This axiomatic implication [13] is explicitly circular in respect to $\mathfrak{z} \models$ and implicitly circular to $\models \mathfrak{z}$. The informational graph for this axiomatic implication is evidently

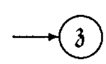
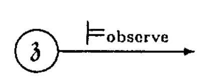


Thus, also,

$$(\models \mathfrak{z}) \Longrightarrow ((\mathfrak{z} \models) \Longrightarrow (\models \mathfrak{z}))$$

The second consciousness axiom can now be formulated.

Axiom 2 (Consciousness Observing) *Consciousness $\mathfrak{z}$ is consciously informed or, simply, $\mathfrak{z}$ observes. Formally and graphically,*

$\models \mathfrak{z}$ *and*  *or* 

respectively. $\mathfrak{z}$ is observingly open, that is, for observing something (the empty left place of $\models$). □

Explicitly, the following consequence of Ax. 2 is possible.

Consequence 1 *Formula $\models \mathfrak{z}$, where $\mathfrak{z}$ has the observing position, can be expressed explicitly in an operator particularized form,*

$$\mathfrak{z} \models_{\text{observe}}$$

[2]Symbol $\mathfrak{z}$ for consciousness was chosen as the last letter in the Fraktur alphabet, to be clearly distinguished from any other letter symbol. In Slovene, consciousness is translated as zavest.

[3]Informational axioms, presented in this paper, meet the principles of the objectivist epistemology (Ayn Rand [19]). Informational axioms identify a primary fact of the reality, consisting of the three axiomatic parts: informational externalism, internalism, and metaphysicalism. Out of these axioms the axiom of informational phenomenalism follows, as a central fact of informing of things, entities, events, phenomena, etc. In this way, existence, identity, and consciousness of entities and phenomena come into the foreground.

[4]The first (meta)mathematical axiom ([13], p. 66) has the form

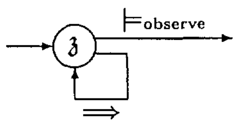
$$A \longrightarrow (B \longrightarrow A)$$

In the discussed informational case we insert $\mathfrak{z} \models$ for A, $\models \mathfrak{z}$ for B and informational implication $\Longrightarrow$ for mathematical implication $\longrightarrow$.

Thus, logically,

$$(\models \mathfrak{z}) \Longrightarrow (\mathfrak{z} \models_{\text{observe}});$$
$$(\mathfrak{z} \models_{\text{observe}}) \Longrightarrow (\models \mathfrak{z})$$

and graphically,

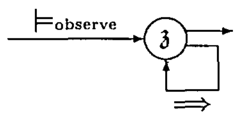


respectively.

Simultaneously, as a consequence of Ax. 1, there is logically,

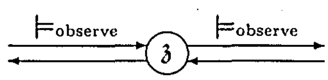
$$(\mathfrak{z} \models) \Longrightarrow (\models_{\text{observe}} \mathfrak{z});$$
$$(\models_{\text{observe}} \mathfrak{z}) \Longrightarrow (\mathfrak{z} \models)$$

and graphically,



respectively. □

Consequence 2 (Bidirectionality of the consciousness informing-observing phenomenalism) *According to Cons. 1, the following basic informational graph for consciousness $\mathfrak{z}$ is coming in the foreground:*



The dualism (in the form of the informational bidirectionality) of informing and observing of consciousness $\mathfrak{z}$ will become still more evident in the circular and metaphysicalistic organization of consciousness. □

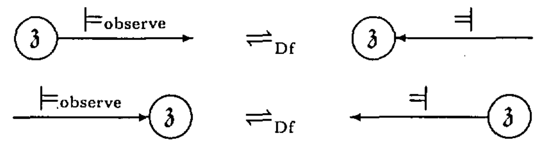
The following is evident: if consciousness informs (something), it must be observed (by something); if consciousness observes (something), it must be informed (by something). In case of an arbitrary informational entity instead of consciousness, the *must* will be replaced by the *can*.

Informationally, the informing and the observing are antisymmetric phenomena. For the sake of formalistic symmetry the following definition is senseful.

Definition 1 *Let the operator $\models_{\text{observe}}$ be replaced by the counter-directional operator $=\!\mid$. Then,*

$$(\mathfrak{z} \models_{\text{observe}}) \rightleftharpoons_{\text{Df}} (\mathfrak{z} =\!\mid);$$
$$(\models_{\text{observe}} \mathfrak{z}) \rightleftharpoons_{\text{Df}} (=\!\mid \mathfrak{z})$$

The particularized (observing) operator $\models_{\text{observe}}$ is replaced by the right-left (informing, called also alternative) operator $=\!\mid$. Graphically, the following definitional equivalence is introduced:

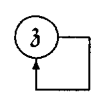


Operator $\models_{\text{observe}}$ and $=\!\mid$ is a particularization of operator $\models$. □

The informing and observing of consciousness can concern the consciousness itself, where consciousness informs itself and is informed by itself, or where consciousness observes itself and is being observed by itself. The following axiom is a consequence of the preceding axioms.

Axiom 3 (Consciousness Void Informational Circularity) *Consciousness $\mathfrak{z}$ consciously informs itself and is consciously informed by itself or, simply, consciousness observes itself. Formally and graphically, there is,*

$$\mathfrak{z} \models \mathfrak{z} \quad \text{and}$$



respectively. This formula constitutes the so-called void or pure consciousness (e.g., [27]). □

According to the general informational theory [33, 36], this axiom could be called the void consciousness metaphysicalism[5]. Void consciousness is an informational artifact existing only as a meditation process in eastern philosophy [27]. On the other hand, $\mathfrak{z} \models \mathfrak{z}$ is the initial situation, in which the so-called general (circular-serial, circular-parallel) or more specific (general metaphysicalistic or standardized metaphysicalistic) informational decomposition can be started.

[5]A general concept of consciousness metaphysicalism will be discussed later. Metaphysicalism means a loosely determined (organizational invariance, according to [3], interpreted also as a void consciousness, according to [46], p. 406) structure and organization of an informational entity.

In such a decomposition, inner components of consciousness come to the surface in a circular serial and/or circular parallel manner. The so-called *pure* or *void* consciousness which appears as the final state of the extremely skilled and disciplinary meditation in Eastern philosophies (see the discussion in [46]) becomes, in an informational decomposition process, the beginning situation from which the complexity of consciousness develops. A similar situation happens in a living embryo when after the development of neurons (still in the condition of tabula rasa) the synaptic-dendritic connection among neurons begin to emerge, as a consequence of circumstances, learning, and experience events, disturbances, and pressures of the life.

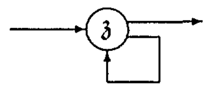
Informational phenomenalism of consciousness is the most general principle of possible consciousness informing, emerging of its structure and organization, determination of its inner and outer structural decomposition. In its formalistic, conceptual, and constructive sense, this phenomenalism must preserve at least: the coming potentiality of consciousness evolution, the conscious and unconscious development, the surpassing of the instantaneous transparent horizons, and the intervening beyond the disciplinarily traced scientific and ideological frames of reference and understanding.

Within this perspective, consciousness phenomenalism unites its externalism, internalism, and metaphysicalism as stated in Axs. 1–3. In this respect, consciousness remains open to the impactingness and to the impactedness of itself and its environment.

Axiom 4 (Phenomenalistic Nature of Consciousness) *Formalistically, the consciousness phenomenalism is best described by the basic parallel system of the form*

$$\mathfrak{z} \rightleftharpoons \begin{pmatrix} \mathfrak{z} \models; \\ \models \mathfrak{z} \end{pmatrix}$$

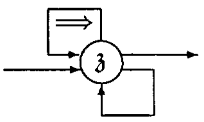
and



where the following informational implication of consciousness

$$\begin{pmatrix} \mathfrak{z} \models; \\ \models \mathfrak{z} \end{pmatrix} \Longrightarrow (\mathfrak{z} \models;\ \models \mathfrak{z};\ \mathfrak{z} \models \mathfrak{z})$$

must be considered. This implication increases the circularity in the sense of the sense of the informational graph of the form



Evidently, informational phenomenalism of consciousness includes [38] its externalism, internalism, and metaphysicalism. Thus,

$$\mathfrak{z} \models,\ \models \mathfrak{z},\ \mathfrak{z} \models \mathfrak{z} \subset \begin{pmatrix} \mathfrak{z} \models; \\ \models \mathfrak{z} \end{pmatrix}$$

is true. □

In the next definition we have to clear up the potentiality of operators $\models$ and $\rightleftharpoons$ also in the so-called trivial cases.

Definition 2 (General Meaning of Operator $\models$ and Operator $\rightleftharpoons$ in a Trivial Case) *Additional explanation of formulas $\mathfrak{z} \models \mathfrak{z}$ and $\mathfrak{z} \rightleftharpoons \mathfrak{z}$ is the following:*

$\mathfrak{z} \models \mathfrak{z}$: *Besides that what is said in Ax. 3, $\mathfrak{z}$ on the left is the informer of $\mathfrak{z}$ on the right of operator $\models$. The left and the right $\mathfrak{z}$ can be developed by the essentially different serial, parallel, and circular $\mathfrak{z}$'s decompositions. That what remains is that the left $\mathfrak{z}$ part informs (impacts) the right one $\mathfrak{z}$-part. Both parts remain constituents of $\mathfrak{z}$ as an integrated entity—which may be marked by $\mathfrak{z}$. The last concerns already the next situation, that is $\mathfrak{z} \rightleftharpoons \mathfrak{z}$.*

$\mathfrak{z} \rightleftharpoons \mathfrak{z}$: *Operator $\rightleftharpoons$ is understood to be a particularization of the general operator $\models$ (informational joker) and expresses the meaning of the left denotation (designator, marker) in concern to the right formula system. Usually, the left $\mathfrak{z}$ marks the right formula complexly developed (decomposed) to an arbitrary serial, parallel, and/or circular complexity. In principle, the same can certainly hold for the left $\mathfrak{z}$.*

Difference: *Between formulas $\mathfrak{z} \models \mathfrak{z}$ and $\mathfrak{z} \rightleftharpoons \mathfrak{z}$ is the difference in informing and meaning. The first formula is in principle a beginning of the possible informational decomposition, where in formula $\mathfrak{z} \models_{\mathfrak{z}} \circ \models_{\mathfrak{z}} \mathfrak{z}$ (as an operator composition) the left part $\mathfrak{z} \models_{\mathfrak{z}}$ as well as the right part $\models_{\mathfrak{z}} \mathfrak{z}$ can be entirely differently decomposed. In formula $\mathfrak{z} \rightleftharpoons \mathfrak{z}$, the left*

> *part is used as a designator of the arbitrarily complex right part and as a shortcut in other complex formula systems.*

The presented difference is essential for comprehension of informationally conceptualized symbolism, denotations and formula systems. □

3.2.2 General and Metaphysicalistic Circular Serial Decomposition of Consciousness

On the other hand, that what concerns the study of consciousness is the possibility of consciousness decomposition, in a circular and spontaneous manner, and in a serial and parallel form. Consciousness $\mathfrak{z}$ as a general entity is decomposed into its circular-serial components, marked by $\mathfrak{z}_0$, $\mathfrak{z}_1$, $\ldots, \mathfrak{z}_n$, where $\mathfrak{z}_0$ simultaneously marks the general entity $\mathfrak{z}$. A consciousness component is denoted by $\mathfrak{z}_j$, where $0 \le j \le n$. Such a decomposition possesses $n+1$ components.

This sort of a general decomposition is an informational function [39] of the initial general circular position $\mathfrak{z} \models \mathfrak{z}$ or shortly $\mathfrak{z}$, marked by ${}^{n+1}_{\;i_j}\Delta^{\circlearrowleft}_{\rightarrow}$. Another sort of decomposition of $\mathfrak{z}$ is the so-called metaphysicalistic decomposition ${}^{n+1}_{\;i_j}\mathsf{M}^{\circlearrowleft}_{\rightarrow}$ constituted by the three characteristic (metaphysicalistic) parts: intentional informing, intentional counterinforming, and intentional embedding. The term 'intention' is a joker (metaphor) for characteristic coherence (components) of consciousness like experience, qualia, emotion, memory, introspection, observing, etc. Thus,

$$ {}^{n+1}_{\;i_j}\Delta^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}) \quad \text{and} \quad {}^{n+1}_{\;i_j}\mathsf{M}^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}) $$

mean the following:

- $n+1$ is the length (number of binary operators of type $\models$) of circular decomposition and, simultaneously, the number of occurring loop operands;
- j is the subscript of a concrete operand, the one of $\mathfrak{z}$'s components, $\mathfrak{z}_j$, thus, $0 \le j \le n$;
- i_j is a case of causal possibilities in the interval $1 \le i_j \le \frac{1}{n+2}\binom{2n+2}{n+1}$;
- $\circlearrowleft$ is the symbol of circular structure;
- $\rightarrow$ marks the serial structure; and
- $\mathfrak{z}$ in this context, represents a circularly ordered sequence of operands, according to the circularly running subscript j, $\mathfrak{z}_j, \mathfrak{z}_{j+1}, \ldots, \mathfrak{z}_{n-1}, \mathfrak{z}_n, \mathfrak{z}_0, \mathfrak{z}_1, \ldots, \mathfrak{z}_{j-1}$.

Circular serial decompositions deliver circular serial formulas and informationally coherent consciousness formula systems. According to the form of circular formulas [43, 44, 48, 50, 47, 49] obtained by the circular serial decomposition, for the case of consciousness $\mathfrak{z}_0$, there is,

$$
\begin{aligned}
{}^{n+1}_{\;i_0}\Delta^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_0) &\rightleftharpoons {}^{n+1}_{\;i_0}\mathfrak{z}\underline{0}^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_0, \mathfrak{z}_1, \mathfrak{z}_2, \ldots, \mathfrak{z}_n); \\
{}^{n+1}_{\;i_1}\Delta^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_1) &\rightleftharpoons {}^{n+1}_{\;i_1}\mathfrak{z}\underline{1}^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_1, \mathfrak{z}_2, \ldots, \mathfrak{z}_n, \mathfrak{z}_0); \\
&\vdots \\
{}^{n+1}_{\;i_j}\Delta^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_j) &\rightleftharpoons {}^{n+1}_{\;i_j}\mathfrak{z}\underline{j}^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_j, \mathfrak{z}_{j+1}, \ldots, \mathfrak{z}_n, \mathfrak{z}_0, \ldots, \mathfrak{z}_{j-1}); \\
&\vdots \\
{}^{n+1}_{\;i_n}\Delta^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_n) &\rightleftharpoons {}^{n+1}_{\;i_n}\mathfrak{z}\underline{n}^{\circlearrowleft}_{\rightarrow}(\mathfrak{z}_n, \mathfrak{z}_0, \mathfrak{z}_1, \ldots, \mathfrak{z}_{n-1}); \\
1 \le i_0, i_1, &\ldots, i_j, \ldots, i_{n-1}, i_n \le \tfrac{1}{n+2}\tbinom{2n+2}{n+1}
\end{aligned}
$$

From the decomposition scheme, it is evident that the number of all possible circular-serial decompositions of length $n+1$, considering the rotation of the occurring operands in a cycle, for the described situation, is

$$ {}^{\circlearrowleft}\!N^{\circlearrowleft}_{\rightarrow} = \frac{n+1}{n+2}\binom{2n+2}{n+1} $$

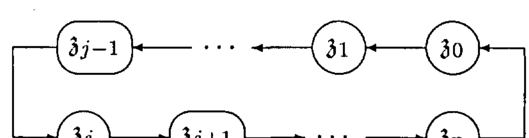


Figure 1: *A generalized circular graph (which fits the serial as well as the parallel case) of consciously informing components* $\mathfrak{z}_j$, *if* $0 \le j \le n$. *In fact, the single (main) loop of the graph, without additional feedbacks (subloops including some successive operands of the main loop), concerns all of the circularly involved operands,* $\mathfrak{z}_0, \ldots, \mathfrak{z}_n$.

In [48], Fig. 28, the details for the structure of an informational function ${}^{n+1}_{\;i_j}\varphi^{\circlearrowleft}_{\rightarrow}$, corresponding to the circular structure of a consciousness component ${}^{n+1}_{\;i_j}\mathfrak{z}\underline{j}^{\circlearrowleft}_{\rightarrow}$, are presented where, certainly, $0 \le j \le n$. The graph, presenting roughly the listed $n+1$ decompositions is shown in Fig. 1. One of the possible circular serial interpretation

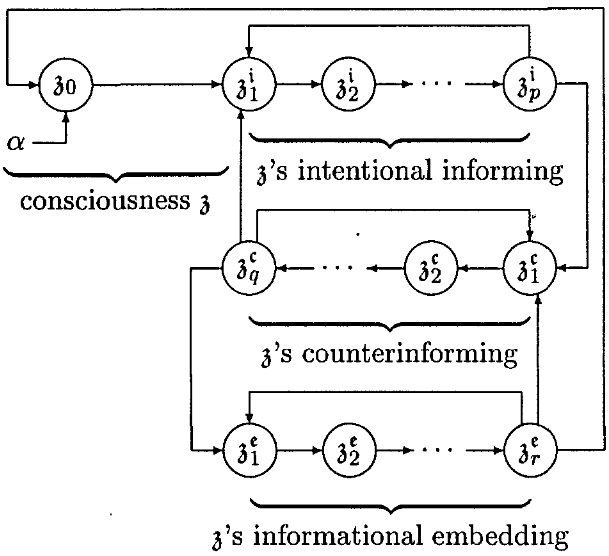


Figure 2: *A generalized metaphysicalism of consciousness* $\mathfrak{z}_0$ *(marked, in general, by symbol* $\mathfrak{z}$*) with consciousness-intrinsic informing, counterinforming and informational embedding, concerning something exterior or interior, denoted by* α. *In this scheme, there are six metaphysicalistically characteristic feedbacks, connecting several components:* $\mathfrak{z}_r^{\mathfrak{e}}$ *with* $\mathfrak{z}_0$, $\mathfrak{z}_q^{\mathfrak{c}}$ *with* $\mathfrak{z}_1^{\mathfrak{i}}$, $\mathfrak{z}_r^{\mathfrak{e}}$ *with* $\mathfrak{z}_1^{\mathfrak{c}}$, $\mathfrak{z}_p^{\mathfrak{i}}$ *with* $\mathfrak{z}_1^{\mathfrak{i}}$, $\mathfrak{z}_q^{\mathfrak{c}}$ *with* $\mathfrak{z}_1^{\mathfrak{c}}$, *and* $\mathfrak{z}_r^{\mathfrak{e}}$ *with* $\mathfrak{z}_1^{\mathfrak{e}}$.

of the graph in Fig. 1 is, for instance, the first formula of existing $\frac{1}{n+2}\binom{2n+2}{n+1}$ formulas, the general decomposition $\overset{n+1}{\underset{i_j\,\to}{\Delta}}{}^{\circlearrowleft}(\mathfrak{z}_j)$, concerning operand $\mathfrak{z}_j$, that is,

$$\begin{array}{l}(\cdots(((\cdots(\mathfrak{z}_j \models \mathfrak{z}_{j+1}) \models \cdots \mathfrak{z}_{n-1}) \models \mathfrak{z}_n) \models \\ \quad \mathfrak{z}_0) \models \mathfrak{z}_1) \models \cdots \mathfrak{z}_{j-2}) \models \mathfrak{z}_{j-1}\end{array}$$

In principle, the metaphysicalistic structure meets the presented general circular scheme. The difference to the general circular case lies in a loose form of the metaphysicalistically invariant organization, by which some specific, meaningly (semantically, pragmatically) founded informational details (operands, feedbacks) come into the foreground. In this respect, the metaphysicalistic scheme possesses intrinsically characteristic parts (structure with feedbacks) of a consciousness loop, as shown in Fig. 2. For this scheme there exist six circular decompositions, expressed by a unique system of circular formulas. An example of such a unique system is, for instance,

$$\left(\begin{array}{l}(\cdots(((\cdots(((\cdots((\mathfrak{z}_0 \models \mathfrak{z}_1^{\mathfrak{i}}) \models \mathfrak{z}_2^{\mathfrak{i}}) \models \cdots \mathfrak{z}_p^{\mathfrak{i}}) \\ \qquad \models \mathfrak{z}_1^{\mathfrak{c}}) \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \\ \qquad \models \mathfrak{z}_1^{\mathfrak{e}}) \models \mathfrak{z}_2^{\mathfrak{e}}) \models \cdots \mathfrak{z}_r^{\mathfrak{e}}) \\ \quad \models \mathfrak{z}_0; \\ (\cdots(((\cdots(\mathfrak{z}_1^{\mathfrak{i}} \models \mathfrak{z}_2^{\mathfrak{i}}) \models \cdots \mathfrak{z}_p^{\mathfrak{i}}) \models \\ \qquad \mathfrak{z}_1^{\mathfrak{c}}) \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \models \mathfrak{z}_1^{\mathfrak{i}}; \\ (\cdots(((\cdots(\mathfrak{z}_1^{\mathfrak{c}} \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \models \\ \qquad \mathfrak{z}_1^{\mathfrak{e}}) \models \mathfrak{z}_2^{\mathfrak{e}}) \models \cdots \mathfrak{z}_r^{\mathfrak{e}}) \models \mathfrak{z}_1^{\mathfrak{c}}; \\ (\cdots(\mathfrak{z}_1^{\mathfrak{i}} \models \mathfrak{z}_2^{\mathfrak{i}}) \models \cdots \mathfrak{z}_p^{\mathfrak{i}}) \models \mathfrak{z}_1^{\mathfrak{i}}; \\ (\cdots(\mathfrak{z}_1^{\mathfrak{c}} \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \models \mathfrak{z}_1^{\mathfrak{c}}; \\ (\cdots(\mathfrak{z}_1^{\mathfrak{e}} \models \mathfrak{z}_2^{\mathfrak{e}}) \models \cdots \mathfrak{z}_r^{\mathfrak{e}}) \models \mathfrak{z}_1^{\mathfrak{e}}\end{array}\right)$$

Later we shall see how all the circular causal possibilities are determined by the graph, and how this situation is described formally by the parallel formula system consisting of primitive informational transitions only.

The basic standardized scheme of consciousness metaphysicalism can now be discussed in a greater detail in the next paragraph.

3.2.3 The Standardized Fundamental Organization of Consciousness Metaphysicalism

Consciousness as a natural phenomenalism is not only an extremely appropriate case of informational philosophy, but fits astonishingly suitable the presented informational formalism also. It explicitly shows the most characteristic properties of informational emerging (arising in the process of informing, counterinforming, and informational embedding), in the spirit of coming of the new information into existence, its changing and disappearing. Informational arising brings new and again new informational objects into the appearance of consciousness, its specific informationally concerning objects. In this respect, consciousness is much more an evident entity within the informational phenomenalism as it could be some other physical entity, e.g. a thing, where a thing's emerging, changing, and vanishing might be not so evident as it is a case of consciousness. On the other hand, it should be said that the informational phenomenalism can meet biological systems in their evolutionary development and in reactions as consequences of intrinsic and extrinsic physical, biological, and informational disturbances. Within this ascertainment lies the perspective of the use of the new informational formalism in the fields of biology, sociology, psychology, and other intelligently structured phenomena [44].

The organizational invariance[6] of a consciousness informational system fits the requirements characteristic for the metaphysicalism of informational entities [36, 37, 40, 44, 47]. An adequate term for this kind of organization within the informational theory is the *standardized fundamental organization of metaphysicalism*, which applies for consciousness too. The details of consciousness come into the foreground when a specific case is studied and then decomposed to the possible details. Within this context, some specific components must (in an organizationally invariant sense) belong to a specific section of the fundamental metaphysicalistic scheme. Indeed, specific artificial decompositions are possible, in which consciousness components can appear in different sections. Such cases occur in the process of parallel decomposition (parallelization), when different parallel loops for consciousness come into existence.

The graph in Fig. 3 shows such a standardized situation. Within this scheme, each component (an informing and its entity) can be further decomposed, where an informing should preserve the attributes of informing, and to it belonging entity should appear as a consequence of this informing. Because of the circular structure of the system, causality is circular too, and in this view, informings and their entities become informationally depended on all in the loop informing entities.

How could the scheme in Fig. 3 be interpreted for a concrete case of consciousness? Which entities could occupy the determined parts as consciousness components? At the first glance, one could say that, for instance, consciousness concerns understanding [44], by which the intentional part of consciousness includes intending, sensing, and observing as being conscious; the counterinforming part includes the being unconscious and conceiving; this part is responsible for the essential emerging of information from the unconscious and for the emerging of concepts from the unconscious background; the informational-embedding

[6]The term *organizational invariance* was introduced by Chalmers [3], and has been discussed and additionally interpreted in [46] by the author.

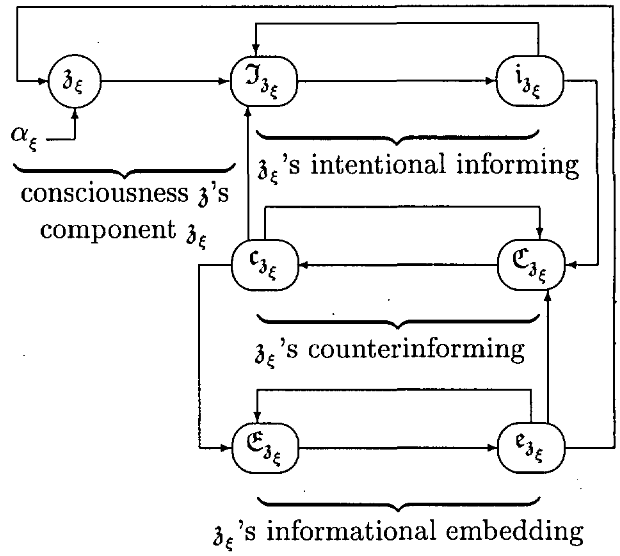


Figure 3: *A standardized metaphysicalistic organization of consciousness components* $\mathfrak{z}_\xi$*, where* $\mathfrak{z}_\xi$ *applies to components* $\mathfrak{z}_j$, $0 \leq j \leq n$, *in Fig. 1, as well as to* $\mathfrak{z}_\xi \in \{\mathfrak{z}_1^{\mathfrak{i}}, \ldots, \mathfrak{z}_p^{\mathfrak{i}}; \mathfrak{z}_1^{\mathfrak{c}}, \ldots, \mathfrak{z}_q^{\mathfrak{c}}; \mathfrak{z}_1^{\mathfrak{e}}, \ldots, \mathfrak{z}_r^{\mathfrak{e}}\}$ *in Fig. 2. In this scheme, each metaphysicalistic part is divided into informing* $(\mathfrak{I}, \mathfrak{C}, \mathfrak{E})$ *of the part, and informational entity, that is, operand* $(\mathfrak{i}, \mathfrak{c}, \mathfrak{e})$*, to which the informing belongs.*

part decides upon the contents which should be incorporated into the subject of the instantaneous consciousness: such components could be signifying (recognizing of importance of something), making sense (bringing the sense of a certain consciousness into the foreground), perceiving (making an interpretation as unavoidable and necessary), concluding (generating inferential processes with specific goals), and lastly, generating meaning of a conscious process as an informational result in a global and particular sense.

The described pragmatic case of understanding meets consciousness as small and particular case only. Consciousness has many other and very different and controversial components, and its own parallel cycles, on the conscious and unconscious (subconscious) level. The most exhaustive, but still not sufficiently integrated presentation in this direction will be described in [50].

If each consciousness component is organized metaphysically, and the same applies for a consciousness system as a whole too, then the question arises, how it would be possible to identify the system's integral intentionality, its intentional counterinforming, and intentional embedding? It becomes evident that these informational functions are distributed over the consciousness components, and can be comprehended simply as nothing else than *distributed* intentionality, its counterinforming and embedding. In this respect, consciousness appears as a distributed system in regard of its basic properties of informing. It comes up the evidence that, formally, the consciousness system as an informational system could be expressed by means of distributed operands. What could such an operand mean and how could it be expressed formally and efficiently?

To grasp consciousness as an integratively as well as componently distributed entity (a complex informational operand), we can introduce the equational (equivalence) denotation

$$\mathfrak{z}_\xi \rightleftharpoons \|\mathfrak{z}_\xi\rangle$$

Denotation $\|\mathfrak{z}_\xi\rangle$ reminds someone on the symbol of a state vector (quantum state), e.g. $|\psi\rangle$, in Hilbert space. Although, a certain affinity between denotations $\|\mathfrak{z}_\xi\rangle$ and $|\psi\rangle$ could be possible, the difference is essential. The parallelism symbol $\|$ in $\|\mathfrak{z}_\xi\rangle$ denotes the parallel structure of $\mathfrak{z}$, where its components inform in parallel (concurrently and simultaneously), although they can be informationally circularly and/or serially connected. Symbol $\|$ represents the distributivity of an informational entity in a parallel (componentially-coexistent) manner.

In Hilbert space, $|x\rangle + |y\rangle$ is a vector (resultant) composed of vectors $|x\rangle$ and $|y\rangle$, where '+' is the composition (combination) operator. In informational theory, in $\|\alpha\rangle \models \|\beta\rangle$, symbol $\models$ is the composition operator, and $\|\alpha\rangle$ and $\|\beta\rangle$ are components of the basic informational transition. Transition $\|\alpha\rangle \models \|\beta\rangle$ is a new informational entity (an autonomous operand), $\|\alpha \models \beta\rangle$, in regard to its constituting entities (operands) $\|\alpha\rangle$ and $\|\beta\rangle$. The notional parallelism between a Hilbert space and an informational space could be developed also in the direction of the scalar product $(|a\rangle, |b\rangle)$ (a sum of sums of products) and a vector length (norm) $\||a\rangle\|$. In informational theory, notation (α, β) means coexistent entities α and β, for which, by this sort of notation, their interaction is not determined. A sort of informational distributive law is

$$(\alpha, \beta \models \gamma) \rightleftharpoons \begin{pmatrix} \alpha \models \gamma; \\ \beta \models \gamma \end{pmatrix}$$

while this law in a Hilbert space is $(x, y + z) = (x, y) + (x, z)$.

Evidently, informational coexistence formula (α, β) is not an adequate equivalent to the Hilbertian product (x, y), which is a scalar measure. One of the possible informational measures could be the meaning μ of an informational entity. Thus, for instance,

$$\mu(\alpha, \beta)$$

can be defined as a function (informational Being-of [39]) concerning entities α and β. The definition [39] delivers, evidently, the circular system

$$\mu(\alpha, \beta) \rightleftharpoons \begin{pmatrix} \mu \models_{\text{of}} \alpha, \beta; \\ \alpha, \beta \models \mu; \\ (\mu \models_{\text{of}} \alpha, \beta) \subset \mu; \\ (\alpha, \beta \models \mu) \subset_{\text{of}} \mu \end{pmatrix}$$

It can be easily seen how a multivariable function

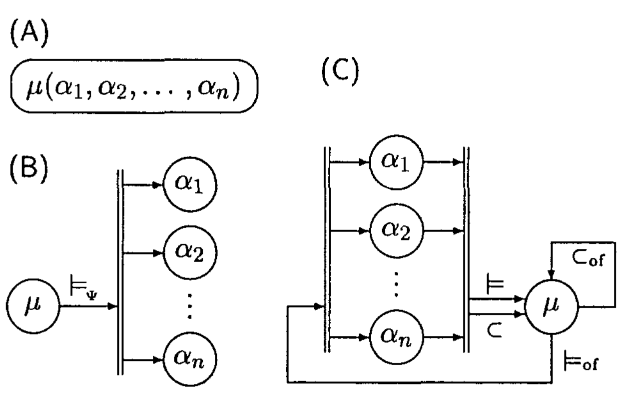


Figure 4: *Informational graph for the case of meaning* μ *as a multivariable informational function:* (A) *for* $\mu(\alpha_1, \alpha_2, \dots, \alpha_n)$; (B) *for the functional transition* $\mu \models_\Psi \alpha_1, \alpha_2, \dots, \alpha_n$; *and* (C) *for the definition of informational function* $\mu(\alpha_1, \alpha_2, \dots, \alpha_n)$.

of meaning would be formally expressed and how it would look like graphically. Fig. 4 shows the situation for the three equivalent cases which can be used within an informational graph. Case (C) presents all the details which must be considered. Usually, in a graph presentation, case (B) is applied which delivers the possible causal diversity considering different paths within a graph, especially when exploring cases of star gestalts [43].

Meaning as an entity of consciousness appears often in the form of informational function of an informational function, to an arbitrary depth, as presented in Fig. 5. Thus,

$$\mu(\alpha_1(\alpha_2 \ldots (\alpha_{n-1}(\alpha_n)) \ldots))$$

In this context, to the Hilbertian norm corre-

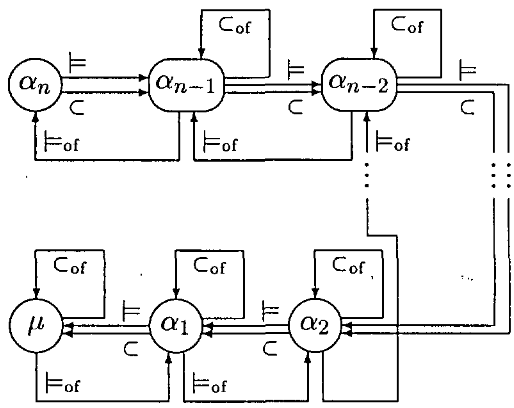


Figure 5: *Informational graph for the function* $\mu(\alpha_1(\alpha_2 \ldots (\alpha_{n-2}(\alpha_{n-1}(\alpha_n))) \ldots))$, *where* $\subset$ *and* $\subset_{of}$ *represent complex operators of informational Being-in [38].*

sponding meaning μ of an informational entity $\mathfrak{z}$ would mean to decompose the function $\mu(\mathfrak{z})$ as an informational interpretation of $\mathfrak{z}$. In principle, there are at least two possibilities for the place of meaning $\mu(\mathfrak{z})$. It can, for example, appear in a metaphysicalistic environment (decomposition) of $\mathfrak{z}$. In a different case, it can appear as an autonomous informational formula system informing in parallel to $\mathfrak{z}$. All this should suffice to give the reader an outlook on possibilities of construction of informational space, with essentially different meaning and structure in comparison to Hilbert space.

Meaning belongs to the central notions of informational embedding and, in case of consciousness, it is indispensable within various components of consciousness. As soon as meaning appears in a consciousness informational loop it becomes, directly or indirectly, impacted by the components of the loop. On the other hand, it may certainly impact the development of consciousness components. For instance, the informing of component α_n in Fig. 5, as a main circular operator, can be described by the formula

$$((\ldots(((((\ldots((\alpha_n \subset \alpha_{n-1}) \subset \alpha_{n-2}) \subset \ldots \alpha_2) \subset \alpha_1) \subset \boxed{\mu}) \models_{of} \alpha_1) \models_{of} \alpha_2) \models_{of} \ldots \alpha_{n-2}) \models_{of} \alpha_{n-1}) \models_{of} \alpha_n$$

Meaning μ can appear in a consciousness component loop. But, it can be treated also as a parallel formula concerning consciousness components. In this way, it can have its own metaphysicalistic structure, e.g., in the sense,

$$\mu(\mathfrak{z}_0, \mathfrak{z}_1, \cdots, \mathfrak{z}_n) \quad \text{or/and}$$
$$\mu(\mathfrak{z}_0(\mathfrak{z}_1(\cdots \mathfrak{z}_{n-1}(\mathfrak{z}_n(\mu)) \ldots)))$$

In case of $\mu(\mathfrak{z}_0(\mathfrak{z}_1(\cdots \mathfrak{z}_{n-1}(\mathfrak{z}_n(\mu)) \ldots)))$ conscious-

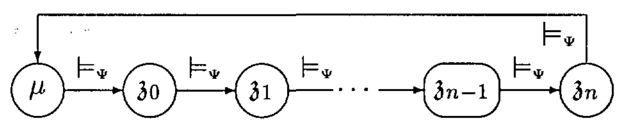


Figure 6: *Informational graph for the circular function formula* $\mu(\mathfrak{z}_0(\mathfrak{z}_1(\cdots \mathfrak{z}_{n-1}(\mathfrak{z}_n(\mu)) \ldots)))$, *where* $\models_\Psi$ *denotes the function operator.*

ness components as arguments of function μ are ordered. The situation of the loop is shown in Fig. 6. Here, μ figures as the main operand. But, according to the *operand rotation principle* for a loop, each of the occurring operands can take the place of the main operand. Thus,

$$\mathfrak{z}_j(\mathfrak{z}_{j+1}(\cdots \mathfrak{z}_{n-1}(\mathfrak{z}_n(\mu(\mathfrak{z}_0(\mathfrak{z}_1(\cdots \mathfrak{z}_{j-1}(\mathfrak{z}_j) \ldots))))) \ldots))$$

In a loop, each loop operand can be expressed by the remaining loop operands. This applies for common loop formulas as well as function formulas, which are nothing else than particular formula expressions.

3.2.4 Metaphysicalistic General and Standardized Circular Parallel Decomposition of Consciousness

Parallel decomposition belongs to the typical reductionistic reasoning with a various possibilities effect in the framework of a case, phenomenon, or problem generalization. As already recognized, this sort of decomposition enables the construction of a graph in which more precise and detailed causal circumstances are blurred, unexpressed, uncertain, or simply unknown sufficiently. In this manner, a parallel decomposition embraces several and probable many certain possibilities. It enables them, as it could be seen, by the magnitude of numbers $N_{\rightarrow}^{\circlearrowleft}$ and ${}^{\circlearrowleft}N_{\rightarrow}^{\circlearrowleft}$.

There are different ways of a parallel circular decomposition of consciousness entities. The well-known method pertains to a system of parallel circular formulas, by which various components of a consciousness system are described in parallel. On the basis of such a system it is possible to draw an informational graph being circled in a complete way [48]. It means that each operand of the graph belongs to one or more loops, that loops are mutually connected (possess common operands), and that isolated operands can exist only for the sake of a distinguished (additional) input or output operand of the system.

On the other hand, the question emerges, if the description of a completely circled graph is possible by non-circled informational formulas. The answer to this question is positive, and one of the possibilities is to use the basic transition formulas, that is those of the form $\mathfrak{z}_i \models \mathfrak{z}_j$. A parallel system consisting of such primitive transitions is called the primitive parallel system (a system of primitive transitions) and denoted by ${}^{n+1}\mathfrak{z}_{j\,\parallel}^{\circlearrowleft\prime}$ [48] for a single circular loop or by $\mathfrak{z}_{j\,\parallel}^{\circlearrowleft\prime}$ in case of several loops. Several loops, the number of which is k, can be exactly considered by an arithmetic function f as the fore superscript, that is,

$${}^{f}\mathfrak{z}_{j\,\parallel}^{\circlearrowleft\prime}, \text{ where } f = \prod_{i=1}^{k} \frac{1}{\ell_i + 1}\binom{2\ell_i}{\ell_i}$$

Here, ℓ_i denotes the loop length. Thus, f is the number of all possible causal situations within the primitive parallel system ${}^{f}\mathfrak{z}_{j\,\parallel}^{\circlearrowleft\prime}$.

Similar as in case of circular serial decomposition, for the primitive circular parallel decomposition of a single loop there is

$${}^{n+1}\Delta_{\parallel}^{\circlearrowleft\prime}(\mathfrak{z}) \quad \text{and} \quad {}^{n+1}\mathsf{M}_{\parallel}^{\circlearrowleft\prime}(\mathfrak{z})$$

in a general and metaphysicalistic case, respectively. A multiloop metaphysicalistic decomposition is denoted by ${}^{n+1}\mathsf{M}_{\parallel}^{\circlearrowleft\prime}(\mathfrak{z})$. A multiloop occurrence is a consequence of shorter loops within the main loop, as shown, for example, in Figs. 2 and 3.

The graph in Fig. 2 realizes the general primitive parallel circular consciousness system of the form

$${}^{f_{\mu_g}}\mathfrak{z}_{\parallel}^{\circlearrowleft\prime} \rightleftharpoons$$

$$\left(\begin{array}{llll}
\alpha \models \mathfrak{z}_0; & & & \\
\mathfrak{z}_0 \models \mathfrak{z}_1^{\mathfrak{i}}; & \mathfrak{z}_1^{\mathfrak{i}} \models \mathfrak{z}_2^{\mathfrak{i}}; & \cdots & \mathfrak{z}_{p-1}^{\mathfrak{i}} \models \mathfrak{z}_p^{\mathfrak{i}}; \\
\mathfrak{z}_p^{\mathfrak{i}} \models \mathfrak{z}_1^{\mathfrak{c}}; & \mathfrak{z}_1^{\mathfrak{c}} \models \mathfrak{z}_2^{\mathfrak{c}}; & \cdots & \mathfrak{z}_{q-1}^{\mathfrak{c}} \models \mathfrak{z}_q^{\mathfrak{c}}; \\
\mathfrak{z}_q^{\mathfrak{c}} \models \mathfrak{z}_1^{\mathfrak{e}}; & \mathfrak{z}_1^{\mathfrak{e}} \models \mathfrak{z}_2^{\mathfrak{e}}; & \cdots & \mathfrak{z}_{r-1}^{\mathfrak{e}} \models \mathfrak{z}_r^{\mathfrak{e}}; \\
\mathfrak{z}_r^{\mathfrak{e}} \models \mathfrak{z}_1^{\mathfrak{e}}; & & & \\
\mathfrak{z}_q^{\mathfrak{c}} \models \mathfrak{z}_1^{\mathfrak{i}}; & \mathfrak{z}_r^{\mathfrak{e}} \models \mathfrak{z}_1^{\mathfrak{c}}; & & \\
\mathfrak{z}_r^{\mathfrak{e}} \models \mathfrak{z}_0; & \mathfrak{z}_p^{\mathfrak{i}} \models \mathfrak{z}_1^{\mathfrak{i}}; & \mathfrak{z}_q^{\mathfrak{c}} \models \mathfrak{z}_1^{\mathfrak{c}}; &
\end{array}\right);$$

$$f_{\mu_g} = \prod_{i=1}^{6} \frac{1}{\ell_i + 1}\binom{2\ell_i}{\ell_i}$$

where $\ell_1 = p + q + r + 2$, $\ell_2 = p + q$; $\ell_3 = q + r$, $\ell_4 = p$, $\ell_5 = q$, and $\ell_6 = r$. Subscript μ_g denotes the general metaphysicalistic case. In the first row of the array there is an exterior connection (of α) to the component $\mathfrak{z}_0$. In the second, third, fourth, and the fifth row the main loop resides. In the sixth row the feedbacks of the two middle-sized loops reside, and their remaining elements are already within the main loop. In the last row of the array the feedbacks of the three short-sized loops are located, and their remaining elements appear in the main loop. Later the reader will see how f_{μ_g} is related to the different serial loops which cover entirely the graph in Fig. 2.

Similarly, it can be shown how the graph in Fig. 3 is completely described by the standardized primitive parallel circular consciousness system of the form

$${}^{f_{\mu_s}}\mathfrak{z}_{\parallel}^{\circlearrowleft\prime} \rightleftharpoons \left(\begin{array}{lll}
\alpha_\xi \models \mathfrak{z}_\xi; & & \\
\mathfrak{z}_\xi \models \mathfrak{I}_{\mathfrak{z}_\xi}; & \mathfrak{I}_{\mathfrak{z}_\xi} \models \mathfrak{i}_{\mathfrak{z}_\xi}; & \\
\mathfrak{i}_{\mathfrak{z}_\xi} \models \mathfrak{C}_{\mathfrak{z}_\xi}; & \mathfrak{C}_{\mathfrak{z}_\xi} \models \mathfrak{c}_{\mathfrak{z}_\xi}; & \\
\mathfrak{c}_{\mathfrak{z}_\xi} \models \mathfrak{E}_{\mathfrak{z}_\xi}; & \mathfrak{E}_{\mathfrak{z}_\xi} \models \mathfrak{e}_{\mathfrak{z}_\xi}; & \\
\mathfrak{e}_{\mathfrak{z}_\xi} \models \mathfrak{z}_\xi; & & \\
\mathfrak{c}_{\mathfrak{z}_\xi} \models \mathfrak{I}_{\mathfrak{z}_\xi}; & \mathfrak{e}_{\mathfrak{z}_\xi} \models \mathfrak{C}_{\mathfrak{z}_\xi}; & \\
\mathfrak{i}_{\mathfrak{z}_\xi} \models \mathfrak{I}_{\mathfrak{z}_\xi}; & \mathfrak{c}_{\mathfrak{z}_\xi} \models \mathfrak{C}_{\mathfrak{z}_\xi}; & \mathfrak{e}_{\mathfrak{z}_\xi} \models \mathfrak{E}_{\mathfrak{z}_\xi}
\end{array}\right);$$

$$f_{\mu_s} = \tfrac{1}{8}\tbinom{14}{7} \cdot \left(\tfrac{1}{5}\tbinom{8}{4}\right)^2 \cdot \left(\tfrac{1}{3}\tbinom{4}{2}\right)^3 = 429 \cdot 14^2 \cdot 2^3 = \\ = 672\,672$$

Subscript μ_s denotes the standardized metaphysicalistic case. In the first row of the array there is an exterior connection (of α) to the component $\mathfrak{z}_\xi$. In the second, third, fourth, and the fifth row the main loop of the length 7 resides. In the sixth row the feedbacks of the two middle-sized loops of length 4 reside, and their remaining elements are already within the main loop. In the last row of the array the feedbacks of the three short-sized loops of length 2 are located, and their remaining elements appear in the main loop. Later the reader will learn how f_{μ_s} is related to the different serial loops which cover entirely the graph in Fig. 3.

3.2.5 Parallelism and Serialism of Consciousness Informational Graphs

Looking into an informational graph, the first impression is that it represents a serially looped structure. Serialism is the informing property which comes up at the first glance. However, such a naïveté is not only misleading but also concealing. The concealment lies in the causally hidden situations on one side, and on the various parallel informing not only of the occurring operands but also of any causally structured entity, that is, of any parenthesized formula within a formula. However, certainly, an informational graph does not eliminate all these situations: it does not determine them specifically at all. In this respect, an informational graph leaves open concrete causal situations and offers a kind of overlook of all different possibilities of concrete informing.

To a certain extent, we have already experienced how an informational graph can be functionally covered by a parallel system of different circular serial formulas and, simultaneously, by a parallel system of primitive informational transitions. In case of more than one loop, we have always to do with a situation of formula parallelism. But also in case of a single non-trivial loop (a loop of the length greater than 1), the situation can be interpreted by parallel transitions. Thus, parallelism of an informational system is ubiquitous. Serialism—as we stated—is graphically evident and experientially present in the common way of human understanding of time phenomena.

Informational graph, representing a system, is a serial-parallel mixture of informational situations, described by informational formulas. Consciousness is evidently one of the best examples of such a view, knowledge, and epistemology. We owe the covering of graphs in Figs. 2 and 3 by parallel systems of circular serial formulas.

Evidently, the graph in Fig. 2 can be covered entirely by the six loops, expressed in the form

$$
{}_{1}^{f}\mathfrak{z}_{\underset{\to}{0}}^{\circ} \rightleftharpoons
\left(\begin{array}{l}
(\cdots(((\cdots(((\cdots((\mathfrak{z}_0 \models \mathfrak{z}_1^{\mathfrak{i}}) \models \mathfrak{z}_2^{\mathfrak{i}}) \models \cdots \mathfrak{z}_p^{\mathfrak{i}}) \\
\qquad\qquad \models \mathfrak{z}_1^{\mathfrak{c}}) \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \\
\qquad\qquad \models \mathfrak{z}_1^{\mathfrak{e}}) \models \mathfrak{z}_2^{\mathfrak{e}}) \models \cdots \mathfrak{z}_r^{\mathfrak{e}}) \\
\qquad \models \mathfrak{z}_0; \\
(\cdots(((\cdots(\mathfrak{z}_1^{\mathfrak{i}} \models \mathfrak{z}_2^{\mathfrak{i}}) \models \cdots \mathfrak{z}_p^{\mathfrak{i}}) \models \\
\qquad \mathfrak{z}_1^{\mathfrak{c}}) \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \models \mathfrak{z}_1^{\mathfrak{i}}; \\
(\cdots(((\cdots(\mathfrak{z}_1^{\mathfrak{c}} \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \models \\
\qquad \mathfrak{z}_1^{\mathfrak{e}}) \models \mathfrak{z}_2^{\mathfrak{e}}) \models \cdots \mathfrak{z}_r^{\mathfrak{e}}) \models \mathfrak{z}_1^{\mathfrak{c}}; \\
(\cdots(\mathfrak{z}_1^{\mathfrak{i}} \models \mathfrak{z}_2^{\mathfrak{i}}) \models \cdots \mathfrak{z}_p^{\mathfrak{i}}) \models \mathfrak{z}_1^{\mathfrak{i}}; \\
(\cdots(\mathfrak{z}_1^{\mathfrak{c}} \models \mathfrak{z}_2^{\mathfrak{c}}) \models \cdots \mathfrak{z}_q^{\mathfrak{c}}) \models \mathfrak{z}_1^{\mathfrak{c}}; \\
(\cdots(\mathfrak{z}_1^{\mathfrak{e}} \models \mathfrak{z}_2^{\mathfrak{e}}) \models \cdots \mathfrak{z}_r^{\mathfrak{e}}) \models \mathfrak{z}_1^{\mathfrak{e}}
\end{array}\right)
$$

This system describes a single distinguished situation (the fore subscript 1, where the parenthesis pairs are strictly positioned from the left to the right in each circular formula), and still many other situations remain unutilized. The number of all possible systems of such a kind is

$$
\frac{1}{p+q+r+3}\binom{2(p+q+r+2)}{p+q+r+2} \cdot
\frac{1}{p+q+1}\binom{2(p+q)}{p+q} \cdot \frac{1}{q+r+1}\binom{2(q+r)}{q+r} \cdot
\frac{1}{p+1}\binom{2p}{p} \cdot \frac{1}{q+1}\binom{2q}{q} \cdot \frac{1}{r+1}\binom{2r}{r}
$$

This situation does not consider the so-called rotation principle for operands in a loop. The factor to the upper product would yield

$$(p+q+r+2)(p+q)(q+r)pqr$$

additionally. The number of possibilities increases rapidly by the number of binary operators between operands.

In the second, standardized case (Fig. 3), the graph covering loops are

$$
{}_{672\,672}^{f}\mathfrak{z}_{\underset{\to}{0}}^{\circ} \rightleftharpoons
\left(\begin{array}{l}
\mathfrak{z}_\xi \models (\mathfrak{I}_{\mathfrak{z}_\xi} \models (\mathfrak{i}_{\mathfrak{z}_\xi} \models (\mathfrak{C}_{\mathfrak{z}_\xi} \models (\mathfrak{c}_{\mathfrak{z}_\xi} \models \\
\qquad (\mathfrak{E}_{\mathfrak{z}_\xi} \models (\mathfrak{e}_{\mathfrak{z}_\xi} \models \mathfrak{z}_\xi)))))); \\
\mathfrak{I}_{\mathfrak{z}_\xi} \models (\mathfrak{i}_{\mathfrak{z}_\xi} \models (\mathfrak{C}_{\mathfrak{z}_\xi} \models (\mathfrak{c}_{\mathfrak{z}_\xi} \models \mathfrak{I}_{\mathfrak{z}_\xi}))); \\
\mathfrak{C}_{\mathfrak{z}_\xi} \models (\mathfrak{c}_{\mathfrak{z}_\xi} \models (\mathfrak{E}_{\mathfrak{z}_\xi} \models (\mathfrak{e}_{\mathfrak{z}_\xi} \models \mathfrak{C}_{\mathfrak{z}_\xi}))); \\
\mathfrak{I}_{\mathfrak{z}_\xi} \models (\mathfrak{i}_{\mathfrak{z}_\xi} \models \mathfrak{I}_{\mathfrak{z}_\xi}); \mathfrak{C}_{\mathfrak{z}_\xi} \models (\mathfrak{c}_{\mathfrak{z}_\xi} \models \mathfrak{C}_{\mathfrak{z}_\xi}); \\
\mathfrak{E}_{\mathfrak{z}_\xi} \models (\mathfrak{e}_{\mathfrak{z}_\xi} \models \mathfrak{E}_{\mathfrak{z}_\xi})
\end{array}\right)
$$

This system describes a single distinguished situation (the fore subscript 672 672, where the parenthesis pairs are strictly positioned from the right to the left in each circular formula), but still 672 671 other situations remain unutilized. Considering the rotation principle for operands in a loop, the factor to the upper product would yield 896, that is, 602 714 112 possibilities. The reader can realize how already simple graphical schemes offer a tremendous number of possible cases.

3.2.6 Gestaltism of Consciousness

Informational—and within it the consciousness—gestaltism [43] can be described in the following straightforward manner: a simple formula has its representation in the adequate informational graph. However, such a graph, constructed by the neglecting of all parentheses pairs, represents all possible formulas in which the parenthesis pairs are displaced in the well-formed manner. Now, the graph can be described in its whole by a primitive parallel system of basic transitions. But, the other possibility is to express the circular-serial nature of a graph by serial formulas with differently displaced parenthesis pairs.

Gestalts, coming fore, are the so-called (simple, common) gestalt, Γ, circular gestalt, $\Gamma^{\circlearrowleft}$, and star gestalt, $\Gamma^{\star}$ [48]. The circular gestalt is based on the operand rotation principle being valid for a loop. The star gestalt considers arbitrary movings along the arrows in a graph and, on this basis, the forming of the well-formed circular formulas, also in cases of repeated moving along the same parts of a graph path. Because of arbitrary looping, the star gestaltism explicates the possibility of the potential infinity.

In case of a simple formula, gestaltism seems to be a trivial approach. But in case of a complex informational consciousness system, e.g., like in Fig. 7, to the gestalts attributed numbers of possible cases, $\mathcal{N}_{\rightarrow}$, $\mathcal{N}_{\rightarrow}^{\circlearrowleft}$, ${}^{\circlearrowleft}\mathcal{N}_{\rightarrow}^{\circlearrowleft}$ (see also Sec. 3.2.2) and ${}^{\circlearrowleft}\mathcal{N}_{\rightarrow}^{\circlearrowleft^{\star}}$ ($\longrightarrow \infty$), become relevant for the evaluation of informational possibilities.

In case of the graph in Fig. 7, the evaluation of the number of all possible combinations of parenthesis pairs in the occurring loops can be evaluated. One has to consider systematically all the horizontal and all the vertical loops (considering the feedbacks being visible in the graph) and form the products

$$\mathcal{N}_{\rightarrow}^{\circlearrowleft} = \prod_{\forall i} \frac{1}{\ell_i + 1} \binom{2\ell_i}{\ell_i}$$

for a simple circularity and

$${}^{\circlearrowleft}\mathcal{N}_{\rightarrow}^{\circlearrowleft} = \prod_{\forall i} \frac{\ell_i}{\ell_i + 1} \binom{2\ell_i}{\ell_i}$$

in case of operand-rotating circularity, where $\ell_i \geq 2$ is a loop length.

4 On the Way to a Concrete Formal Structure and Organization of Informational Consciousness

A concrete formal structure and organization of informational consciousness can be achieved step by step, studying and considering realistic, scientific, and experiential observations and result in various and interdisciplinary fields. An initial archive of such a knowledge is collected in [50], where also certain problems of consciousness bidirectionality are presented.

4.1 An Initial Decomposition of Consciousness Structure and Organization

In the very beginning one can grasp consciousness as an "empty" (abstractly, as-such) structured and organized informational shell which can be filled by concrete experiences, step by step. The approach of building up the concept of consciousness structure and organization follows some axiomatic and experiential principles of consciousness decomposition in several basic aspects:

- natural (physical, biological, physiological);
- artificial (constructive, conceptual, imaginable);
- scientific (logical, formalistic, systemic);
- epistemological (experiential, conceptual, cognitive);
- phenomenal (philological, philosophical, psychological);
- abstract (apart from things having the property, qualia-like, mathesis-like, universal); and

- informational (joining the preceding items by its own principles and formalism).

To overview the situation of the emerging consciousness shell, as the most appropriate approach, the methodology of graph presentation comes fore, simultaneously using the possibilities of description by parallel and serial circular formulas of different kinds: transition primitives (an operational connection from one to the other operand), serial transitions, and mixed circularly structured serial-parallel formulas. Such an approach can guarantee the necessary and emerging complexity, satisfying the conceptual circumstances and the possibilities to improve and widen them to a more complete form of structure and organization.

4.2 Informational Decomposition of Consciousness

In the beginning of this investigation—construction of the consciousness shell—we have in mind a consciousness machine, realized by *general* informational means (principles, formalism) which include:

- conceptualism of informational externalism, internalism, metaphysicalism, and phenomenalism;

- informational arising as a metaphor for: spontaneity [based, e.g., on the quantum-physical spontaneous symmetry breaking (SSB) [20, 30, 14]]; emerging, changing, and vanishing (evanescing) of entities and their components, structure and organization; computability and non-computability; uncertainty, unforeseeability, unpredictability;

- informational serialism, parallelism and circularism, together with formalistically based causalism;

- decomposition principles, being within the informational axioms and rules of procedure;

- informational causalism emerging as the informational gestaltism and star-gestasltism, spontaneously and circularly;

- informational distributivism of entities in various other entities and ditributiveness of informational components within an entity itself (constituting a kind of informational space, e.g., in the sense of Hilbert space [28]).

4.3 General (Concrete) and Standard Decomposition of Consciousness

The *concrete* informational means—the filling of the consciousness shell by concrete experiences—of the present investigation will include:

- informational entities being components of consciousness metaphysicalism in a *distributive* form;

- *intention* of the object becoming conscious, where intention characterizes, identifies, stabilizes, generates and makes the object inertial as the present, the transitional, the emerging or the diminishing (evanescing) state of consciousness; intention—as any other component of consciousness—is distributed through the metaphysicalistic parts of informing (intending), counterinforming (counterintending) and informational embedding (intentional embedding);

- *memorizing* as a fundamental identity of consciousness of something is presumably present in a form of informational circularity, on the very local level of basic components, and informs circularly on different informational compositions of components, as the identity essential and developing informational loops; in this sense, memory distributivity is evident and it presents the most substantial property of consciousness;

- *experience* as a concretized subject (e.g., behavior) is based on the *learned* and *memorized* affairs; *adaptation* of behavior depends on learned, memorized, and experienced and impacts these three components informationally;

- *understanding* appears as an integrating component of consciousness; it performs upon the consciousness components, interviews and impacts them, in an understanding way of informing them and being informed by them; in this way, understanding produces meaning, concerning different complexes of the conscious affairs; understanding belongs

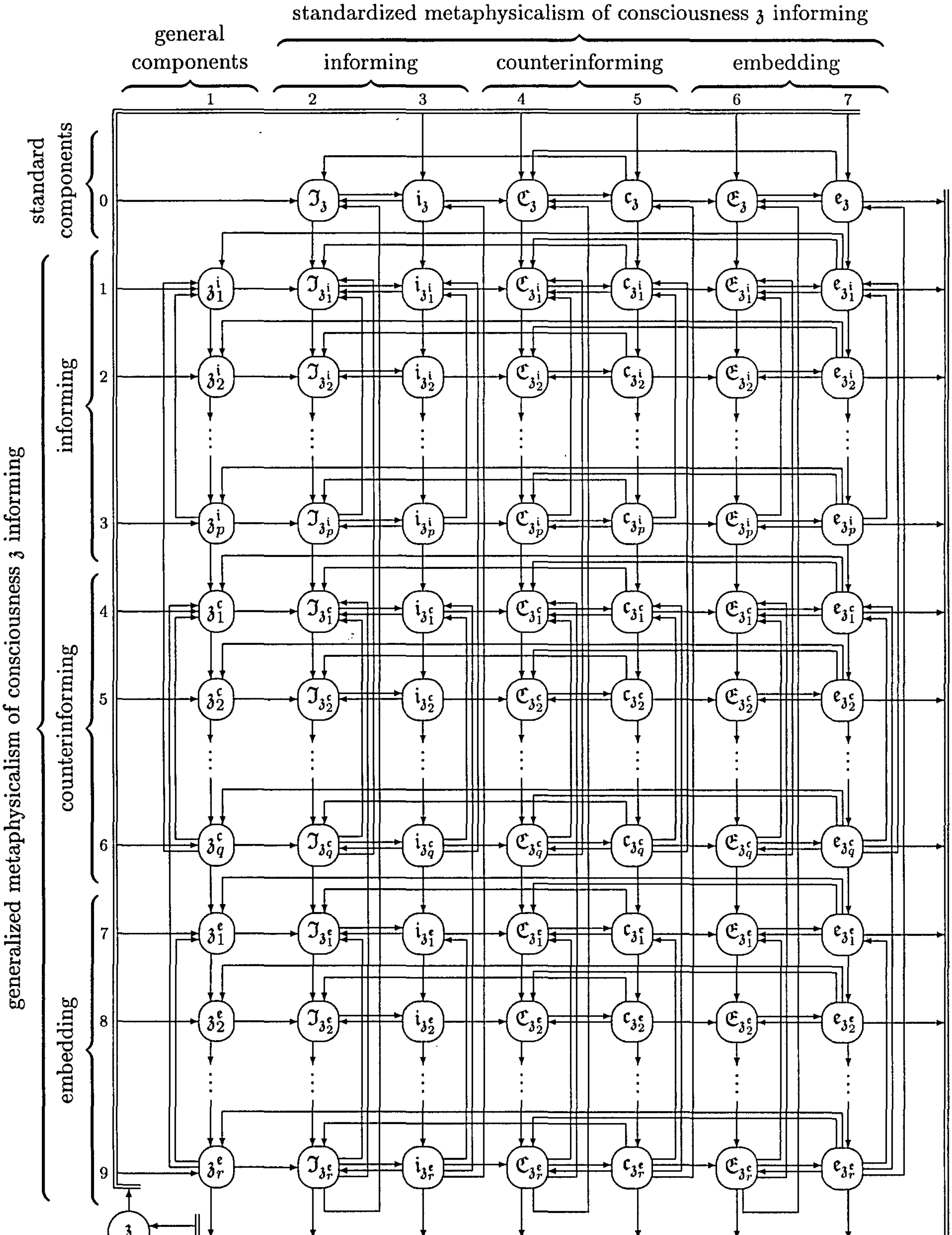


Figure 7: *An initial informational shell of the generalized and standardized metaphysicalism of consciousness system* $\mathfrak{z}$.

to the most extensive and sophisticated components of consciousness;

- *emotions* impact consciousness on different informational levels and places; they are informationally distributed within consciousness intention, experience, memory, understanding, etc.;

- *sensing* is a component which connects consciousness with its environment; the question is where to place the sensing subsystem in the column 1 of the general components in Fig. 7, to consider the most appropriate neighbor general components, being intensively dependent on the informing of sensing; sensing concerns—in its distributed form—the conscious as well as the unconscious;

- *subconscious* and *unconscious* components are substantial parts of the counterinformational segments in Fig. 7 when conscious entities emerge by coming of the subconscious and unconscious into the conscious; in general, both components can be distributed within the system in Fig. 7;

- consciousness *conceptualism* originating in memory, learned experience, understanding and produced meaning can develop its own spontaneous way deriving its feedback influence on the constituting components; concepts generate knowledge as an informational archive of experience; the developing conceptualism concerning something informs distributively on different organizational levels and parts of consciousness;

- *consciousness abstraction of informational abstractions* is also a way by which the scheme in Fig. 7 has been constructed; this kind of abstraction is recursive and leads to the multidimensional concept of consciousness within the *informational space*, as the most sophisticated (abstract) concept of consciousness formalization;

etc. There are many other generally recognized concrete components which can be considered in a complex model of consciousness. The question is how to model a consciousness shell which would include the general informational principles as well as the concrete—general and particular—components.

4.4 A Complete Description of the Graph in Fig. 7 Using the Primitive Parallelism

We have already seen that circular structures—especially those using informational metaphysicalism—can offer an appropriate background for an efficient and complex modeling of consciousness informing. What we could present in the form of an informational graph is a kind of "two-dimensional" metaphysicalism, built on the basis of the generalized and standardized metaphysicalism, discussed in Fig. 2 and Fig. 3, respectively. Such a metaphysicalism has to be captured also formally when using informational "vectors", introduced in Sec. 3.2.3. In this respect, additional rules of informational space have to be introduced. To give the reader a motivation, let us look at the graph in Fig. 7.

In this graph, initially, consciousness $\mathfrak{z}$ is determined by the two main loops. The first loop is constituted by the row 0 and its metaphysically generalized extension downwards the graph. The second loop consists of column 1 and its standardized extension rightward the graph. Row 0 is a standardized metaphysicalistic decomposition of $\mathfrak{z}$ (e.g., in the sense of Fig. 3), while column 1 is a generalized metaphysicalistic decomposition of $\mathfrak{z}$. As it is evident, $\mathfrak{z}$ has simultaneously (in parallel) two different "vectored" structures, where the generalized structure (column 1) explicates an additional parallelism (of the second degree), realized by the direct standardized metaphysicalisms of the general components. The new informational formalism has to be designed in such a manner that it could uniquely capture the complexity of the informational graph. The graph in Fig. 7, as a whole, is nothing else than a complex informational "vector" representing consciousness $\mathfrak{z}$, and possessing—in the framework of possible individual operators' decompositions by the parallel informing systems—a potentially infinite number of causal possibilities (e.g., a product of numbers ${}^{\circ}\mathcal{N}^{\circ}_{\rightarrow}$ for all possible loops).

The easiest way of a formally exact description of $\mathfrak{z}$ in Fig. 7 would be the primitive parallel system of the graph, consisting of all possible primitive transitions, that is, from one operand to the next operand in the arrow direction. Such a formal system can be written in a transparent way because of the formal periodicity not only of rows and columns but also of their feedbacks. Thus, for ${}^{f\mu gs}\mathfrak{z}_{\|}^{\circlearrowleft'}$ (compare Sec. 3.2.4), there is,

$$(\mathfrak{k}=\mathfrak{i}) \Longrightarrow (\mathfrak{j}=1,2,\ldots,p); \qquad \text{[\textit{Superscript-}}$$
$$(\mathfrak{k}=\mathfrak{c}) \Longrightarrow (\mathfrak{j}=1,2,\ldots,q); \qquad \text{\textit{subscript}}$$
$$(\mathfrak{k}=\mathfrak{e}) \Longrightarrow (\mathfrak{j}=1,2,\ldots,r); \qquad \text{\textit{implications}]}$$

[*𝔷's outputs and inputs to the loop matrix*]

$$\mathfrak{z} \models \mathfrak{z}_\mathfrak{j}^\mathfrak{k}, \mathfrak{I}_\mathfrak{z}, \mathfrak{i}_\mathfrak{z}, \mathfrak{C}_\mathfrak{z}, \mathfrak{c}_\mathfrak{z}, \mathfrak{E}_\mathfrak{z}, \mathfrak{e}_\mathfrak{z};$$
$$\mathfrak{e}_\mathfrak{z}, \mathfrak{e}_{\mathfrak{z}_\mathfrak{j}^\mathfrak{k}}, \mathfrak{z}_\mathfrak{r}^\mathfrak{e}, \mathfrak{I}_{\mathfrak{z}_\mathfrak{r}^\mathfrak{e}}, \mathfrak{i}_{\mathfrak{z}_\mathfrak{r}^\mathfrak{e}}, \mathfrak{C}_{\mathfrak{z}_\mathfrak{r}^\mathfrak{e}}, \mathfrak{c}_{\mathfrak{z}_\mathfrak{r}^\mathfrak{e}}, \mathfrak{E}_{\mathfrak{z}_\mathfrak{r}^\mathfrak{e}} \models \mathfrak{z};$$

[*Horizontal loops*]

$$\mathfrak{I}_\mathfrak{z} \models \mathfrak{i}_\mathfrak{z};\quad \mathfrak{i}_\mathfrak{z} \models \mathfrak{C}_\mathfrak{z};\quad \mathfrak{C}_\mathfrak{z} \models \mathfrak{c}_\mathfrak{z};\quad \mathfrak{c}_\mathfrak{z} \models \mathfrak{E}_\mathfrak{z};\quad \text{[\textit{Row 0}]}$$
$$\mathfrak{E}_\mathfrak{z} \models \mathfrak{e}_\mathfrak{z};\ |\,\mathfrak{i}_\mathfrak{z} \models \mathfrak{I}_\mathfrak{z};\quad \mathfrak{c}_\mathfrak{z} \models \mathfrak{C}_\mathfrak{z};\quad \text{|\textit{fdbs 0}|}$$
$$\mathfrak{e}_\mathfrak{z} \models \mathfrak{E}_\mathfrak{z};\quad \mathfrak{c}_\mathfrak{z} \models \mathfrak{I}_\mathfrak{z};\quad \mathfrak{e}_\mathfrak{z} \models \mathfrak{C}_\mathfrak{z};\,|$$

$$\mathfrak{z}_1^\mathfrak{i} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}};\ \text{[\textit{Row 1}]}$$
$$\mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{i}};\ \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}};\,|\,\mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{i}};\ \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}};\ \text{|\textit{fdbs 1}|}$$
$$\mathfrak{i}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{z}_1^\mathfrak{i};\,|$$

$$\mathfrak{z}_2^\mathfrak{i} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{i}};\quad \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{i}};\quad \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{i}};\quad \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{[\textit{Row 2}]}$$
$$\mathfrak{c}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{i}};\ \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{i}};\,|\,\mathfrak{e}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{i}};\ \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{|\textit{fdbs 2}|}$$
$$\mathfrak{i}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{i}};\quad \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{i}};\quad \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{i}};\quad \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{i}} \models \mathfrak{z}_2^\mathfrak{i};\,|$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$\mathfrak{z}_p^\mathfrak{i} \models \mathfrak{I}_{\mathfrak{z}_p^\mathfrak{i}};\quad \mathfrak{I}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{i}_{\mathfrak{z}_p^\mathfrak{i}};\quad \mathfrak{i}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_p^\mathfrak{i}};\quad \mathfrak{C}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{c}_{\mathfrak{z}_p^\mathfrak{i}};\ \text{[\textit{Row 3}]}$$
$$\mathfrak{c}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_p^\mathfrak{i}};\ \mathfrak{E}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{e}_{\mathfrak{z}_p^\mathfrak{i}};\,|\,\mathfrak{e}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_p^\mathfrak{i}};\ \mathfrak{c}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_p^\mathfrak{i}};\ \text{|\textit{fdbs 3}|}$$
$$\mathfrak{i}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_p^\mathfrak{i}};\quad \mathfrak{e}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_p^\mathfrak{i}};\quad \mathfrak{c}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_p^\mathfrak{i}};\quad \mathfrak{e}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{z}_p^\mathfrak{c};\,|$$

$$\mathfrak{z}_1^\mathfrak{c} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}};\ \text{[\textit{Row 4}]}$$
$$\mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}};\,|\,\mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}};\ \text{|\textit{fdbs 4}|}$$
$$\mathfrak{i}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{z}_1^\mathfrak{c};\,|$$

$$\mathfrak{z}_2^\mathfrak{c} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{c}};\quad \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{c}};\quad \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{c}};\quad \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{c}};\ \text{[\textit{Row 5}]}$$
$$\mathfrak{c}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{c}};\ \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{c}};\,|\,\mathfrak{e}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{c}};\ \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{c}};\ \text{|\textit{fdbs 5}|}$$
$$\mathfrak{i}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{c}};\quad \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{c}} \models \mathfrak{z}_2^\mathfrak{c};\,|$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$\mathfrak{z}_q^\mathfrak{c} \models \mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}};\quad \mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_q^\mathfrak{c}};\quad \mathfrak{i}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}};\quad \mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}};\ \text{[\textit{Row 6}]}$$
$$\mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_q^\mathfrak{c}};\ \mathfrak{E}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}};\,|\,\mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_q^\mathfrak{c}};\ \mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}};\ \text{|\textit{fdbs 6}|}$$
$$\mathfrak{i}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}};\quad \mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{z}_q^\mathfrak{c};\,|$$

$$\mathfrak{z}_1^\mathfrak{e} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{e}};\ \text{[\textit{Row 7}]}$$
$$\mathfrak{c}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{e}};\,|\,\mathfrak{e}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}};\ \text{|\textit{fdbs 7}|}$$
$$\mathfrak{i}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{z}_1^\mathfrak{e};\,|$$

$$\mathfrak{z}_2^\mathfrak{e} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{e}};\quad \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{e}};\quad \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{e}};\quad \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{e}};\ \text{[\textit{Row 8}]}$$
$$\mathfrak{c}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{e}};\ \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{e}};\,|\,\mathfrak{e}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{e}};\ \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{e}};\ \text{|\textit{fdbs 8}|}$$
$$\mathfrak{i}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{e}};\quad \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{e}};\quad \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{e}};\quad \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{e}} \models \mathfrak{z}_2^\mathfrak{e};\,|$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$\mathfrak{z}_r^\mathfrak{e} \models \mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}};\quad \mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{i}_{\mathfrak{z}_r^\mathfrak{e}};\quad \mathfrak{i}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}};\quad \mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}};\ \text{[\textit{Row 9}]}$$
$$\mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_r^\mathfrak{e}};\ \mathfrak{E}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}};\,|\,\mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_r^\mathfrak{e}};\ \mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}};\ \text{|\textit{fdbs 9}|}$$
$$\mathfrak{i}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}};\quad \mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}};\quad \mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}};\quad \mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{z}_r^\mathfrak{e};\,|$$

[*Vertical loops*]

$$\mathfrak{z}_1^\mathfrak{i} \models \mathfrak{z}_2^\mathfrak{i};\quad \mathfrak{z}_2^\mathfrak{i} \models \mathfrak{z}_3^\mathfrak{i};\quad \cdots \quad \mathfrak{z}_{p-1}^\mathfrak{i} \models \mathfrak{z}_p^\mathfrak{i};\ \text{[\textit{Col. 1}]}$$
$$\mathfrak{z}_p^\mathfrak{i} \models \mathfrak{z}_1^\mathfrak{c};\quad \mathfrak{z}_1^\mathfrak{c} \models \mathfrak{z}_2^\mathfrak{c};\quad \cdots \quad \mathfrak{z}_{q-1}^\mathfrak{c} \models \mathfrak{z}_q^\mathfrak{c};$$
$$\mathfrak{z}_q^\mathfrak{c} \models \mathfrak{z}_1^\mathfrak{e};\quad \mathfrak{z}_1^\mathfrak{e} \models \mathfrak{z}_2^\mathfrak{e};\quad \cdots \quad \mathfrak{z}_{r-1}^\mathfrak{e} \models \mathfrak{z}_r^\mathfrak{e};$$
$$|\,\mathfrak{z}_p^\mathfrak{i} \models \mathfrak{z}_1^\mathfrak{i};\quad \mathfrak{z}_q^\mathfrak{c} \models \mathfrak{z}_1^\mathfrak{c};\quad \mathfrak{z}_r^\mathfrak{e} \models \mathfrak{z}_1^\mathfrak{e};\quad \mathfrak{z}_q^\mathfrak{c} \models \mathfrak{z}_1^\mathfrak{i};\quad \text{|\textit{fdbs 1}|}$$
$$\mathfrak{z}_r^\mathfrak{e} \models \mathfrak{z}_1^\mathfrak{c};\,|$$

$$\mathfrak{I}_\mathfrak{z} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{i}};\quad \cdots \quad \mathfrak{I}_{\mathfrak{z}_{p-1}^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{[\textit{Col. 2}]}$$
$$\mathfrak{I}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{c}};\quad \cdots \quad \mathfrak{I}_{\mathfrak{z}_{q-1}^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}};$$
$$\mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_2^\mathfrak{e}};\quad \cdots \quad \mathfrak{I}_{\mathfrak{z}_{r-1}^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}};$$
$$|\,\mathfrak{I}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}};\ \mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{I}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{i}};\ \text{|\textit{fdbs 2}|}$$
$$\mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{I}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{I}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{I}_\mathfrak{z};\,|$$

$$\mathfrak{i}_\mathfrak{z} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{i}};\quad \cdots \quad \mathfrak{i}_{\mathfrak{z}_{p-1}^\mathfrak{i}} \models \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{[\textit{Col. 3}]}$$
$$\mathfrak{i}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{c}};\quad \cdots \quad \mathfrak{i}_{\mathfrak{z}_{q-1}^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_q^\mathfrak{c}};$$
$$\mathfrak{i}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{i}_{\mathfrak{z}_2^\mathfrak{e}};\quad \cdots \quad \mathfrak{i}_{\mathfrak{z}_{r-1}^\mathfrak{e}} \models \mathfrak{i}_{\mathfrak{z}_r^\mathfrak{e}};$$
$$|\,\mathfrak{i}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{i}};\ \mathfrak{i}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{i}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{i}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{i}};\ \text{|\textit{fdbs 3}|}$$
$$\mathfrak{i}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{i}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{i}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{i}_\mathfrak{z};\,|$$

$$\mathfrak{C}_\mathfrak{z} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{i}};\quad \cdots \quad \mathfrak{C}_{\mathfrak{z}_{p-1}^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{[\textit{Col. 4}]}$$
$$\mathfrak{C}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}};\mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{c}};\quad \cdots \quad \mathfrak{C}_{\mathfrak{z}_{q-1}^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}};$$
$$\mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}};\mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_2^\mathfrak{e}};\quad \cdots \quad \mathfrak{C}_{\mathfrak{z}_{r-1}^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}};$$
$$|\,\mathfrak{C}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}};\mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}};\mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{e}};\mathfrak{C}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{i}};\text{|\textit{fdbs 4}|}$$
$$\mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{C}_{\mathfrak{z}_1^\mathfrak{c}};\mathfrak{C}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{C}_\mathfrak{z};\,|$$

$$\mathfrak{c}_\mathfrak{z} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{i}};\quad \cdots \quad \mathfrak{c}_{\mathfrak{z}_{p-1}^\mathfrak{i}} \models \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{[\textit{Col. 5}]}$$
$$\mathfrak{c}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{c}};\quad \cdots \quad \mathfrak{c}_{\mathfrak{z}_{q-1}^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}};$$
$$\mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{c}_{\mathfrak{z}_2^\mathfrak{e}};\quad \cdots \quad \mathfrak{c}_{\mathfrak{z}_{r-1}^\mathfrak{e}} \models \mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}};$$
$$|\,\mathfrak{c}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}};\ \mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{c}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{i}};\ \text{|\textit{fdbs 5}|}$$
$$\mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{c}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{c}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{c}_\mathfrak{z};\,|$$

$$\mathfrak{E}_\mathfrak{z} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{i}};\quad \cdots \quad \mathfrak{E}_{\mathfrak{z}_{p-1}^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{[\textit{Col. 6}]}$$
$$\mathfrak{E}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{c}};\mathfrak{E}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{c}};\quad \cdots \quad \mathfrak{E}_{\mathfrak{z}_{q-1}^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_q^\mathfrak{c}};$$
$$\mathfrak{E}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{e}};\mathfrak{E}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_2^\mathfrak{e}};\quad \cdots \quad \mathfrak{E}_{\mathfrak{z}_{r-1}^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_r^\mathfrak{e}};$$
$$|\,\mathfrak{E}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{i}};\mathfrak{E}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{c}};\mathfrak{E}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{e}};\mathfrak{E}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{i}};\text{|\textit{fdbs 6}|}$$
$$\mathfrak{E}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{E}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{E}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{E}_\mathfrak{z};\,|$$

$$\mathfrak{e}_\mathfrak{z} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}} \models \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{i}};\quad \cdots \quad \mathfrak{e}_{\mathfrak{z}_{p-1}^\mathfrak{i}} \models \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{i}};\ \text{[\textit{Col. 7}]}$$
$$\mathfrak{e}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{c}};\quad \cdots \quad \mathfrak{e}_{\mathfrak{z}_{q-1}^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}};$$
$$\mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{e}};\quad \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{e}} \models \mathfrak{e}_{\mathfrak{z}_2^\mathfrak{e}};\quad \cdots \quad \mathfrak{e}_{\mathfrak{z}_{r-1}^\mathfrak{e}} \models \mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}};$$
$$|\,\mathfrak{e}_{\mathfrak{z}_p^\mathfrak{i}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}};\ \mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}};\ \mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{e}};\ \mathfrak{e}_{\mathfrak{z}_q^\mathfrak{c}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{i}};\ \text{|\textit{fdbs 7}|}$$
$$\mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{e}_{\mathfrak{z}_1^\mathfrak{c}};\quad \mathfrak{e}_{\mathfrak{z}_r^\mathfrak{e}} \models \mathfrak{e}_\mathfrak{z};\,|$$

But, in a real case, not all of the possible situations take place. The extreme situation would be a single case in the framework of the consciousness graph in Fig. 7, describing all the different loops, each by a single circular informational formula, and in this way covering the entire graph.

4.5 General Circularism of the Standard Metaphysicalistic Components

It is important to bring to the attention the general circularity of the standardized metaphysicalistic components $\mathfrak{I}_{\mathfrak{z}}$, $\mathfrak{i}_{\mathfrak{z}}$, $\mathfrak{C}_{\mathfrak{z}}$, $\mathfrak{c}_{\mathfrak{z}}$, $\mathfrak{E}_{\mathfrak{z}}$, and $\mathfrak{e}_{\mathfrak{z}}$ of consciousness $\mathfrak{z}$ in Row 0 of Fig. 7. Each of these components is a complete general metaphysicalism consisting of the adequate standard components of the general metaphysicalistic operands $\mathfrak{z}^{\mathfrak{i}}_1, \mathfrak{z}^{\mathfrak{i}}_2, \ldots, \mathfrak{z}^{\mathfrak{i}}_p, \mathfrak{z}^{\mathfrak{c}}_1, \mathfrak{z}^{\mathfrak{c}}_2, \ldots, \mathfrak{z}^{\mathfrak{c}}_q, \mathfrak{z}^{\mathfrak{e}}_1, \mathfrak{z}^{\mathfrak{e}}_2, \ldots, \mathfrak{z}^{\mathfrak{e}}_r$. Thus, the standardized informing $\mathfrak{I}_{\mathfrak{z}}$ is vertically (Col. 2) general-metaphysicalistically constituted by the informings $\mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_q}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_r}$, etc., respectively. A similar general metaphysicalism which holds for consciousness $\mathfrak{z}$ in respect to its general components $\mathfrak{z}^{\mathfrak{i}}_1, \mathfrak{z}^{\mathfrak{i}}_2, \ldots, \mathfrak{z}^{\mathfrak{i}}_p, \mathfrak{z}^{\mathfrak{c}}_1, \mathfrak{z}^{\mathfrak{c}}_2, \ldots, \mathfrak{z}^{\mathfrak{c}}_q, \mathfrak{z}^{\mathfrak{e}}_1, \mathfrak{z}^{\mathfrak{e}}_2, \ldots, \mathfrak{z}^{\mathfrak{e}}_r$, holds for the consciousness informing $\mathfrak{I}_{\mathfrak{z}}$ in respect to the informings of the general components $\mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_q}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_r}$, etc. Thus, a characteristic six-loop vertical metaphysicalism for informing $\mathfrak{I}_{\mathfrak{z}}$ is (without the rotation of operands)

$$
\begin{array}{l}
((((\cdots(((\cdots((\mathfrak{I}_{\mathfrak{z}} \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_p}) \models \\
\quad \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_q}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_1}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_2}) \models \cdots \\
\quad \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_r}) \models \mathfrak{I}_{\mathfrak{z}};
\end{array}
$$

$$
\begin{array}{l}
(\cdots(((\cdots(\mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1} \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_p}) \models \cdots \\
\quad \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_q}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1}; \\
(\cdots(((\cdots(\mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1} \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_p}) \models \cdots \\
\quad \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_1}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_q}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1};
\end{array}
$$

$$
\begin{array}{l}
(\cdots(\mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1} \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_p}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1}; \\
(\cdots(\mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1} \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_q}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1}; \\
(\cdots(\mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_1} \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_2}) \models \cdots \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_r}) \models \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_1}
\end{array}
$$

Similar six-loop vertical systems can be written for the consciousness components $\mathfrak{i}_{\mathfrak{z}}$, $\mathfrak{C}_{\mathfrak{z}}$, $\mathfrak{c}_{\mathfrak{z}}$, $\mathfrak{E}_{\mathfrak{z}}$, and $\mathfrak{e}_{\mathfrak{z}}$. Usually, a system with different parenthesis pair positioning as the last one will be required. In parallel, on some other place, the principle of operand rotation in a loop can be considered. However, such additional formula systems do not change the graph in Fig. 7. This means, that by applying the rotation principle, a formula system would describe more than an informational graph might show at the first glance.

4.6 Standard Circularism of the general Metaphysicalistic Components

From the graph in Fig. 7 it is evident that all the general components $\mathfrak{z}^{\mathfrak{i}}_1, \mathfrak{z}^{\mathfrak{i}}_2, \ldots, \mathfrak{z}^{\mathfrak{i}}_p, \mathfrak{z}^{\mathfrak{c}}_1, \mathfrak{z}^{\mathfrak{c}}_2, \ldots, \mathfrak{z}^{\mathfrak{c}}_q, \mathfrak{z}^{\mathfrak{e}}_1, \mathfrak{z}^{\mathfrak{e}}_2, \ldots, \mathfrak{z}^{\mathfrak{e}}_r$ of consciousness $\mathfrak{z}$ are structured in the standardized form.

5 Informational Investigations and Experiments Concerning Consciousness

5.1 Possibilities of Informational Investigations and Experiments Concerning Consciousness

Informational investigations and experiments concerning consciousness, also in the spirit of the scheme in Fig. 7, are possible in many directions and fields of research. The most evident direction is an informational formalization of meaningly dense texts after which the informational graph can be constructed. Experiments as such can then be performed by "moving" along the graph arrows. By abstraction, and in a multimedia environment, experiments of various kinds are possible, concerning text, voice, and image. For the last two, an informational machine [41] would be necessary. A special account to such experiments and investigation could be taken in the field of scientific research.

A preliminary study of Heideggerian understanding and interpretation (in English [35] and in German [48, 49]) as informational phenomenalism showed how various language experiments can generate reasonable philosophical sentences which additionally interpret the existing authorized philosophical text. Such experiments bring new understanding and the widening of the semantic contents and meaning of groups of sentences, paragraphs, and texts [49]. Thus, for instance, from original German sentences, interesting interpretative sentences can be generated by moving along the arrows within a text graph[7].

[7]Several such sentences in German, proceeding from the eight Heidegger's sentences [11], are shown in [49].

The scheme in Fig. 7 can be taken as it is, without additional decompositions in the graph itself. The connection with exterior and interior operands can be described by separate parallel formula systems. Also, additional informational interpretations can be described separately, and can become as complex as necessary. In this way, the resulting graph becomes more and more complex, exceeding the complexity of the scheme in Fig. 7 substantially. This techniques points to the possibility to make an initial organizational scheme as transparent as possible and, afterwards, develop it in a further way by the parallel formula systems. Each time a parallel system is added, the graph becomes more complex. In this respect, a computer supported system for a systematic graph drawing and its presentation (on the screen and/or paper) would be of extreme importance.

5.2 A Possible Choice and Disributiveness of General Components of Consciousness

A concrete model of consciousness can proceed from the general case, considering the first column of the graph in Fig. 7. The dilemmas, concerning the generalized informing, counterinforming and embedding can be resolved by the three possible approaches:

1. for operands $\mathfrak{z}_1^{\mathfrak{i}}, \mathfrak{z}_2^{\mathfrak{i}}, \ldots, \mathfrak{z}_p^{\mathfrak{i}}, \mathfrak{z}_1^{\mathfrak{c}}, \mathfrak{z}_2^{\mathfrak{c}}, \ldots, \mathfrak{z}_q^{\mathfrak{c}}, \mathfrak{z}_1^{\mathfrak{e}}, \mathfrak{z}_2^{\mathfrak{e}}, \ldots, \mathfrak{z}_r^{\mathfrak{e}}$, there is possible to insert different concrete operands discussed in Sec. 4; these operands can be additionally determined by parallel formula systems outside of the scheme in Fig. 7;
2. the enumerated operands can appear in a distributed manner and in the standardized form; for instance, intention of a consciousness subject can appear as an informing part (superscript $\mathfrak{i}$), as an appropriate counterinforming part (superscript $\mathfrak{c}$), and as a corresponding informational embedding part (superscript $\mathfrak{e}$); and
3. operands can occur in a mixed mode according to items 1 and 2.

Let us list in short the concrete operands and their informational markers being candidates for operands $\mathfrak{z}_1^{\mathfrak{i}}, \mathfrak{z}_2^{\mathfrak{i}}, \ldots, \mathfrak{z}_p^{\mathfrak{i}}, \mathfrak{z}_1^{\mathfrak{c}}, \mathfrak{z}_2^{\mathfrak{c}}, \ldots, \mathfrak{z}_q^{\mathfrak{c}}, \mathfrak{z}_1^{\mathfrak{e}}, \mathfrak{z}_2^{\mathfrak{e}}, \ldots, \mathfrak{z}_r^{\mathfrak{e}}$. We have:

α's intention	—	$\mathfrak{i}_{\text{intention}}(\alpha)$;
α's experience	—	$\mathfrak{e}_{\text{experience}}(\alpha)$;
α's emotions	—	$\mathfrak{e}_{\text{emotions}}(\alpha)$;
α's qualia	—	$\mathfrak{q}_{\text{qualia}}(\alpha)$;
α's abstraction	—	$\mathfrak{a}_{\text{abstraction}}(\alpha)$;
α's concepts	—	$\mathfrak{c}_{\text{concepts}}(\alpha)$;
α's percepts	—	$\mathfrak{p}_{\text{percepts}}(\alpha)$;
α's sensations	—	$\mathfrak{s}_{\text{sensations}}(\alpha)$;
α's understanding	—	$\mathfrak{u}_{\text{understanding}}(\alpha)$;
α's subconsciousness	—	$\mathfrak{s}_{\text{subconsciousness}}(\alpha)$;
α's unconsciousness	—	$\mathfrak{u}_{\text{unconsciousness}}(\alpha)$;
α's meaning	—	$\mathfrak{m}_{\text{meaning}}(\alpha)$;
α's structure	—	$\mathfrak{s}_{\text{structure}}(\alpha)$;
α's organization	—	$\mathfrak{o}_{\text{organization}}(\alpha)$;
α's self-consciousness	—	$\mathfrak{s}_{\text{self-consciousness}}(\alpha)$;
α's identity	—	$\mathfrak{i}_{\text{identity}}(\alpha)$;
α's memories	—	$\mathfrak{m}_{\text{memories}}(\alpha)$;
α's behavior	—	$\mathfrak{b}_{\text{behavior}}(\alpha)$;
α's existents	—	$\mathfrak{e}_{\text{existents}}(\alpha)$;
α's references	—	$\mathfrak{r}_{\text{references}}(\alpha)$;
α's interpretation	—	$\mathfrak{i}_{\text{interpretation}}(\alpha)$;
α's causation	—	$\mathfrak{c}_{\text{causation}}(\alpha)$;
α's phenomenology	—	$\mathfrak{p}_{\text{phenomenology}}(\alpha)$;
α's reduction	—	$\mathfrak{r}_{\text{reduction}}(\alpha)$;
α's truth	—	$\mathfrak{t}_{\text{truth}}(\alpha)$

etc., where α marks something which might belong to any consciousness component or to something, which the component might functionally

---

One of them is, for instance, the following: Verstehen ist nicht etwas anderes in der Auslegung, das nicht die Kenntnisnahme des Verstandenen, sondern die Ausarbeitung der Möglichkeiten im Seinkönnen ist für Sein des Daseins, erschlossen im Rückschlag, von Möglichkeiten des Entwerfens des Verstehens. This sentence follows from the informational graph, presented in [48], Fig. 12, or from the informational formulas as particular situations of the graph. The informational formula for this sentence is [49]

$$\left(\begin{array}{l}(V \not\models \mathfrak{e}_{\text{etwas}}(\mathfrak{a}_{\text{andere}} \subset A)) \not\models \\ \left(\begin{array}{l} K(V_{\text{Verstandene}}) \models_{\text{sondern}} \\ A_{\text{Ausarbeitung}}(M \subset S_{\text{Seinkönnen}}) \end{array}\right)\end{array}\right) \models_{\text{sondern}}$$
$$(S(D \models_{\text{erschließen}} R))(M(E(V)))$$

In the last formula, some symbols are abbreviated as: V–Verstehen; $\not\models$–ist nicht; $\models$–ist (sein); $\subset$–ist in; A–Auslegung; K–Kenntnisnahme, S–Sein; D–Dasein; R–Rückschlag; M–Möglichkeiten; and E–Entwerfen. An English translation (for philosophical terminology see Heidegger [12]) of the obtained German sentence would be, for example, the following: Understanding is not something other that does not take cognizance of understanding, but is the working-out of possibilities within the potentiality-of-Being for Dasen's Being, being disclosed in the counter-thrust of possibilities of understanding's projecting.

concern. Thus, this list can cause the feeling what the concrete components of consciousness could be, and how could they be informationally interrelated in the most complex and circularly perplexed way. On this way, it becomes clear that experiments, using such a complex organization, cannot be effectively performed by conscious man and, instead, an informational machine [41] is the tool needed.

5.3 The Problem of Pure Consciousness

The problem of *pure* or *void consciousness* was presented in [27] (Shear 1996), and discussed in the informational sense in [46]. Now, it can be shown in more detail what the problem of pure consciousness could mean in the light of the scheme in Fig. 7.

The extreme case of pure consciousness can be conceptualized by different possibilities. To be consciously pure or void means to be concentrating on consciousness as such, excluding other informational components from the process of consciousness. Such a state of concentration is achieved, for example, by meditative training in the Eastern thought. In case of a consciousness model it means to minimize the informational impact of consciousness components and environmental sensation, especially of dealing with concrete intention of something, and perverting the intention (concentration) to consciousness itself as a conscious something.

Using the model in Fig. 7, the goal to achieve a consciously pure consciousness can be informationally implemented by the reduction of the distributive dimensionality of consciousness, e.g., through the transition from the two metaphysicalistic dimensions—the general and the standard one—to the one of them. This means that the problem of consciousness informing becomes simpler and more superficial as in case of several metaphysicalistic dimensions. The scheme in Fig. 7, as it is drawn, seems to be isolated from the environment. But, this is in fact not true since each informational component (operand) can have its own input and output operator to a kind of environment—the interior and/or exterior one. However, for the pure consciousness it is relevant to be excluded from any exterior informational impact (disturbance), and concentrating merely onto the perceiving of consciousness as such. The additional condition for such a situation is, for example,

$$
\begin{array}{l}
\alpha \not\models \mathfrak{c}_{\mathrm{consciousness}}; \mathfrak{c}_{\mathrm{consciousness}} \not\models \alpha; \\
\mathfrak{c}_{\mathrm{consciousness}} \in \\
\quad \{\mathfrak{z}, \mathfrak{z}^{\mathfrak{i}}_1, \mathfrak{z}^{\mathfrak{i}}_2, \ldots, \mathfrak{z}^{\mathfrak{i}}_p, \mathfrak{z}^{\mathfrak{c}}_1, \mathfrak{z}^{\mathfrak{c}}_2, \ldots, \mathfrak{z}^{\mathfrak{c}}_q, \mathfrak{z}^{\mathfrak{e}}_1, \mathfrak{z}^{\mathfrak{e}}_2, \ldots, \mathfrak{z}^{\mathfrak{e}}_r, \\
\quad\; \mathfrak{I}_{\mathfrak{z}}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{c}}_q}, \\
\quad\quad \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{I}_{\mathfrak{z}^{\mathfrak{e}}_r}, \\
\quad\; \mathfrak{i}_{\mathfrak{z}}, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{c}}_q}, \\
\quad\quad \mathfrak{i}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{i}_{\mathfrak{z}^{\mathfrak{e}}_r}, \\
\quad\; \mathfrak{C}_{\mathfrak{z}}, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{c}}_q}, \\
\quad\quad \mathfrak{C}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{C}_{\mathfrak{z}^{\mathfrak{e}}_r}, \\
\quad\; \mathfrak{c}_{\mathfrak{z}}, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{c}}_q}, \\
\quad\quad \mathfrak{c}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{c}_{\mathfrak{z}^{\mathfrak{e}}_r}, \\
\quad\; \mathfrak{E}_{\mathfrak{z}}, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{c}}_q}, \\
\quad\quad \mathfrak{E}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{E}_{\mathfrak{z}^{\mathfrak{e}}_r}, \\
\quad\; \mathfrak{e}_{\mathfrak{z}}, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{i}}_1}, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{i}}_2}, \ldots, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{i}}_p}, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{c}}_1}, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{c}}_2}, \ldots, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{c}}_q}, \\
\quad\quad \mathfrak{e}_{\mathfrak{z}^{\mathfrak{e}}_1}, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{e}}_2}, \ldots, \mathfrak{e}_{\mathfrak{z}^{\mathfrak{e}}_r}\}
\end{array}
$$

where α presents an exterior operand, and $\not\models$ is the operator of non-informing.

Further, the organization of consciousness has to be simplified as much as possible. In the first step, the general components $\mathfrak{z}^{\mathfrak{i}}_1, \mathfrak{z}^{\mathfrak{i}}_2, \ldots, \mathfrak{z}^{\mathfrak{i}}_p, \mathfrak{z}^{\mathfrak{c}}_1, \mathfrak{z}^{\mathfrak{c}}_2, \ldots, \mathfrak{z}^{\mathfrak{c}}_q, \mathfrak{z}^{\mathfrak{e}}_1, \mathfrak{z}^{\mathfrak{e}}_2, \ldots, \mathfrak{z}^{\mathfrak{e}}_r$ can be omitted in the context of consciousness. By such an omission, only the Row 0 in Fig. 7 remains, with the basic intention to examine the consciousness $\mathfrak{z}$ as the only relevant phenomenon.

6 Conclusion

Besides a possible scientific interpretation, the theory presented in this paper has also its own horizons of the possible consciousness artificialness, that is, numerous possibilities of an adequate consciousness constructibility in regard to the concepts in different fields of scientific research. What follows from such a view is the possibility of modeling and experimenting, with the straightforward as well as controversy structures and organization of informational consciousness [44]. Within this context, organization has to be understood as a complex circular and metaphysicalistic perplexed consciousness structure as, for example, presented in Fig. 7. On the other side, arbitrary other schemes of consciousness become possible which do not have any metaphysicalistic organization, but are by their nature complexly circular (e.g., an unconscious functionalism of consciousness).

By the scheme in Fig. 7, a paragon of the so-called *organizational invariance* [3] is given, which could be expanded over several dimensions (potential infinity), where metaphysicalistic components are and emerge in a metaphysicalistic way ad infinitum. Potentially infinite depth of metaphysicalism brings to the surface the concept of an infinitely dimensional informational space, being defined on the basis of a new mathematical (mathesis-like) scope. Such a formalization can lead to a conceptually new type of machine, being able to inform as a complex informational entity [41].

A meticulous reader will observe that the theory of consciousness, as exposed in this paper, roots in the general informational theory, by which the phenomenalism of informing of entities can be efficiently formalized. Within this view, the theory can be built up in the sense of a positivistic and objective epistemology [19], with the firm informational axiomatic background and formalistic rules of theoretical procedure. The initial cognition of informational phenomenalism can be directly transferred to the concepts of consciousness, being in accordance with scientific results in different fields of research, methodology, and practice.

It must be stressed that the formation of the informational concept—and through it the consciousness concept—is straightforward in the basic axiomatic direction, together with the rules of informational deduction, induction, and the other rules in the domain of the so-called modi informationis [48], which concern the informational inference. In this way, some new forms of abstraction are introduced, especially those concerning the basic phenomenalistic properties—informational externalism, internalism, metaphysicalism, and phenomenalism. The four initial axioms open the realm of the entire theory together with the simplest syntax for the informational formula formation. Thus, the concept of abstraction of informational abstraction can seize to an arbitrary depth, complexity and perplexity. This feature of the informational concept abstraction can best be recognized in the case of consciousness where all the possible theoretical and formalistic resources have to be taken into consideration, with the goal to overcome the usual scientific reductionism.

The concept of consciousness coincides to a substantial philosophical depth with the concepts of being (Sein) and identity (Seiendes). Phenomena of consciousness root in the awareness of the internal and external world. The informational concept follows this consciousness aspect in every concern. Existing of things means to have the faculty of informing for the others (spectators), for the thing itself (in the sense of the external impacting of the thing interior), and for the inner (metaphysicalistic) informing of the thing (its characteristic physicalism). In this way, the informational of something covers simultaneously the physicalism and phenomenalism of something.

Each significant theory—and informational and consciousness theory in particular—must be able to identify the nature of its objects (e.g., consciousness operands and operators) by the epistemologically objective concepts. Informational definitions help to introduce the necessary terminology, for instance terms as operand, operator, transition, serialism, parallelism, circularism, metaphysicalism, causality, gestaltism, etc. By a definition, a concept is clearly distinguished from all other concepts, and can be communicated in terms of other concepts. Informationally, concepts can be embedded in other concepts and itself, giving the theory the necessary circularism, perplexity and multi-plasticity.

Formalization (mathematization) of consciousness concepts is the conditio sine qua non for a future theory development (a higher form of formalization) and its application. The higher form of formalization calls for the development of a new sort of multidimensional space—the informational space—the formalism for a more dense, concentrated, and efficient expression of higher forms of circularism and parallelism, especially in the depth-embedded metaphysicalism. On the other hand, the rigorous and precise formalization of consciousness (informational) concepts could substantially contribute to the transparency of the design (engineering) of a new type of machine [41]—the informational machine. Experiments with consciousness problems and tasks, supported by such a machine, would lead to the recognition in which way a machine could essentially surpass the living consciousness, and enable a real breakthrough in the domain of informational phenomena in the field of literature, voice and image, and in the last consequence to the experiments in the field of conscious thought.

It becomes more and more evident in which direction the research of consciousness as informational phenomenalism has to proceed. *In which way different scientific disciplines can profit by the new theory and how can they impact it?* remains an actual open question.

References

[1] Towards a Science of Consciousness 1996. "Tucson II". April 8–13, 1996. Consciousness Research Abstracts. A service from the Journal of Consciousness Studies. Tucson, AZ.

[2] BECHTEL, W. 1994. Levels of Description and Explanation in Cognitive Science. Minds and Machines 4:1–25.

[3] CHALMERS, D.J. 1996. The Conscious Mind. Oxford University Press. New York.

[4] COLE, D. 1994. Thought and Qualia. Minds and Machines 4:283–302.

[5] DAMASIO, A.R. 1994. Descartes' Error: Reason, and the Human Brain: 1–312. Grosset/Putnam. New York.

[6] FUSTER, J.M. 1991. The Prefrontal Cortex and Its Relation to Behavior. Prog. Brain Res. 87:201–211.

[7] GOLDMAN-RAKIC, P. 1992. Working Memory and the Mind. Sci. Am. 267:3:110–117.

[8] GRAFMAN, J., K.J. HOLYOAK, AND F. BOLLER, Eds. 1995. Structure and Functions of the Human Prefrontal Cortex. Annals of the New York Academy of Sciences 769:i–ix + 1–411. The New York Academy of Sciences, New York.

[9] GRAFMAN, J. 1995. Similarities and Distinctions among Current Models of Prefrontal Cortical Functions. *In* [8] 337–368.

[10] HAMEROFF, S. & R. PENROSE. 1996. Conscious Events as Orchestrated Space-Time Selections. Journal of Consciousness Studies 3:36–53.

[11] HEIDEGGER, M. 1927. Sein und Zeit. Sechzehnte Auflage. 1986. Max Niemeyer Verlag. Tübingen.

[12] HEIDEGGER, M. 1962. Being and Time. Translated by J. Macquarrie & E. Robinson. Harper & Row, Publ. New York.

[13] HILBERT, D. & P. BERNAYS. 1934. Grundlagen der Mathematik. Erster Band. Die Grundlagen der mathematischen Wissenschaften in Einzeldarstellungen, Band XL. Verlag von Julius Springer. Berlin, Germany.

[14] JIBU, M., K. PRIBAM & K. YASUE. 1996. From Conscious Experience to Memory Storage and Retrieval: The Role of Quantum Brain Dynamics and Boson Condensation of Evanescent Photons. Intern. J. Mod. Phys. 10:1735–1754.

[15] LURIA, A.R. & L.S. TSVETKOVA. 1990. The Neuropsychological Analysis of Problem Solving: 1–230 (translation). Paul M. Deutsch Press. Orlando, FL.

[16] PENROSE, P. 1989. The Emperor's New Mind. Oxford University Press. Oxford, UK.

[17] PENROSE, R. 1994. Shadows of the Mind. Oxford University Press. Oxford, UK.

[18] RAFF, M.C. 1996. Death Wish. The Sciences 36:4:36–40.

[19] RAND, A. 1967. Introduction to Objectivist Epistemology. With an Additional Essay by Leonard Peikoff. A Mentor Book. New American Library. New York.

[20] RICCIARDI, L.M. & H. UMEZAWA 1967. Brain and Physics of Many-Body Problems. Kybernetik 4:44–48.

[21] ROSENBERG, J.F. 1994. Comments on Bechtel, "Levels of Description and Explanation in Cognitive Science". Minds and Machines 4:27–37.

[22] SCHWARTZ, M.F., E.S. REED, M. MONTGOMERY, C. PALMER & N.H. MAYER. 1991. The Quantitative Description of Action Disorganization after Brain Damage: A Case Study. Cogn. Neuropsychol. 8(5):381–414.

[23] SCHWEIZER, P. 1994. Intentionality, Qualia, and Mind/Brain Identity. Minds and Machines 4:259-282.

[24] SHALLICE, T. 1988. From Neuropsychology to Mental Structure. Cambridge University Press. New York.

[25] SHALLICE, T., P.W. BURGESS, F. SCHON & D.M. BAXTER. 1989. The Origins of Utilization Behavior. Brain 112:1587-1598.

[26] SHALLICE, T. & P.W. BURGESS. 1991. Deficits in Strategy Application Following Frontal Lobe Damage in Man. Brain 114:727-741.

[27] SHEAR, J. 1996. The Hard Problem: Closing the Empirical Gap. Journal of Consciousness Studies 3:54-68.

[28] Шилов, Г.Е. 1960. Математический анализ. Специальный курс. Государственное издательство физико-математической литературы. Москва.

[29] STUSS, D.T., T. SHALLICE, M.P. ALEXANDER & T.W. PICTON. 1995. A Multidisciplinary Approach to Anterior Attentional Functions. *In* [8] 191-211.

[30] UMEZAWA, H. 1993. Advanced Field Theory: Micro, Macro, and Thermal Physics. American Institute of Physics. New York.

[31] WILSON, F.A.W., S.P. O'SCALAIDHE & P. GOLDMAN-RAKIC 1993. Dissociation of Object and Spatial Processing Domains in Primate Prefrontal Cortex. Science 260:1955-1958.

[32] ZAJONC, R.B. 1984. On the Primacy of Affect. Am. Psychol. 39(2):117-123.

[33] ŽELEZNIKAR, A.P. 1988. Principles of Information. Cybernetica 31:99-122.

[34] ŽELEZNIKAR, A.P. 1990. On the Way to Information. The Slovene Society Informatika. Ljubljana, Slovenia (ISBN 86-901125-1-0).

[35] ŽELEZNIKAR, A.P. 1992. An Informational Approach of Being-there as Understanding I-III. Informatica 16:1:9-26, 2:29-58; 3:64-75.

[36] ŽELEZNIKAR, A.P. 1993. Metaphysicalism of Informing. Informatica 17:65-80.

[37] ŽELEZNIKAR, A.P. 1993. Formal Informational Principles. Cybernetica 36:43-64.

[38] ŽELEZNIKAR, A.P. 1994. Informational Being-in. Informatica 18:149-173.

[39] ŽELEZNIKAR, A.P. 1994. Informational Being-of. Informatica 18:277-298.

[40] ŽELEZNIKAR, A.P. 1995. Principles of a Formal Axiomatic Structure of the Informational. Informatica 18:133-158.

[41] ŽELEZNIKAR, A.P. 1995. A Concept of Informational Machine. Cybernetica 38:7-36.

[42] ŽELEZNIKAR, A.P. 1995. Elements of Metamathematical and Informational Calculus. Informatica 19:345-370.

[43] ŽELEZNIKAR, A.P. 1996. Informational Frames and Gestalts. Informatica 20:65-94.

[44] ŽELEZNIKAR, A.P. 1996. Organization of Informational Metaphysicalism. Cybernetica 39:135-162.

[45] ŽELEZNIKAR, A.P. 1996. Informational Transition of the form $\alpha \models \beta$ and Its Decomposition. Informatica 20:331-358.

[46] ŽELEZNIKAR, A.P. 1996. Journal of Consciousness Studies. Informatica 20:401-406.

[47] ŽELEZNIKAR, A.P. 1997. Zum formellen Verstehen des Informationsphänomenalismus. Grundlagenstudien aus Kybernetik und Geisteswissenschaft/Humankybernetik 38:3-14.

[48] ŽELEZNIKAR, A.P. 1997. Informational Graphs. Informatica 21:79-114.

[49] ŽELEZNIKAR, A.P. 1997. Informationelle Untersuchungen. Grundlagenstudien aus Kybernetik und Geisteswissenschaft/Humankybernetik 38:(in print).

[50] ŽELEZNIKAR, A.P. 1998. Informational Consciousness. Cybernetica 41:(in print).

An Informational Conception of Developing the Consciousness of the Child

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Keywords: developing consciousness, information transfer approach to consciousness, developing thinking, developing mental outlook, young child, teenager, artificial intelligence approach, cognitive science, theory of dynamic conceptual mappings, methods of emotional-imaginative teaching, metaphor, theory of teaching, foreign language, mother tongue, developing the personality of the child, conflicts- free teaching, nature, ecological education, symbolic thinking, language of painting, language of poetry

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An original conception of effective developing the consciousness of the child (from five-year olds to teenagers) is stated. Its main part is information transfer oriented and was developed proceeding from the analysis of the peculiarities of the work of young child's and teenager's consciousness and from ideas of artificial intelligence theory. The stated conception is a central constituent of a new theory of teaching suggested by the authors, called the Theory of Dynamic Conceptual Mappings, and presented in a number of previous publications.

One of the most important insights of the conception is a new look at the role of impressions from the nature in the development of the consciousness of 4–7-year-old children. The suggested method (a component of the conception) of teaching young children to describe figuratively the nature is interpreted as a universal starting engine for effective developing the consciousness of each young child of average abilities. The ideas of the conception have been implemented in the new methods of teaching languages called the Methods of Emotional-Imaginative Teaching (EIT-methods) and destined for positive developing the thinking and mental outlook of young children and teenagers at lessons of English as a foreign language.

1 Introduction

During[1] recent years, it has been possible to observe several serious manifestations of the interest of scientists to developing informational theories of consciousness. The examples of such manifestations are the works of Chalmers (1995, 1996) and Železnikar (1993, 1996a, 1996b). Naturally, introspection stays a powerful source of ideas in this extremely complicated sphere of science (see Dennet, 1995). However, the researchers working in this field acutely feel also the necessity of obtaining objective data of studies providing the firm ground for theoretical speculations. Besides, there is also a need of elaborating such forms of

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theoretical reasonings that the results of these reasonings might be tested in some direct but soft for people experiments. That is why our results stated below may be of interest both for theoreticians analysing consciousness as informational phenomenalism and for the specialists interested in social applications of discovered regularities of the work of consciousness.

At the beginning of our way to the theoretical conception stated below we considered two groups of questions: (a) how to transfer to children the skill of adults to analyse every-day-life situations and come to correct decisions, to understand other people and to communicate with them succesfully, to love and protect the nature, to notice and appreciate the beauty in all its manifestations, to understand the languages of painting and poetry; (b) how to prepare children to the challenge of the new technologies, to the storming enlarging of informational flows in the modern world, how to develop in them the desire and ability to acquire actively new knowledge, to establish fruitfull conceptual relations between different spheres of knowledge, to develop the creative abilities of children and to contribute to their growth as well educated people, in particular, people with a good command of one or several foreign languages? We managed to find effective interrelated answers to these questions. For this, we proceeded from a more general look at the problems of education—a look from the positions of the Artificial Intelligence (AI) theory.

The essence of the modern paradigm in the AI theory consists in suggesting special formal means (or structures) for representing diverse kinds of information to be processed and in elaborating complicated interrelated procedures for effective processing information by means of transforming the input data with respect to knowledge base into diverse formal structures on multiple levels of representation. Proceeding from this paradigm, we consider the processes of teaching as the particular cases of conveying information from one intelligent system (a teacher) to other intelligent systems (the learners) in order to enable the learners to carry out some kinds of activities.

Step by step, we elaborated since the end of the 1980's a new theory of teaching called the Theory of Dynamic Conceptual Mappings (the DCM-theory) and based on it new methods of teaching languages called the Methods of Emotional-Imaginative Teaching (the EIT-methods). The DCM- theory and EIT-methods are represented, in particular, in Fomichov & Fomichova (1993, 1994, 1995, 1996, 1997a), Fomichova (1995, 1996), Fomichova & Fomichov (1996). A large-scale, seven-year experiment carried out in Moscow has shown that the DCM-theory and EIT-methods are unusually effective as concerns teaching English as a foreign language (FL) to young children and teenagers and positive developing the personality of the child (the total number of students exceeds three hundred as concerns diverse years of the seven year period, the age—from four-and-half to sixteen years). In particular, it is noted in Fomichova & Fomichov (1996) that the EIT-methods highly outstrip the methods of teaching English as a FL to children under ten reflected in Scott & Ytreberg (1994). One of the most striking features of the obtained practical results is the ability of even five-seven-year-old students from experimental groups to use a very rich, very beautiful language (a part of the studied FL) for describing the nature around, the landscapes and seascapes. The corresponding examples of the young students' compositions may be found in Fomichov & Fomichova (1993, 1995, 1997b, 1997c, 1997d), Fomichova & Fomichov (1996, 1997).

We elaborated the initial version of the DCM-theory proceeding from the analysis of the peculiarities of the work of consciousness of young children and teenagers. Implementing the ideas of the DCM- theory in the EIT-methods, we continued to study the manifestations of the functioning of consciousness in the children's work at FL lessons and in their home compositions. Our seven-year large-scale experiment has convincingly confirmed the ideas of the initial version of the DCM-theory. Besides, we have observed some additional important manifestations of the work of consciousness. This enabled us to extend the DCM-theory and successfully test its new ideas during several years in teaching young children and teenagers.

The purpose of this paper is to represent a central constituent of the DCM-theory in its current state—a conception of effective developing the consciousness of the young child and teenager (of developing the thinking and mental outlook of the child). The stated conception explains the deep reasons of unusual effectiveness of the

EIT-methods; in particular, it explains why very young children are able (and it is natural to them !) to describe so beautifully the pictures of the nature that it is impossible for the dominant part of adults. The fragments of that our conception were published earlier in Fomichov & Fomichova (1993, 1994, 1995, 1996, 1997b, 1997c, 1997d, 1997e), Fomichova (1996), Fomichova & Fomichov (1996) and are represented also in Fomichov (1997), Fomichova & Fomichov (1997). The main part of our conception is *information transfer oriented*; it sets forth em a general line, a method of effective developing the thinking and mental outlook of young children and teenagers. The other part of the conception determines the *manners of realizing that general line at lessons* with respect to the peculiarities of the work of consciousness of the young child or teenager. Since the first, main part of the elaborated conception is information transfer oriented and, besides, the standpoint of information processing plays an important role in its second part, the conception as a whole is called an *informational conception.* The main subject of this paper is the information transfer oriented part of our new conception.

A particular important aspect of the significance of this article for studies of consciousness as informational phenomenalism is as follows. Proceeding from our informational conception of developing the consciousness of the child while carrying out a seven-year experiment on teaching very many child ren at the age from 4 to 16 years, we discovered *three fundamental regularities* reflecting the peculiarities of the work of child's consciousness and concerning (a) the real role (much greater than it is generally accepted to believe in modern science) of processing the impressions from the nature in the development of the five–seven-year-old child and about the possibility to use this phenomenon for highly effective developing the consciousness of the child possessing average, usual abilitites and (b) the possibility of explicating and realizing the potential of figurative thinking in *all* average five-seven- year-old children (Sections 4–6).

In Section 7, the stated results are discussed from diverse standpoints. First, deep connections of our informational conception with the theory of metaphor being one of the central parts of modern Cognitive Linguistics are analysed. Second, it is shown that the new conception and based on it EIT-methods are important for teaching arbitrary mother tongues and foreign languages with the purpose to influence positively the development of the personality of the child. Section 3 outlines the initial steps of the suggested method of effective developing the consciousness of the child.

2 Task Statement and a General Characterization of Its Solution

The expression "He (she) has good brains" is widely used. Likely, it is difficult not to agree that the collection of properties characterizing a "good brain" includes the following abilities concerning information processing:

1. The ability to construct the generalized conceptual representations (CRs), or mental representations, of perceived (observed, read, heard) situations.

2. The ability to look at perceived situations from different standpoints and construct generalized CRs of the perceived situations corresponding to multiple different standpoints.

3. The ability to establish conceptual connections (links) between objects, situations, phenomena pertaining to highly distant, different cognitive spheres.

4. The ability to collect, integrate, and interprete in the inner conceptual world's picture the pieces of information about diverse things, events, phenomena perceived at various moments of life under very different circumstances, in particular, disperced through various sources.

5. The ability to form, test, and correct the beliefs about such knowledge and such goals of people which are important for the interaction with these people in some spheres of activity.

6. The ability not only to understand the immediate, "surface" meaning of words and phrases of other people but to attract also all available knowledge in order to construct

the deep meaning of phrases in the concrete situation of communication.

7. The ability to attract all available knowledge for finding, first, a generalized decision of a problem situation to be solved and, second, for finding an appropriate concretization of that generalized decision for following it in the life.

A good development of the enumerated abilities is an essential indicator of a "good brain".

All listed abilities have one common feature: it is their informational character. That is why some time ago we conjectured that it would be reasonable to try to elaborate such a theoretical conception of developing the consciousness of the child which would indicate a way of effective developing all these abilities in young children and teenagers. We managed to solve this task and describe in this paper the suggested solution.

Our conception of effective developing the consciousness of the child consists of two parts. The first one is, in essence, an *information transfer oriented part (ITO-part)*. The second one may be called a *person oriented part (PO-part)*. The first part is the principal one and is motivated by the modern paradigm of the AI theory. The ITO-part formulates a *general line* of developing the thinking and mental outlook of children. It is done on the basis of exact indicating the kinds of information playing the most important roles in developing the personality of the child and indicating the manners to teach the child to process effectively the information of these kinds (e.g., to be able to find appropriate words for describing the nature around and to understand the languages of painting and poetry). The PO-part provides the knowledge about the ways of realizing the method given by the ITO-part as concerns the peculiarities of the personality of each concrete pupil. In particular, the PO-part indicates the motives of young children to work actively at lessons and fulfil hometasks, explains how to concentrate the attention of 4–9-year-old pupils at lessons, how to stimulate their learning activity, how to overcome the delays in the psychological development of some pedagogically neglected children. It is interesting that several important components of the PO-part have the informational character too.

For realizing the ideas of our conception, we elaborated concrete methods of developing the thinking and mental outlook of the child at lessons of English as a FL; these methods are a central part of the EIT-methods. Our theoretical conception of developing the consciousness of the child together with the concrete methods of teaching implementing its ideas form a new approach to developing the consciousness of the child. Since the main part of our conception is information transfer oriented part, our new approach may be called an *informational approach* to developing the consciousness of the child.

Proceeding from our approach, we elaborated a unique, highly effective extra-scholastic programme of harmonic humanitarian development of the child. The programme is destined for teaching children during seven years, where the starting age is four-and-half–five years. It includes the following series (or cycles) of lessons: (1) a two-year course (the age of learners is 4–6 or 5–7 years) of studying foundations of reading and speaking English as a FL, including learning basic elements of English grammar (Present Simple and Past Simple Tenses); (2) a course on understanding the language (a part of FL) of describing the nature and feelings evoked by the nature; (3) a course on understanding the language of painting; (4) a course on understanding the language of poetry (with the accent on understanding metaphors and descriptions of the nature); (5) a course aimed at (a) first acquaintance with sciences (the studied topics are, e.g., insects, stars and planets, rivers, man, etc.) and (b) developing the abilities to argument the own opinion, to raise objections, etc.; (6) a course on perfecting the knowledge of English grammar (during mainly the fifth year of studies). In fact, the lessons of the courses (2)—(6) may interchange. So each of the courses (2)–(6) is realy a distributed course.

The programme has been succesfully tested during seven years. The total number of taught students exceeds three hundred. The seven-year experience convincingly confirmed the validity and high effectiveness of the ideas stated below. Our new methods of teaching languages develop abstract thinking and imagination of children, the love to the nature, the ability to see the beauty in all its manifestations, to understand the language of poetry and painting, to see clearly causal relationships of diverse events, to understand other people, to express in words own thoughts and feelings, to acquire actively new knowledge.

3 Initial Steps in the Tested Method of Effective Developing the Consciousness of the Child

The initial steps in the suggested information transfer oriented method of effective developing the consciousness of the child are described in (Fomichov & Fomichova 1994, 1995, 1996; Fomichova & Fomichov 1996). These steps are characterized shortly below.

The destination of the first step is twofold. On the one hand, the goal is to give a considerable impulse to the development of the symbolic, abstract thinking of children at the age 5–6 years and, in some cases, four-and-half years. The way of achieving this goal consists in explaining the rules of reading words in FL (English) and basic elements of FL grammar with the help of thrilling analogies. Such analogies are realized by means of the well-known or (mainly) specially invented and very interesting fairy-tales and stories. E.g., the well known fairy-tale about the Wolf and Seven Little Kids is used for explaining the rule of reading the letter "Y" after introducing the rule of reading the letter "I" (see Fomichov & Fomichova, 1994). The essence of that step consists in demonstrating to young pupils that abstract objects, symbols and combinations of symbols, are associated with emotionally bright coloured objects and situations pertaining to the real or fairy-tale world; e.g., the letter "Y" is associated with the Wolf from the fairy-tale about the Wolf and the Seven Little Kids.

Consider one more example. A difficult problem is to explain to very young children why the verbs in the 3rd person of Past Simple Tense have no ending "s" but the same verbs in the 3rd person of Present Simple Tense do have such ending ("reads" but "read", etc.). An interesting story from one of the previous lessons associates in the consciousness of the child the ending "s" with a bow. That story about Mr. Do and Lady Teacher is given in (Fomichova & Fomichov, 1996). The teacher explains that her young students were in the Past babies and had no hair (were bold). Hence it was impossible to tie a bow. That is why verbs have no ending "s" in the 3rd person of Past Simple Tense. The 5-year-old students accept this explanation with great joy and remember it very good. As a result of having heard the stories of the kind, young children become aware of the fact that symbolic objects have the meanings pertaining to the real or fairy- tale life.

On the other hand, the goal of the first step consists in developing analogical thinking of young children. Each system of symbols is used in some concrete thematic domain (domains) for expressing the meanings pertaining to some other domain (domains). E.g., the combinations of lines and colours are the symbols pertaining to painting and used for expressing the meanings associated with the real world. That is why developing symbolic thinking in a domain is a particular case of developing analogical thinking. For instance, the interesting stories about the life of verbs and other words (like the stories mentioned above) establish in the consciousness of the young child a mapping from the objects and situations of the real life to the domain of language entities (verbs, nouns, pronouns, etc.).

That is why as a result of realizing the first step of our strategy, the consciousness of the young child becomes a considerable impulse to developing the ability to establish diverse analogies.

The second step in developing the consciousness of the child consists in teaching young children to reconstruct the complete situation that is nominated by a word or a word combination proceeding from the background frame-like knowledge represented in the inner world's pictures, or conceptual systems (CSs), of children. Such reconstruction helps children to feel better the meanings of the words and to be ready to see possible consequences, advantages, and disadvantages of this or that situation nominated by a word or a word combination. E.g., a teacher may ask the students of the 2nd year of studies (the age mainly 6–7 years) to describe the events meant by the phrase "There were the preparations in the Kingdom for the celebration of the birth of the baby-princess". That step is described in detail, with the examples of young students' home compositions, in Fomichova & Fomichov (1996). The starting points for suggesting that step were the work Minsky (1974) caused the birth of the frame theory and the paper Fillmore (1985).

4 Developing the Skill of Figurative Describing the Nature

A decisive step in developing the consciousness of young children in accordance with the EIT-methods consists in teaching children to understand the language of describing the nature (a part of the studied FL) and in developing the skill of comparing diverse objects and phenomena of the nature with the well known things and events of every-day life. The reasons to apply essentially to the nature at FL lessons with young learners are simultaneously obvious and deep. On the one hand, when a teacher solves the task of teaching five-seven- year-old pupils to express thoughts and feelings in FL, she/he must have the topics for discussion during many months. Naturally, such topics must be coordinated with the inner world's picture, or conceptual system (CS) of the young learner. The five-seven-year-old child receives the dominant part of the impressions from observing the nature. That is why the most part of the possibilities of developing the thinking of the young child is provided by that part of the child's CS.

On the other hand, the seven-year experience indicates that young students remember very well, with great desire new words and expressions pertaining to the nature. It enables us to conjecture that studying the language of describing the nature with very young learners excellently corresponds to the psychological peculiarities of the child at that age. As the first result of such lessons, young children begin to compose short poems (see Fomichov & Fomichova 1993, 1995, Fomichova & Fomichov 1996).

Having acquired a sufficiently large stock of words and constructions for describing the observed scenes of the nature or the landscapes, pupils are being systematically taught to compare the directly observed objects and phenomena with objects and phenomena being, at first sight, very unsimilar to the directly observed ones. Usually, each day of lessons gives one or several highly interesting examples of comparisons suggested by young students. For instance, *"It is possible to confuse a red fox with a heap of yellow leaves"*, *"It was a starlit night, and shining stars were reflected in the water. That is why he happened to scoop out a bucket full of stars"* (Anton Gussev, 6 years old, 2nd year of studies). Little by little, young pupils acquire the skill and habit to compare a lot of things with a lot of other things. E.g., young children discover that *"The nature is swaying on the sunny swings"* (Polina Rybakova, 8 years old, 3rd year of studies), *"The moon is like a pancake with sour cream"* (Anton Gussev), *"The sun beams dashed through the tops of the trees and looked like spilled orange juice on the white gowns of ever green trees"* (Sveta Yatsyk, 6 years old, 2nd year).

The bright, unexpected comparisons found by one child, become right away the property of all pupils of the group. As a result of active work at such lessons during several months, many objects and phenomena of the nature are associated in the consciosness of young child with something well known, pleasant, cosy from the every-day environment of the child. And the child begins to love the nature as a part of his/her pleasant and cosy every-day environment. The other consequence of acquiring the habit to compare objects and phenomena observed in every-day life with different real and imaginary things is that every-day life becomes much brighter, much more interesting for the child. We can clearly see this, in particular, on the following home compositions in FL.

Example 1. THE KINGDOM OF THE WINTER (Polina Rybakova, 8 years old, 3rd year)

One winter day I was sitting near the window looking at the street covered with fresh clean snow. At first sight, there was nothing so very remarkable in that. Nor did I think it so very much out of the way to see the falling snowflakes, snow storm, the grey cloudy sky and the noisy crows.

But when afterwards in the evening going to sleep I thought it over it occured to me that I ought to have wondered at this. I thought that the snow storm might be a wicked magician Winter, the grey sky with running clouds—his kingdom. Every beautiful princess that refused to be his wife because he was very angry and cruel was turned by him into a crow. And then their tears he turned into the falling snowflakes. And only the coming of the kind Fairy Spring can destroy this magic.

Example 2. THE WINTERDAY)
(KSENIYA GLASHKINA, 5 YEARS OLD, 2ND YEAR)

In the picture I see a winter day. On the branches of fir-trees, pine-trees, and birches lies flaffy, white snow, glimmering in sunshine. It seems that snowdrops are covered with jewels. Near the wood there are fields with snow. On the edge of the snowfield the rill is dreaming. The snow is everywhere. Sunrays make one way through the grey, big, heavy clouds and run over top-trees. Pine-trees and fir-trees shine hoary green. The bare bushes of birches are coverd with snow. It seems that the oak is with soft, white, and big leaves.

Suddenly someone in heaven has dashed a big cup of sunlight upon the Earth, and the big old oak has turned into a fairy King in orange magnificient gown. And around him young birches in nice gowns are accompanying their beloved King.

In the nestle in roots of a big fir-tree lived the family of the butterfly. Two little baby-butterflies were sleeping in their beds. In the warm room there was a fireplace. In the fireplace firwoods were snapping brightly. On the table stood candles, and the room was aglow with amberlight. Near in the kitchen mother-butterfly was making an apple pie. The father-butterfly was decorating branches of the fir-tree.

Christmas night was coming. Santa Claus was in a hurry with presents to the family of the butterflies. And this fairy-tale about Christmas comes to end.

From the scientific point of view, the great significance of that step in developing the thinking of young pupils is that the consciousness of the child acquires the skill and habit to synthesize many generalized conceptual representations (CRs) of diverse perceived objects and situations, and it builds these CRs looking simultaneously from numerous different sides at many things. This ability of consciousness is perfected during several years of studies, when children are taught to decipher poetical metaphors and understand the thoughts and feelings encoded in the famous works of art. Step by step, the consciousness of the child acquires during several years the highly precious skill and habit to construct generalized CRs of every-day-life problem situations proceeding from diverse standpoints in order to find an optimal generalized solution of the situation and then to invent a concretization of that generalized solution for following it in the life. And the ability to do this is, naturally, one of the main goals of school education.

5 A New Look at the Role of the Impressions from the Nature in the Development of the Young Child's Consciousness

The goal of this section is (a) to generalize the observations accumulated in the course of successful application of the method stated in Sections 3, 4 in teaching 4–7-year-old children, (b) to draw the conclusions from these observations.

5.1 A hypothesis about the roots of a deep interest of young children to describing the nature

A prolongated and large-scale experient has indicated that *all unselected preliminary, average five-seven-year-old children* master very easily the poetical, elevated style of describing the nature, the skill of comparing the objects and phenomena of the nature with seemingly very different objects and phenomena. This surprising easiness enables us to conjecture that (a) the role of the impressions from the nature in the life of 4–7-year-old children is extremely high, much higher than it is generally accepted to believe, (b) we managed to find experimentally, by means of interchanging tests and theoretical speculations, such words and expressions that, likely, the conceptual representations (CRs), or mental representations, constructed by the consciousness of the child harmonize very good with the most bright impressions of young children from the nature, are in a good resonance with these impressions. Probably, the height, the brightness of the emotional coloration of the created CRs of considered phrases and discourses pertaining to the nature coincide with the height, the brightness of the inner images of children's visual impressions from the nature.

All this may be explained as follows: just at the age 4–7 years and earlier children open for themselves the surrounding world, and this causes in young children the most strong emotions which are not always visible or clear for adults. It is well known how strong are the impressions of very young children from many new observed phenomena. For instance, we know a case when a child at the age 11 months cried when he saw for the first time the snow covering all around.

A very short time separates five–seven-year-old children from the period of discovering the surrounding world; besides, children discover a number of things at the same age 5–7 years. Our *hypothesis* is that our new methods of teaching young children to describe figuratively the nature and their own feelings evoked by the nature *activate* such regions of the consciousness which were *activated earlier* at the moments of astonishment before the discovered pictures and phenomena of the surrounding world.

Due to just this reason, the descriptions of the landscapes made by means of a too complicated (from the adults' point of view) language are *natural* for the 5–7-year-old child, he/she accepts them with all the heart, all the soul. Just this explains why very young children carry out with such interest a very considerable work on studying FL, on fulfilling home tasks, and why there is *no question about the discipline* at lessons in groups with 5–7-year-old children.

Let's mention only one example. Waiting for her grandmother, Asya Rybakova, 5 years old, was learning independently texts in English with descriptions of the nature during two hours at the lessons of FL with other children. She was so carried away by her reading that she began to read texts aloud. We adduce below one of the home compositions of Asya in FL.

Example. LANDSCAPE
(Asya Rybakova, 5 years old, 2nd year of studies)

In the picture I see an autumn landscape. Beauty up and down. Gleaming gold meadows lay around the small village. Far away stands a church.

I see a mountain. The slopes of the mountain are covered with forest. The trees are dressed in golden finery. The top of the mountain is covered with snow. There is a castle on the top of the hill.

A beautiful girl lived in the castle. She had long-long hair. Her hair was as yellow as the sun in the blue sky. Her eyes were as green as the summer meadows. She sang a song and was happy.

The methods of emotional-imaginative teaching (the EIT-methods) develop the ability of children to describe the nature proceeding from the deep inner requirement of the child's consciousness. When the advantage of that age is not used for explicating and developing the ability of children to describe figuratively the nature, this ability vanishes. Due to the indicated reasons, the adults (except of a few number of outstanding poets) organically are not able to decribe so brightly, metaphorically the nature around as it is possible for 5-, 6-, 7-year-old children. It is a *regularity*.

5.2 The look of young children at themselves, animals, birds, and plants as particles of the nature

Consider additional arguments in favour of our hypothesis. The first one is as follows. It was explained in details in Fomichova & Fomichov (1996) and, shortly, in Section 3, that one of the initial steps in developing the consciousness of the very young child in accordance with the EIT-methods consists in teaching pupils to attract all available background knowledge for reconstructing the situations, events associated with a given word or expression. We analyse below the results of fulfilling by 5–7-year-old children the home task consisted in describing in FL the meaning of the expression "the preparations in the Palace for the birth of a Princess".

The submitted texts reflecting the work of the consciousness of young children have a lot of various motives and details. However, they strike by the presence of some interesting and unexpected common features.

First, children see in this celebration an embodyment of all the most light, the most festive, the most joyful. That is why children see the most dear for them living beings as guests at this celebration. And these living beings are not only people but always the animals (squirrels, hares, deer, etc.) or birds; they present very often flowers or other plants. For instance, young children say that:

"The *swans* presented their soft fluff for a princess's cushion ... The *bear* presented the full *basket of berries and mushrooms and honey. The rabbit* with his friends presented a lot of *medical herb from the forest*, because the girl could be ill. The *tiger* presented the *finest flower from the jungle*, and all the rooms in the Palace were filled with *wonderful smell (odour). The dog and* *cat* presented small plate and glass and fork and spoon out of the gold" (*Olya Kossova, 7 years old, 2nd year of studies*);

"The gardener planned his *best flowers and rose bushes* to smelt sweetly in honour of this birthday. The *hunter* brought a *deer Bamby* as a gift for a baby. The *fishman* got a *gigantic golden fish*. The servant presented a baby with a funny fluffy *puppy* ... The *woodman* carried to the castle *singing birds* he had caught in the *woods*. The *dawn* presented his *flaming light*. It seemed *the whole nature was celebrating* this birth" (*Andrey Poletayev, 7 years old, 2nd year*);

"The unicorn—*a magic white horse with a horn*—got ready for princess birthday *a lot of flowers* ... The *little angel* with silver hair and St. Peter prepared for present *silver and gold stars*. Even the little *mermaid* prepared to swim from *the sea* through the *rivers, springs, lakes, and rills* and reached the ditch surrounded the Castle. She prepared to present some *marvellous sea shells* and some strings of *pearls*" (*Masha Sapozhnikova, 6 years old, 2nd year*).

Meanwhile, the fragment of the fairy-tale "Sleeping Beauty" which was the ground for the considered home task doesn't mention animals, birds, and fishes at all.

Second, nobody of young pupils considers the cradle of the Princess as a little bed decorated by something. Children see, first of all, the *shape, form* of the cradle, and that shape, form is associated with, is similar to either an *animal* or a *flower*. E.g., young students say that "The carpenter made a finest cradle as a big *sea shell, mother-of-pearl*, and decorated with *roses, lilas*, silk, velvet, and laces" (*Masha Sapozhnikova, 6 years old, 2nd year*); "The carpenter made a cradle. It looked like a *dolphin*. *Gold stars* were in eyes. On the tail was a ball" (Nadya Vorobyova, 9 years old, 2nd year); "The Carpenter would make the cradle in a form of *rabbit* that would befit a Princess" (*Dasha Smilga, 6 years, 2nd year of studies*), "The dressmaker prepared the new curtains from the *rose petals*. The carpenter was commanded to make the finest cradle that would befit a Princess. He made the magic cradle like a *cat* with soft and fluffy bedcover. The cradle *could swing and tenderly purr, song a lullaby, tell the fairy-tales*" (*Olya Kossova, 7 years old, 2nd year*).

One complete fulfilled home task of the kind is given below.

Example PREPARATIONS IN THE KINGDOM
(Asya Ivanova, 7 years old, 2nd year)

"The Carpenter made the cradle for a Princess. The cradle was in the form of *a rose opening in the morning dawn*. The walls of the cradle looked like *the rose petals*. The cradle was decorated with *branches of grapes and flowers*. It was a wonderful perfume.

There were many pretty pictures on the walls of this nursery. In these pictures everyone could see *lucent and serene woods, deep and blue sea* with beautiful beaches with pink sands and *sea-shells*. It was a pretty sight! The carpet in this room was so beautiful, *like field with flowers in spring*. The windows in the nursery were magic windows, and the room was aglow with amber light, even if the weather was rainy. When unhappy man came into this room, he heard beautiful low music and became happy.

Everyone prepared nice gifts for Princess. Everyone wanted to congratulate Queen and King. Snow White brought a basket full of tiny dresses. There were pretty tiny gowns with bowes and laces, beautiful tiny slippers, flashing like countless diamonds. Everyone was waiting for Royal baby, like for sun in a rainy day".

All this shows that the children at the age 5–7 years consider people as a part of the nature including obligatorily animals, birds, and plants but not as a some separate part of the nature. Since very young children consider themselves as the particles of the nature, the impressions from observing the nature play a so important role in the work of the child's consciousness.

5.3 Teaching to describe the nature causes the realization of the creative potential of all young children

The next argument is that all pupils of the 2nd year of studies in experimental groups (the age mainly 6–7 years) exposed, realized the potential of their own personality at FL lessons devoted to describing landscapes, seascapes, the nature around. Let's mention only two bright examples from many available ones.

One girl during one-and-half year learned to read good in FL but (it is a very rare situation) she didn't answer questions, didn't compose fairy-tales, etc. But after the lessons on describing the nature that six-year-old girl began to like painting very much. The deepness and strength of her emotions were so high that she began to paint the pictures of the nature using only the sheets of the size 85 cm by 60 cm.

After that moment, in the course of learning the fairy-tale "Sleeping Beauty", she began to discuss very actively this fairy-tale, to answer questions, etc. It was really impossible to recognize this child at lessons. It was the most strong impression that, as in the studied fairy-tale, the girl was awakened after a deep sleep, and now her consciousness is open for intensive intellectual work.

One other girl began to study in an experimental group when she was only 3 years old. During two years, that girl was silent most often at lessons. But one day that girl suddenly descibed in FL (English) a landscape so brightly a landscape that all the group appreciated it with applause: her words were so bright and unexpected.

5.4 A paradox: in fact, very young children don't think about the future

All said above explains, probably, the following highly unexpected observation: children at the age 5—7 years don't need to know the future tenses, though they need acutely to know the forms of expressing the events in the past. Likely, emotional impressions of young children from the nature and from the events in their life are so strong, bright that children are overfilled with these impressions. This prevents the consciousness of the child from concentrating on the possible events in the future. So we come to a paradoxical conclusion: very young children don't think about the future, they live by the present and past.

There is one more explanation of this fact: young children don't plan their future—it is done by adults. On the contrary, the experience of FL studies with adults shows that adults need acutely the forms of expressing the future tenses, they are planning permanently their own actions.

5.5 The skill of figurative describing the nature as an important precondition of conflict-free teaching

At the age 4–7 years, the children discover the surrounding world, and their feelings, their impressions are unusually acute, much more acute and intensive than the feelings and impressions of adults in the similar situations. As a result, the river of impressions and emotions seethes inside the young child, he/she is overfilled with them. Usually, the child at that age is unable to find the appropriate words for expressing these impressions and emotions. But since a location of excitation does exist in his/her consciousness, he/she reacts in other manners: may cry, romp, be naughty, and even be harmful.

Our methods of emotional-imaginative teaching (the EIT-methods) give the child the possibility and the means of expressing by words the most strong, most acute impressions and emotions evoked by the pictures of the nature. Having expressed these impressions and emotions by words, the children calm down, the location of excitation vanishes.

As a result, the conflictness of their behaviour diminishes (as concerns the relations with teachers, parents, and friends). Unconsciously, young children feel this calm. That is why they like very much to learn new words and expressions for describing the nature.

Our prolongated experience has shown convincingly that *all* five–seven-year-old children of average abilities *may be taught to paint by means of words*. That is why explicating and developing the skill of 5–7-year-old children of figurative describing the nature is, to our opinion, an important precondition of conflicts-free teaching.

5.6 Some of the discovered fundamental regularities pertaining to the work of the child's consciousness

We suppose that the results of our seven-year large-scale experiment (the sum of the numbers of the 4–7-year-old students for diverse years of this period exceeds two hundred fifty) show the existence of the following fundamental regularities pertaining to the work of the young child's consciousness:

1. The processing of the information conveyed by the pictures of the nature plays an extremely important role in the development of the consciousness of the child at the age 4–7 years. The strength, the brightness of the emotions evoked by the impressions from the nature in the child of average abilities is very high, much higher than it is widely accepted to believe in modern science and than, as a consequence, it is reflected in the curricula of preprimary and primary education.

   The consciousness of the average child needs very much the appropriate language means for adequate expressing these emotions. Having expressed such emotions by means of appropriate words and expressions, the child feels calm. This calm greatly diminishes the conflictness of the child's communication with a teacher (teachers), parents, and friends.

2. It is possible to explicate and develop the ability of figurative, metaphoric describing the nature, landscapes and seascapes in all five–seven-year-old children possessing average, usual abilities. All five–seven-year-old average children may be taught to paint by words the pictures of the nature. The consciousness of the five–seven-year-old child is open to mastering the skill of the kind.

6 The Elaborated and Tested Method of Effective Developing the Consciousness of the Child

6.1 The formulation of the method

Now it is an appropriate moment to set forth the suggested and successfully tested method of developing the consciousness of the child. The most original components of that method are stated in Sections 4, 5 and in our previuos publications. Taking into account the requirements to the volume of the article, the other components will be only outlined below. Though these components (or steps of the method) have a lot of original features, it seems to be reasonable to describe them shortly, because the essence of these further steps is quite understandable even after acquaintance with their brief formulation, some of them are set forth in our previous works, and these further steps have many connections with the ideas accumulated in cognitive science, theory of painting, theory of poetry, theory of literature.

The method stated below has been implemented in seven-year extra- scholastic teaching English as a FL. However, the analysis indicates that it may be realized in teaching other FLs or arbitrary mother tongues. That is why we will use the term "language" instead of writing "a foreign language or a mother tongue".

The components of our method are called steps. The lessons pertaining to different steps may interchange. In fact, one lesson may include the learning of materials relating to different steps.

Step 1. The destination of this step is to give a considerable initial impulse to developing the symbolic thinking and analogical thinking of young learners. For this, the rules of reading words and basic grammar rules of the studied language are explained by means of special stories and fairy-tales being very interesting, thrilling for young students. The duration of that step is approximately one academic year (8 months), the starting age is five–six years and in some cases—four-and-half years. More information about that step may be found in Fomichov & Fomichova (1994, 1995, 1996), Fomichova & Fomichov (1996).

Step 2. The purpose of the step is to teach young children to reconstruct the complete situation meant by a word or a word combination proceeding from all available frame-like background knowledge. The paper Fomichova & Fomichov (1996) contains a detailed description of that step.

Step 3. This step is destined for (a) learning the lexics of describing the nature, (b) teaching young children to use the rich language means for bright describing the nature around, the landscapes and seascapes, (c) explicating and developing the ability of young children to describe objects and phenomena of the nature in a figurative, metaphorical way. One of the consequences of realizing that step is that young students acquire a very high attention to the details observed in the surrounding nature, to the little changes in its state.

[**Step 4**. The goal of the step is teaching basic elements of the language of painting and, as a consequence, further developing the symbolic thinking of young children. They are taught that a painter uses combinations of lines and colours as symbols for expressing his/her thoughts and feelings. Knowing the meanings of such symbols, one is able to reconstruct a message conveyed by a picture and expressing the thoughts and feelings of its author for future generations of people. In particular, young students learn the basic elements of the language of portrait and, later, receive initial knowledge about the language of impressionism.

One of the central ideas underlying this step is that the study of the artistic legacy of the past enriches our knowledge and feelings and makes more keen our perception of the beautiful.

The well developed (by that moment) ability of young students to notice and remember various peculiarities of the pictures of the nature help them very much to discover in the works of art the symbols associated with definite meanings. One may find more information about this step in Fomichova & Fomichov (1996), Fomichov & Fomichova (1997d).

Step 5. The purpose is to develop the skill of integrating numerous disperced information pieces for making judgements about a person, about his/her character, habits, and motives.

The experience indicates that initially young students don't possess this ability. But it may be considerably developed very quickly, during several lessons, due to the well developed (by that moment) ability of children to notice even little changes in the pictures of the nature around and due to the previous lessons devoted to studying the symbolic language of painting, including the language of portrait. The implementation of this step in the EIT-methods includes, in particular, solving by children the following task: to describe the character and habits of the White Rabbit after the reading of Chapter 1 of "Alice's Adventures in Wonder Land" by Lewis Carroll.

Step 6. The destination of this step is to extend the ability of children to understand metaphors and, for this, to teach children to understand complicated poetical metaphors occuring in the works of the best poets. This step is described in Section 6 of Fomichova & Fomichov (1996). That is why we indicate below only its main features.

In our experiment, the principal attention was paid to analysing a number of metaphors from the works of the world-known Russian poet Boris Pasternak and from the translations of these works into English. That step is essentially based on the knowledge and skills acquired by young students at the steps 2, 3, 4, 5. It should be added that young children begin to learn and compose simple poems during the first year of studies; they learn by heart the poems with beautiful descriptions of feelings evoked by the nature at the 3rd step and later.

From the scientific point of view, the purpose of that step is the further development of children's symbolic thinking and figurative, metaphoric thinking. Young children are taught that poetical metaphors are symbolic representations of some meanings reflecting the thoughts and feelings of the poem's author. The pupils are taught to consider the task of understanding a poetical metaphor as a particular case of the task of decoding a symbolic expression in order to penetrate the feelings and thoughts of its author. For the success of decoding a metaphor, it is necessary to attract all available background knowledge pertaining to the described situation.

The idea is to make a new important step in teaching children to process effectively symbolic information of diverse kinds accumulated by the mankind during many centuries—from painting and sculpture to musics, hence the purpose is further developing figurative thinking of children.

The experience shows that all eight-ten-year-old children of average, usual abilities are able to make this step. But when a child is studying additionally painting or musics, this step exerts even more voluminous, more many-sided influence on the development of his/her personality. This influence is reflected, in particular, in the following home composition in FL showing the emergence of a picture in words as a result of visualizing musics:

Example. A home composition of Eugenia Todua, 10 years old, 5th year of studies, about "The Song Without Words" of Felix Mendelssohn-Bartholdy.

"Silent night. Moon. All around is aglow with moonlight. It is listening to the quite splash of water and calm blows of scull. Beautiful song is dashing through this silence".

Step 7. The purpose of this step is to teach young students to find appropriate language means, including metaphors, for conveying some given information and emotions to a partner in communication in a manner providing the possibility of achieving the goal of communication. The children are to be taught to attract all knowledge and skills acquired during the previous steps in order to realize successfully their goals in communication.

An important role in realizing that step (as in the case of Step 2) is played by the ideas of the theory of frames suggested by Minsky (1974). Children are taught to proceed from a frame-like representation of a situation (or event) to be discussed. E.g., the frame "Birthday" may include the slots "The awakening in anticipation of a holiday", "Season", "Gifts", "Birthday cake with candles". Young students are taught to find images associated with all or some slots and being able to activate the fantasy of the communication partner in order to enable him/her to perceive better, more completely the transferred information and emotions.

Step 8. It is a distributed step covering several years of studies and aimed at developing in children the skill of building the generalized conceptual representations of problem situations, finding an appropriate decision first on a generalized level and then concretizing that decision for following it in the life.

Step 9. The goal of this final distributed step is to develop the ability of applying all accumulated skill and knowledge for self- expressing and for effective reasoning about the character and motives of the litarary personages and, the most important, of parents, friends, colleagues, because the integral goal is to contribute to effective social adaptation of children, their success in the personal life and professional career.

6.2 About a realization of the method

Our methods of emotional-imaginative teaching English as a FL (the EIT-methods) are a realization and concretization of the method stated above. The seven-year personal experience of teaching children at the age from four-and-half to sixteen years (the total number of students for diverse years exceeds three hundred) has indicated that the EIT-methods implement effectively the formulated method and, as a consequence, develop all information processing abilities enumerated in Section 2 as the qualities of a "good brain".

Besides, our observations have shown that the EIT-methods enrich considerably the mental outlook of young children and teenagers: develop the desire and ability to acquire actively new knowledge, the understanding of poetry and painting, the love to the nature, the ability to see the beauty in all its manifestations, to see clearly causal relationships of diverse events, to analyse effectively every- day-life situations, the ability to understand other people and communicate with them. As a result, the conflictness of children's communication with adults diminishes, because they understand much better the words and requests of adults, their motives.

Consider only one example giving an impression about the perception of the every-day life by a child studying in an experimental group during the sixth year. We'll see that nothing, even whitewashing and restoration, can prevent a girl from penetrating the beauty and serenity of the flowers, the candlelight, the angel. A strong sense of beauty lets her see the bright colours of the world. And even the rain and whitewashing can't spare her impression.

Example. SUMMER (a home composition in FL) (Dasha Samoilova, 12 years old, 6th year)

"The first part of my summer holidays I spent in a village, but then my mother took me to Novgorod. There we lived at my mother's friend's. The day of our arrival was gloomy and rainy. We were tired, because the train had come very early in the morning. Mummy took me to the restaurant. There I tasted splendid pancakes with sour cream. It helped me much in that rainy day.

Next day we visited one church. From the distance it seemed that it was made out of red clay, but when I came nearer I saw that its walls consisted of many uneven stones—all different colours and hues. There was a restoration, that is *why I could't see quite well the frescos inside. On the table near one of the icons a basket was standing full of medow flowers—buttercups and clover. A little candle was gleaming near the icon. In the candle light I saw silent and serene faces of angels, the line fringed their wings. It seemed that they were floating in the cloud very far from the world.*

When I left the church, the strong smell of paint and whitewashing was mixed with the delicious smell of medow flowers. At that moment the drizzling rain began, and its first drops spattered on my outstretched hand. I looked up. The steaple was hardly visible. Everything was enfolded soft in the blueish-green summer light".

Realizing in practice the stated method of developing the consciousness of the child, a teacher should permanently be aware of the fact that she/he deals with young and very young children, and their innner conceptual pictures of the world, their interpretations of words and visual images may considerably (and even surprisingly) differ from the interpretations of adults.

Example. Everyone who looks at Leonardo da Vinci's picture "Madonna and Child" ("Madonna with a Flower") can't help being excited on witnessing the manifestation of the tender and moving feeling of motherly love, so dear to all the people. While describing this picture, the seven-eight-year-old children spoke much about the inner world of Madonna, her feelings towards her child, the role of the background and the flower in the hand. Together with the teacher, they tried to penetrate her thoughts and explain the expression of her face and the smile as a sign of her state of mind and state of soul. Children spoke about happiness, calm, about the blessed moments of communication between the mother and her very little baby. They tried to prove their ideas, analysing the picture.

But suddenly, one of the boys began to speak about the subtle sadness in the smile and in the eyes of Madonna. When the teacher asked him to prove or explain somehow his ideas, he told that the cause of her sadness lies in the existence of the nimbus around the bold head of the baby. The boy said very seriously: "The mother can't help thinking about the future of her child, because his nimbus, preventing her from combing his hair, will cause the breaking of a great number of combs. It makes her look at him with sadness in her eyes".

By that moment, we considered (sometimes very shortly) the basic ideas of the information transfer oriented part (ITO-part) of our conception of effective developing the consciousness of the child. Besides, we analysed a number of central ideas of the person oriented part (PO-part) of our conception—the ideas concerning the great role of processing impressions from the nature in the development of the young child's consciousness. The destination of the other important ideas of the PO-part may be explained as follows.

The learning of the child in accordance with the EIT-methods requires that the child works intensively at lessons and fulfils regularly home tasks. Meanwhile, the undesire of children (not only of young children but also of teenagers) to work actively at lessons and fulfil home tasks is throughout the world one of the main reasons of deep conflicts between a teacher and the students. Hence it would be important to explain what stimulates young children (even five-year- old) being taught in accordance with EIT-methods to work intensively at lessons and to fulfil regularly home tasks.

On the one hand, a partial answer is given in Sections 3, 4: the tasks on figurative describing the nature are very interesting for young children, carry away them very strong. On the other hand, we elaborated a lot of original special manners to stimulate the learning activity of children at lessons and as concerns fulfilling home tasks. A part of these special manners (or "ruses", "tricks") is described in Fomichov & Fomichova (1995, 1996), Fomichova (1996), Fomichova & Fomichov (1996). Elaborating these manners, we proceeded from the peculiarities of the work of young child's or teenager's consciousness.

For instance, it is well known that the consciousness of the child at the age 5–7 years needs to receive very often new information, new impressions. This peculiarity is effectively used for concentrating the attention of young children at lessons on intellectual activity without any physical excercises during one lesson. For this, it is sufficient to use at each lesson three different kinds of studied topics (the topics must require different states of the child's mood).

Describing and grounding all invented manners of stimulating the learning activity of young children and teenagers goes far beyond the scope of this article and will be the subject of a series of our future works.

6.3 A discovered regularity and a hypothesis

Our theoretical analysis reflected in Sections 3, 4 and in Fomichov (1997), Fomichov & Fomichova (1997b, 1997c, 1997d, 1997e), Fomichova & Fomichov (1997) together with the results of the carried out large- scale experiment enable us to distinguish the role of the 3rd step (developing the skill of figurative describing the nature) between the all other steps (or components) of the elaborated method of effective developing the consciousness of the child.

Describing figuratively the nature around, a landscape, or a seascape, the child finds such a look at the perceived picture of the nature which enables him/her to construct the same generalized conceptual representations of a fragment of that picture and of some other thing or phenomenon or picture. As a consequence, he/she establishes a mapping from one fragment of the inner conceptual world's picture to some other its fragment.

The components of our method provide the possibility to extend, enrich such an ability of the child. As a result, our method develops considerably the ability of the child to establish conceptual ties between diverse, even very distant domains, i.e. develops the analogical thinking of children. The combination of a well developed analogical thinking and other abilities of effective information processsing are the signs of a positive development of the child's consciousness.

We believe that the results of the carried out large-scale seven-year experiment enable us to say about the *discovery of the following fundamental regularity* pertaining to the work of the young child's consciousness: explicating the potential and developing the skill of figurative, metaphoric describing the nature may be used as a universal starting engine for effective developing the consciousness of the child, for the most complete realizing the creative potential of his/her personality.

It has been no one failure in employing our method in teaching more than two hundred fifty children at the age 5–7 years (including a number of pupils with the peculiarities of the psychological development: very shy children, too excited children, children not ready to communicate with people, etc.).

Our prolongated observations have shown that the method of developing the skill of figurative describing the nature gave a powerful impulse to the realization of the creative potential of all young children studied in experimental groups. Since the creative potentials of young children differ, the results of applying this method have had some distinctions for different children. But the existence of a strong positive result has been obvious in each concrete case. To our opinion, this shows that our method deeply corresponds to the requirements of the consciousness of the child at that crucial period of his/her life.

That is why we believe that this method is a discovery in cognitive science of a high significance for education and, likely, medicine, opening new prospects for cognitive psychology.

Proceeding from our theoretical analysis and the observations accumulated in the course of the seven-year experiment, we put forward *hypothesis about the existence of the following fundamental regularity*: it is possible to preserve in teenagers the ability of figurative, metaphoric thinking explicated and developed when they were five- seven-year-old, to extend this ability to a well-developed ability of analogical thinking and several other abilities of effective information processing and, as a consequence, to contribute effectively to more complete realization of the creative potential of all average children and to diminishing the conflictness of the communication of teenagers with parents, teachers, and friends.

We suppose that it may be done by means of correct employing the method described above. We believe that our method is universally applicable, because it is based on developing information processing abilities being important for all people, on figurative describing the nature, and its realization doesn't require some special technical equipment (hence it may be used everywhere—in each little town, each village).

6.4 The essential features of the mechanism of successful ripening of the young child's consciousness

It appears that the obtained experimental results admit one more interpretation. A very high practical effectiveness of the method stated in Subsection 6.1, many observed really wonderful positive transformations of the creative abilities of young children and teenagers enable us to conjecture that our informational conception highlights a number of important preconditions of successful ripening of the young child's consciousness, outlines essential features of the mechanism of successful ripening of the child's consciousness.

Hence we may conjecture that our informational conception of developing the child's consciousness and obtained experimental results both open new perspectives for cognitive science, education, medicine and raise new important questions concerning the realization of these preconditions in every-day practice of preprimary and school education.

7 Discussion

7.1 Extending the modern theory of metaphor

The theory of metaphor represented, in particular, in Reddy (1979), Lakoff & Johnson (1980), Lakoff (1987, 1993), Johnson (1987), Lakoff & Turner (1989) is one of the central parts of modern cognitive linguistics.

According to Lakoff (1993), a metaphor is a cross-domain mapping, and "the locus of metaphor is not in language at all, but in the way we conceptualize one mental domain in terms of another" (p. 203).

Objectively, our informational conception of developing the consciousness of the child extends essentially the modern theory of metaphor due to the following main reasons.

First, we proved that all average five–seven-year-old children have a high potential of figurative, metaphoric thinking, and this potential may be explicated and effectively developed. It may be done, first of all, through developing in children the skill of figurative describing the nature; we indicated the roots of a deep interest of young children to that activity determining the final success of explicating and developing the skill of figurative thinking (Sections 4–6).

We have shown that explicating and developing the ability of figurative thinking in young children is very important for diminishing the conflictness of their behaviour (Section 5).

Second, we invented a method providing the possibility to preserve and extend this ability in teenagers.

Third, a way is found from developing in children the ability of figurative thinking to developing effective analogical thinking and several other abilities of effective information processing.

Thus, our study establishes strong links between the modern theory of metaphor and the problems of effective development of the child's consciousness.

7.2 Significance of results for positive developing the consciousness of the child through language lessons

Winograd (1995) writes that people create the reality by means of natural language and that the understanding is achieved with the help of background knowledge.

Reddy (1979), Lakoff & Johnson (1980), Johnson (1987), Lakoff (1987, 1993), Lakoff & Turner (1989) and some other researchers showed that the every-day English is deeply figurative as concerns the permanent use of cross-domain conceptual mappings. Our analysis indicates that this conclusion is valid also for the Russian language, and it is possible to conjecture that it is valid for arbitrary well-developped natural languages. Hence, as Lakoff (1993) notes, the standard (for 1970's) division of language into literal and figurative languages is incorrect, doesn't correspond to the real state-of-affairs.

Meanwhile, the curricula of preschool, primary school, and (very often) secondary school education are oriented at considering every-day language as a literal language.

Taking into account the ideas of modern cognitive linguistics and our results stated in this article, we may conclude that the dominant attitude in practice of school teaching to language as to the literal language has essential negative consequences: children are little interested in studying mother tongue, their innate abilities of figurative thinking practically vanish, their every-day language (especially, the language of teenagers) becomes very restricted, even primitive.

It follows from our informational conception that these phenomena essentially influence a considerable diminishing of teenagers' general creative abilities in comparison with the potential of the same children at the age 5–6 years.

The EIT-methods based on our informational conception of developing the consciousness of the child provide the highly precious opportunity to explicate, to prevent from vanishing in teenagers, to develop the ability of figurative, metaphorical thinking, to transform it into the ability of effective analogical thinking , and to complete this ability by a number of other important abilities of effective information processing.

Our prolongated experience shows that, as a result, children begin to understand much better the words of adults, the motives of their requests and demands, their advices, and all this considerably diminishes the conflictness of the communication of teenagers with adults, first of all, with parents and teachers.

Due to a number of special researches (see, e.g., Aplin, 1991; Maclntyres & Gardner, 1991; Phillips, 1991), it is generally recognized that foreign language (FL) is one of the most complicated school disciplines.

However, we are sure that the EIT-methods based on our informational conception are able to make FL one of the most pleasant, joyful disciplines, considerably contributing to harmonic humanitarian development of the child, developing his/her thinking, imagination, and mental outlook, the love to the nature, the understanding of poetry and painting. Besides, FL lessons based on the EIT-methods may effectively contribute to diminishing the conflictness of the child's behaviour.

8 Conclusions

Searching the kinds of information processing abilities being the most important for young children and teenagers, we worked up an original informational conception of developing the consciousness of the child. It is a central part of our theory of teaching called the Theory of Dynamic Conceptual Mappings.

The conception proved to be highly effective in practice. We suppose that the main reason of its effectiveness is that our conception outlines a number of essential features of the mechanism of successful ripening of the young child's (the age 5–7 years) concsciousness; first of all, indicates and explains a great role of impressions from the nature in that subtle process.

The elaborated conception underlies our original methods of emotional- imaginative teaching English as a foreign language (FL) to young children and teenagers (the EIT-methods) being simultaneously the methods of effective positive developing the concsciousness of the child—his/her thinking and mental outlook. The EIT-methods enabled us to create and successfully test during seven years an original programme of many-sided humanitarian development of the child; the programme covers seven years of studies and has been tested in teaching in diverse years totally more than three hundred children at the age from four-and-half to sixteen years. The programme includes a lot of elaborated and accumulated teaching materials covering seven years of studies: texts in English, original language games, home tasks, numerous "ruses" (or "tricks") for stimulating the creative activity of children at lessons. The dominant part of the EIT-methods is language-independent and may be successfully used in developing the personality of the child through lessons of mother tongue.

The analysis of the results of our large-scale seven-year experiment enabled us to discover three fundamental regularities pertaining to cognitive science and reflecting the peculiarities of the work of young child's concsciousness. These regularities allow us to look from a new side, first of all, at the educational potential of very young children. We discovered that the educational potential of 5–7-year-old children is much higher than it is generally accepted to believe and that the dominant part of children at that age underreceive the intellectual food needed for successful development of their thinking and mental outlook.

The EIT-methods provide the opportunity to overcome this shortcoming. The seven-year experience of studies with more than two hundred fifty children at the age 5–7 years has convincingly shown that the consciousness, the soul of the young child are open for teaching him/her to express figuratively, metaphorically the feelings evoked by the nature around, to understand the languages of poetry and painting. Such studies highly positively influence the health of children and their success at school. Besides, the seven-year experience has shown that such studies greatly smooth over the difficulties of the transition age (thirteen and more years), considerably contribute to conflicts-free communication of teenagers with parents, teachers, and friends. Our new methods may be successfully employed in each little town, each village, because they don't require any special technical equipment.

We elaborated our informational conception of developing the consciousness of the child, proceeding both from the analysis of the peculiarities of young child's consciousness and from the methodology of the artificial intelligence (AI) theory. To our opinion, the experience of our study says that the AI theory has a large potential (underrealized by the moment) of developing practically effective informational theories of consciousness.

It appears that our conception and the results of the seven-year experiment enrich the theoretical background and provide precious experimental data for realizing informational approach to modelling the work of consciousness.

Our conception and obtained practical results extend essentially the modern theory of metaphor. Besides, we believe that our results open new important prospects for preprimary and school education (in particular, for teaching foreign languages and mother tongues, developing the understanding of poetry and painting), for cognitive science and medicine. The detailed analysis of these aspects of our study goes far beyond the scope of this article and is to be the subject of our future works.

References

[1] APLIN, R. 1991. The ones who got away: the views of those who apt out of languages. Language Learning Journal (Rugby) 4:2–4.

[2] CHALMERS, D.J. 1995. Facing up to the problem of consciousness. Journal of Consciousness Studies 2:200–219.

[3] CHALMERS, D.J. 1996. The Conscious Mind. Oxford University Press. New York.

[4] DENNET, D.C. 1996. Facing backwords on the problem of consciousness. Journal of Consciousness Studies 3, 4–6.

[5] FILLMORE, C. 1985. Frames and the semantics of understanding. Quaderni di Semantica 6:222–253.

[6] FOMICHOV, V.A. 1997. Formal studies of anticipative systems as a basis of effective humanitarian and computer applications. Keynote Address at the Special Purpose Symposium "Modeling Anticipative Systems" of the 9th Intern. Conf. on Systems Research, Informatics and Cybernetics. Germany. Baden-Baden, August 18–23, 1997. *In* G.E. Lasker, D. Dubois, & B. Teiling, Eds. Advances in Modeling of Anticipative Systems (II). Intern. Inst. for Advanced Studies in Systems Research and Cybernetics, University of Windsor, Canada, 1998 (to be published in March 1998).

[7] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1993. The role of the artificial intelligence theory in developing new, highly effective methods of foreign languages teaching. *In* PEG93: Proc. of the Seventh Intern. PEG Conf. AI Tools and the Classroom: Theory into Practice. Moray House Institute of Education. Heriot-Watt University. Edinburgh. July 2–4, 1993. 319–329. ISBN 0901580 570.

[8] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1994. The theory of dynamic conceptual mappings and its significance for education, cognitive science, and artificial intelligence. Informatica 18:131–148.

[9] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1995a. From ideas of artificial intelligence and cognitive science to the discovery in the theory and methods of teaching. *In* Abstracts of Papers. 14th Intern. Congress on Cybernetics. Namur (Belgium), August 21–25, 1995. Symposium "From Ideas of Artificial Intelligence and Cognitive Science to New Theories and Methods of Teaching". President-Chairperson: V. Fomichov (Rus-

sia). International Association for Cybernetics, Namur, p. 1.

[10] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1995b. The artificial intelligence theory and highly effective methods of teaching young children foreign languages, Cybernetica 38:321–344.

[11] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1996. From ideas of artificial intelligence and cognitive science to the discovery in the theory and methods of teaching. *In* Proc. of the 14th Intern. Congress on Cybernetics. Namur (Belgium), August 21–25, 1995. International Association for Cybernetics. 731–736.

[12] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1997a. About computer and formal tools for supporting methods of emotional-imaginative teaching languages. Abstracts of the IFIP WG 3.3 Working Conference "Human Computer Interaction and Educational Tools". Sozopol, Bulgaria. May 27–28, 1997. University of Sofia. Faculty of Mathematics and Informatics. WWW http://www-it.fmi.uni-sofia.bg/HCIET/.

[13] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1997b. About computer and formal tools for supporting methods of emotional-imaginative teaching languages. Proceedings of the IFIP WG 3.3 Working Conference "Human Computer Interaction and Educational Tools". Sozopol, Bulgaria. May 27–28th 1997. University of Sofia. Faculty of Mathematics and Informatics.

[14] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1997c. The potential of the Theory of Dynamic Conceptual Mappings for teaching children and preparation of teachers. Proc. of the Eighth Intern. PEG Conference "Meeting the Challenge of the New Technologies". Sozopol, Bulgaria. May 30–June 1, 1997. University of Sofia. Faculty of Mathematics and Informatics.

[15] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1997d. New prospects opened by the artificial intelligence approach for developing children's thinking and mental outlook. Proc. of the International Conference "Knowledge Transfer—1997 (KT97)". University of London. 14–16 July, 1997.

[16] FOMICHOV, V.A. & OLGA S. FOMICHOVA. 1997e. From studying operations on conceptual structures to new methods of teaching languages and realizing intelligent tutoring. Intern. Conference on Learning: From Natural Principles to Artificial methods (AIDRI97). Switzerland. University of Geneva. June 23–26, 1997. Book of Extended Abstracts.

[17] FOMICHOVA, OLGA S. 1995. Emotionally-imaginative teaching children foreign languages as a highly effective realization of a general approach to conflicts-free teaching. In Abstracts of Papers. 14th Intern. Congress on Cybernetics. Namur (Belgium), August 21–25, 1995. Symposium "From Ideas of Artificial Intelligence and Cognitive Science to New Theories and Methods of Teaching". President-Chairperson: V. Fomichov (Russia). Intern. Association for Cybernetics. Namur, p. 2.

[18] FOMICHOVA, OLGA S. 1996. Emotionally-imaginative teaching children foreign languages as a highly effective realization of a general approach to conflicts-free teaching. In Proc. of the 14th Intern. Congress on Cybernetics. Namur (Belgium), August 21–25, 1995. International Association for Cybernetics, Namur. 743–748.

[19] FOMICHOVA, OLGA S. & V.A. FOMICHOV. 1996. Theoretical foundations of a new method of teaching children effective information processing. Informatica 20:381–399.

[20] FOMICHOVA, OLGA S. & V.A. FOMICHOV. 1997. From analysis of conceptual mappings to new principles of teaching languages and designing intelligent tutoring systems. A paper presented at the Special Purpose Symposium "Modeling Anticipative Systems" of the 9th Intern. Conf. on Systems Research, Informatics, and Cybernetics. Baden-Baden. Germany. August 18–23, 1997. *In* G.E. Lasker, D. Dubois, and B. Teiling, Eds. Advances in Modeling of Anticipative Systems (II).

Intern. Inst. for Advanced Studies in Systems Research and Cybernetics. University of Windsor. Canada (to be published in March 1998).

[21] JOHNSON, M. 1987. The Body in the Mind: the Bodily Basis of Meaning, Reason and Imagination. University of Chicago Press.

[22] LAKOFF, G. 1987. Women, Fire, and Dangerous Things. What Categories Reveal about the Mind. The University of Chicago Press.

[23] LAKOFF, G. 1993. The contemporary theory of metaphor. *In* A. Ortony, Ed. Metaphor and Thought. 2nd edition. Cambridge University Press. 202–251.

[24] LAKOFF, G. & M. JOHNSON. 1980. Metaphors We Live By. University of Chicago Press.

[25] LAKOFF, G. & M. TURNER. 1989. More Than Cool Reason: A Field Guide to Poetic Metaphor. University of Chicago Press.

[26] MACLNTYRE, R.D. & R.C. GARDNER. 1991. Investigating language class anxiety using the focused essay technique. Modern Language Journal 75:296–304. Madison, WI.

[27] MINSKY, M. 1974. A Framework for Representing Knowledge. Massachusetts Institute of Technology, Cambridge, MA.

[28] PHILLIPS, E.M. 1991. Anxiety and oral competence: classroom dilemma. French Review 65:1–14. Baltimore, MD.

[29] REDDY, M.J. 1979. The conduit metaphor—a case of frame conflict in our language about language. *In* A. Ortony, Ed. Metaphor and Thought. Cambridge University Press.

[30] SCOTT, W.A. & L.H. YTREBERG. 1994. Teaching English to Children. Seventh impression. Longman Group UK Limited. London.

[31] WINOGRAD, T. 1995. Thinking machines: Can there be? Are we? *In* Mind ¡¿ Computer. Informatica 19:443–459.

[32] ŽELEZNIKAR, A.P. 1993. Metaphysicalism of informing. Informatica 17:65–80.

[33] ZELEZNIKAR, A.P. 1996a. Organization of informational metaphysicalism. Cybernetica 39:135–162.

[34] ŽELEZNIKAR, A.P. 1996b. $\Pi o\lambda\varepsilon\mu o\varsigma$ of Consciousness. The Informational in the Conscious Mind. A short counter-essay with a commentary to a book. Informatica 20:429–434.

Information and the Dynamics of Phenomenal Consciousness

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Cognitive science has traditionally assumed that all mental phenomena except consciousness can be explained by an information-processing account. Natural selection has been seen as the best hope for legitimising the explanatory entities of such an account. The problem of explaining phenomenal consciousness then reduces to that of getting subjective experiences or "qualia" out of functionally and/or causally defined internal representations that can be "grounded" or "naturalised" through evolution. I shall argue that this model is unhelpful even for the so-called "easy" problems of mind, and that its general acceptance in cognitive science has become part of the "problem" of consciousness. The informational content of neural signals and changes of state is not so easily brought into concordance with "information about the world" as has generally been assumed. This paper proposes an alternative approach to explanations of human behaviour that draws on ethology, developmental psychology, situated robotics, and dynamical systems theory. It suggests that human infants are born with (or develop soon after birth) species-typical activity patterns that have been selected by a specifically human environment of man-made artifacts, language, and conspecifics who interpret behaviour in intentional terms. Complex and apparently purposive behaviour arises by interactive emergence from the operation of these activity patterns within a dynamic developmental context. An evolutionary explanation of human behaviour and mental phenomena along these lines implies that there is no specific physical, neurophysiological, or "software" ingredient that human beings inherit through their genes and that makes them conscious. Nor can consciousness be conceived as a virtual architecture that is installed by learning in an exceptionally large and plastic brain. The explanation for consciousness cannot be found in entities and processes that reside in the head: it requires an historical explanation that embraces the environment-infant-caregiver system as a whole.

1 Introduction

The standard view in cognitive science has been that, in principle, if not so far in practice, all mental phenomena except consciousness can be explained by an information-processing model. Even if the details have not been completely worked out, such problems as the discrimination and categorisation of environmental stimuli, the ability to access and reflect on internal states, and the ability to select, plan, and execute appropriate courses of action are all assumed to be reducible to computational processes that perform the recovery, combination, storage, retrieval, and transformation of information-bearing entities. This is thought to provide a satisfactory and potentially comprehensive explanation for the *contents* of consciousness.

Depending on the outlook of the cognitive scientist or philosopher, phenomenal consciousness is then seen as either a folk-psychological construct that does not require a scientific explanation (Dennett 1991), or as some extra ingredient or process that serves to highlight specific items of information and differentiate them from the subconscious functional and causal substratum. Explanations of how this might be achieved vary from positing a fundamental, phenomenal aspect for information itself (Chalmers 1996), to various forms of neural "binding" (Crick & Koch 1990; Hardcastle 1996), to the collapse of the quantum wave function within subneural information-bearing structures of the brain (Hameroff & Penrose 1996). The problem of phenomenal consciousness is thus seen as the problem of getting subjective experiences or "qualia" out of functionally and/or causally defined information.

In the first half of this paper I shall argue that this concept of information is unhelpful even for the so-called "easy" problems of mind, and that its general acceptance in cognitive science has become part of the "problem" of consciousness. The informational content of neural signals and changes of state is not so easily brought into concordance with "information about the world" as has generally been assumed in cognitive science. Doing so requires commitment to decomposition by function and to an ontology that reduces the world to a series of task-domains pre-registered into objects, properties, and features. Both of these assumptions have recently been called into question (Boden 1996; Brooks 1991; Hendriks-Jansen 1996).

In the second half of the paper I shall put forward an alternative approach to explanations of human behaviour and thought that draws on ethology, developmental psychology, situated robotics, and dynamical systems theory. I shall argue that this provides better prospects for a naturalised theory of mind, and that it also holds out greater promise for an explanation of phenomenal consciousness.

2 The Elusive Nature of "Natural" Information

Following Shannon and Weaver (1949), cognitive science and artificial intelligence have depended crucially on the notion of selective information-content, which has been interpreted in many different ways. Shannon himself was careful to warn that his theory had nothing to say about semantic content. It is an engineering tool that relates channel capacity and noise to the amount of redundancy required if a string of symbols with a known frequency distribution is to get across with a specified degree of accuracy from a sender to a receiver. However, the mathematical precision of Shannon's theory, coupled with indiscriminate use of the term "information" to describe computational, psychological, and social, as well as aesthetic phenomena, has proved seductive to philosophers and scientists.

It is of course true that electrical signals pass around the neural circuits of the brain that can be conceptualised as carrying information in Shannon's terms, and it may also be said that a creature's environment potentially contains "information" that is useful to its survival. The question is whether a meaningful and principled link can be forged between these two senses of information that will support a coherent theory of mind.

One philosopher who has devoted a considerable amount of thought to that question is Dretske (1986, 1988). Dretske assumes that an adequate theory of mind needs to be a representational theory and that its representations can be naturalised only by a causal-informational account that ultimately depends on an evolutionary grounding. He distinguishes among three basic types of information-bearing representation. Type I representations are symbols used by human beings. They lack what Dretske calls intrinsic representational power. Their meaning is dictated by convention, and they will perform their function only if the users stick to that convention. Type II representations are what Dretske calls *natural* signs. They derive their representational power, not from us, but from the way they are objectively related to the conditions they specify. Thus, according to Dretske, the number of rings in a tree is not merely correlated to the age of the tree, it actually *represents* and even *means* the age of that tree. This move is essential to Dretske's argument. He is progressing from the conventional idea of representation to a type of representation that is both natural and intrinsic to the system. The implication is that there exist conditions in nature—objective, observer-independent facts—that can be said to serve as natural indicators of other facts because there is a lawful dependency between the indicator and the thing it indicates, and that this warrants describing those conditions as natural representations, carrying information about the conditions they indicate.

Dretske's definition of a natural representation begs a number of questions. It is certainly not the *function* of tree rings to indicate the age of a tree, nor, presumably, did they indicate such a thing until human beings learned to "read" them. Tree rings are the result of variations in growth rate over the seasons. They have no natural function and no natural "users" of their representational potential.

Type III representations in Dretske's classificatory scheme do have natural users. They are used by the system of which they form a part: "Natural systems of representation, systems of Type III, are ones which have *their own* intrinsic indicator functions, functions that derive from the way the indicators are developed and used *by the system of which they are a part*" (Dretske, 1988, p. 62). Dretske has thus arrived at a notion of representation that can be used for the purpose of naturalising the symbols of a physical symbol system as defined in classical AI. Like Millikan (1984), Dretske compares the function of such representations to the functions of physical organs like the heart: "Can there be a serious question about whether, in the same sense in which it is the heart's function to pump blood, it is, say, the task of the nocturnal moth's auditory system to detect the whereabouts and movements of its arch-enemy, the bat?" (Dretske, 1988, p. 63)

Although functional decomposition or "reverse engineering" based on taking a "design stance" to the products of evolution has become extremely popular (Dennett 1987, 1995; Pinker 1994), I shall try to show by an analysis of Dretske's position that this strategy for deriving explanatory entities for the behaviour of natural creatures can be highly problematic. In the discussion on Sterelny that follows, I shall also point to the difference between using an evolutionary account in support of a functional description of some internal mechanism (such as the moth's auditory system), and using it in support of a functional description of information *produced* by such a mechanism. As Millikan (1984) has shown, it is possible to sidestep many of these problems by making a clean break with causal and informational accounts and defining natural function as a normative and historical concept. However, Dretske is not prepared to go that far. He feels it is necessary to spell out the details of the causal and informational links that enable an internal representation to perform the function that is ascribed to it by taking the design stance.

The best way to understand the differences between these two positions is to compare their approaches to misrepresentation (Dretske 1986; Millikan 1989). How is it possible for an organism to get things wrong, given that it is a product of evolution? Is it not an essential condition for a creature's survival that its information-bearing states should reliably and accurately reflect states of the world? Millikan's account refers to the "normal conditions" for a representation's "proper function", determined by its "history of use". She argues that it is not necessary that a representation be true in every instance. Many biological devices perform their proper function only on rare occasions during the creature's life-time, but it is this rare performance that constitutes their contribution to the creature's survival through natural selection. Millikan is not interested in the mechanistic details of how misrepresentations might occur. Dretske feels that commitment to a representational theory of mind requires him to give a full and coherent causal/informational account and therefore commits him to an explanation of how the underlying mechanism can go wrong.

To clarify the problem, Dretske uses the example of a species of bacteria that live in the northern hemisphere and avoid toxic, oxygen-rich water near the surface of the sea by means of internal magnets called magnetosomes. Since these magnets always point towards the north pole, they function, under normal conditions, as infallible indicators that are totally independent of the condition it is their function to indicate. However, the magnetosome can obviously be fooled by a magnet. Is this, Dretske asks, a primitive form of misrepresentation? Only if you accept that the function of the magnetosome is to indicate the whereabouts of oxygen-free water. But why describe its function in this way? Why not say that its function is to indicate the direction of geomagnetic north, or simply of magnetic north? If I need vitamin C, my perceptual system should not be automatically credited with recognising objects as containing vitamin C, just because it supplies me with the information required to satisfy that need. Representing things internally as lemons and oranges will do quite nicely.

The determination of a system's function must take account of how the system actually performs that function. The magnetosome is a magnetotactic sensor, not a chemotactic one, and if we choose to describe the function of the sensor in this more modest way, we no longer have an example of a system with misrepresentational powers. It requires more complexity to get genuine misrepresentation. Dretske advises us to imagine a system that has more than one way of detecting the presence of a toxic substance F. The representation of F may be triggered by any one of the alternative stimuli. It does not stand in a one-to-one relation with a specific proximal stimulus. In other words, it becomes legitimate to say that its function is to signal the distal cause, rather than the proximal stimuli, and that it misrepresents this distal cause when one of the mechanisms is fooled.

Or does it? It is still possible to object, Dretske concedes, that the representation has a *disjunctive* proximal cause (either f_1 *or* f_2 *or* f_3). But now take an organism that can learn by association. A conditioned stimulus can come to stand for the presence of F. What the representation means will depend on the individual's learning history. There is no time-invariant meaning for the representation, no proximal stimulus which, over time, we could take to be its function to indicate. So, if we want a time-invariant function for the cognitive mechanism, we *must* think of it, not as indicating the nature of the proximal, or even the distal stimulus, but as indicating the condition F for which the various stimuli are signs. At this level you do have a genuine capacity for misrepresentation.

Dretske's argument is a perfect example of the tensions between functional concepts borrowed from computer science and the attempt to naturalise meaning through natural selection. The basic problem lies in his determination to naturalise a sense of function that cannot in fact be naturalised. Is it the function of the magnetosome that exists in the oxygen-shy bacterium to point to geomagnetic north, or to indicate the presence of oxygen-free water? Clearly, from an ecological point of view, its function is to ensure that the bacterium keeps heading towards oxygen-free water. But if we examine the bacterium as we might examine a product of engineering design, and assume that it works by passing information from one component to another, then we must conclude that the information passed from the magnetosome to the efferent centres of the bacterium has the function of signalling geomagnetic north. And it is this information, together with the functional role assigned to it by our causal/informational account, that Dretske wishes to naturalise. Dretske pretends that the discrepancy he has uncovered is in fact a boon—that it provides a starting-point from which he can build to a full-blown naturalisation of misrepresentation. But here he is in my opinion evading the issue.

Computer science tells a causal/informational story. Dretske believes that his acceptance of the representational theory of mind commits him to deploying internal representations in that way. In order to ground meaning by a causal chain that might have come about through natural selection, he posits various types of meaning and increasing degrees of complexity to prove that it really is possible for an internal representation that is a product of evolution to falsely represent states of the world. But Dretske's argument from complexity is unconvincing. It cannot establish a natural correlation between an internal representation and its object-in-the world, rather than between that internal representation and a more proximal stimulus.

This is the problem that chiefly exercises Sterelny (1990). He discusses various causal relations that have been suggested and notes that they all run into the problem of referential ambiguity. The causal chain that is assumed to link the mental representation to its object-in-the-world turns out to be long and complicated, both as regards the formation of concepts, and with respect to particular instances of their use. Why is my concept of a tiger a concept of tigers rather than of mammals or tigers-in-zoos, or even of keeping-tigers-in-zoos? A causal account of concept formation must make clear how concepts are generalised beyond the stimulus set encountered by the subject, but generalised only to the proper degree.

On the other hand, what defines the stimulus set implicated in a particular instance of representational use? As Sterelny points out, the causal chain posited by this type of explanation stretches back through a sequence of representational stages "inside the head", to the retinal image of a tiger, to a structure of ambient light which the tiger produces, to various tiger surfaces, and finally to the tiger as object-in-the-world. Why isn't my concept of tiger a concept of tigerish retinal projections, or of a certain configuration of ambient light? What legitimises the link between my internal representation of a tiger and tigers-in-the-world?

Sterelny notes that authors like Dretske and Millikan have appealed to natural selection to solve these problems. Our perceptual systems are designed to maintain a constancy between percept and the perceived world, even across a great variety of proximal stimuli. The stable correlation is between object and concept, not between the concept and its sensory intermediaries. Sterelny objects that this is fine for simple, isolated, and presumably innate structures like the frog's fly-detector or the bacterium's magnetosome, but that it will not work for propositional attitudes. Most human beliefs, he argues, have not been around long enough to be the products of a selective process. Few of them can be innate. An adaptionist "grounding" of internal representation requires that an evolutionary rationale be found for the causal link between every instance of representation and the corresponding object-in-the-world. But certain beliefs may simply be side-effects of something else. Most concepts do not even have a clearly identifiable behavioural consequence that could have caused them to be selected for. Can it really be the *natural* function of some neural states to indicate the presence of kitchen utensils or playing cards?

Sterelny concludes that it is possible to give a teleological explanation for a cognitive mechanism, but not for the *products* of that mechanism. Our beliefs and desires relating to playing cards are the products of a general purpose system, and because of that they interact. It is not possible to define the content of such beliefs by building up from representations of naturalised features. The referent of a particular concept is to a large extent determined by its relation to other concepts. This threatens to make the causation of behaviour holistic, and Sterelny wishes to steer clear of a purely holistic account of content. He argues that it would make causation utterly idiosyncratic. There would be no true intentional generalisations, and generalisation, allowing taxonomy, is the first requirement for a scientific explanation.

Sterelny's solution involves a basic set of input modules that are innately specified, providing a semantic foundation of primitive concepts. This enables him to avoid the problems of holism. (A causal explanation of the concepts produced by such modules does not require reference to other concepts, and the concepts produced by the modules will not be idiosyncratic but species-specific.) It also, in Sterelny's opinion, avoids most of the teleological pitfalls he has sign-posted earlier in his discussion. Sterelny believes that modular representation extends beyond representations of such basic features as shape and colour. There are likely to be modules for the recognition of faces and phonemes, for instance. The candidates for modular representation are features that were biologically important to our ancestors and are also reliably detectable by a special-purpose mechanism. All such modules represent objective features of the world, because that is what they were selected for. Sterelny argues that this deflects any attempt to equate his system with traditional concept empiricism. The properties represented by his modules are not sensory properties, as posited in classical empiricism, but properties *of the world* which those modules have been specifically selected to represent. He further defends his proposal by claiming that his nonbase concepts do not need to be defined in terms of the base concepts. Many of them will " ... depend in part on causal links between concept and referent. I am not looking for definitions of the nonbase concepts, so I need not worry about the fact that there are no such definitions" (Sterelny, 1990, p. 140).

In view of the difficulties involved in specifying causal links (to which he himself has repeatedly drawn attention), it is not clear why Sterelny believes that he has now provided a satisfactory solution to his problems. His innate modules have a superficial appeal, but they will not "buy" him the causal explanation he is after. Calling something a face-recognition module begs the question of how such a feat is actually accomplished. Sterelny makes vague references to the final stage of Marr's (1982) object-recognition model, but he wisely refrains from going into too much detail. This part of Marr's proposal has never been made to work, and it is almost certain that any attempt to produce a data-driven account that builds from 2-D retinal projections to full-blown, context-free and viewpoint-independent internal representations of objects-in-the world is doomed to failure. Appeals to low-level perceptual modules in support of such a causal/informational account require solutions to the segmentation problem, the 2D-to-3D-conversion problem, the problem of indexing some sort of "library of shapes", and the problem of what to do with the internal representation once it has been "retrieved".

Self-contained, encapsulated mental modules became popular as a result of Marr's (1982) successes with low-level vision. Marr was one of the first to see that computational formalisms by themselves could not carry the weight of a scientific explanation of mental phenomena. This led him to conclude that, in an information-processing view of the mind, internal representations must share much of the burden: that they should be accorded a more active role in explanation than that of mere tokens in a computational process. A computational theory, as Marr saw it, must begin by defining the problem in terms of *what* is being computed and *why,* and the only principled way to do this was by positing the appropriate internal representations: "A representation is a formal system for making explicit certain entities or types of information, together with a specification of how the system does this" (Marr, 1982, p. 20).

Marr's notion of "making explicit" has nothing to do with "making available to consciousness". He repeatedly warned computer scientists against tackling conscious phenomena. Unlike many other researchers in traditional AI, he was keenly aware that even such apparently straightforward activities as mental arithmetic are likely to be subtended by mechanisms that are entirely different in kind from the surface rules they appear to follow. Making explicit, in Marr's terms, is an unconscious process of selection, of extracting form from apparent chaos, or rather, since his research was concerned with the phenomenon of object recognition, of recovering shapes that are underdetermined by the raw data contained in a retinal projection. The specification of how a system does this requires a set of "primitives": elementary units of the type of information that needs to be made explicit. The primitives of a representation determine its "scope"—what can and what cannot be represented by the particular representation—and they also ground the computational theory in the real world, since the nature of these primitives has been determined by the creature's evolution in its natural environment. They represent the constraints imposed on the computation by the animal's ecological niche. Everything that cannot be made explicit in terms of these primitives will be lost in the description that results after the representation has been applied. Mental representations are therefore not inert tokens that are pushed around by computational processes; they are not simply data structures to be modified and transformed as required by these processes. In a very real sense it is the system of representation that defines the computational processes.

Marr clearly felt that by introducing this concept he had liberated explanation in AI from its dependence on computational formalisms. Process was no longer an abstraction, defined in terms of the Turing machine, or heuristic search, or production systems; it could be defined as transformation from one internal representation into another, characterised by the primitives of the successive representations. Internal representations themselves were no longer computational artifacts, such as Newell and Simon's (1972) property lists or Minsky's (1975) frames; they were true explanatory entities defining *what* was being computed and *why,* as well as *how,* because they had been shaped by natural selection to make explicit only certain aspects of the available information and to recover that information from an impoverished 2-D projection on the retina.

Does Marr's approach provide us with genuine explanatory kinds for a psychological theory? Does it bridge the semantic gap between selective information content in Shannon's sense and information about the world that can serve to guide a creature's behaviour? The key to answering that question lies in Marr's repeated insistence that mental phenomena must be seen as *solutions to computational problems.*

Marr realised that a theory of information-processing in natural creatures cannot depend wholly on computational formalisms and abstract task analysis. His concept of internal representation is an important attempt to anchor mental processes in the real world by introducing environmental constraints (what is being computed and why). But since he is wedded to an information-processing view of explanation, he must continue to think in terms of solutions to problems. This involves him in two major assumptions that were already signposted by Dennett (1969) as the necessary concomitants to a computational approach:

1. That evolution has worked as a rational designer to discover optimal solutions (from an engineering point of view) to the problems posed by the creature's ecological niche. This in turn presumes that the ecological niche, as it can be observed today, has been around long enough to constitute the determining factor, and that the history of successive adaptations has not imposed its own logic.

2. That the "problems" posed by the environment can be unambiguously determined. How do we decide what the computational problems really are? Does it make sense to talk about a "problem" of motor control, or the "problem" of object recognition from an evolutionary perspective?

Introducing natural constraints into solutions to problems defined in computational terms does not guarantee that the resulting explanatory entities will be illuminating natural kinds for a psychological explanation. The formal method of explanation based on Turing's notion of computability dictates the character of the explanatory entities, even if the programmer manages to avoid the obvious pitfalls of "mimicry" that Marr (1982) criticised in Newell and Simon (1972) and Minsky (1975). Nature does not solve problems; it produces creatures by the undirected, opportunistic process of natural selection. To discover natural kinds that accord with an evolutionary account, it is necessary to examine the historical contingencies of this process, as well as the mechanisms of ontogeny and development that result in adult behaviour (Hendriks-Jansen 1996). Natural selection works on behavioural outcomes, not directly on mental or neural structures. If we wish to naturalise knowledge through evolution, we need to isolate putative entities of behaviour that would confer differential fitness and relate these to the underlying mechanisms. Our investigation will have to take an ethological approach, focusing on natural behaviour in natural settings rather than on formally defined tasks performed in fully specified task domains. Similarly, it cannot restrict itself to adult behaviour. Although adult behaviour is an important determinant for the survival of a species, the behaviour of adult human beings is the result of complex developmental processes that involve interactions between early behavioural propensities and a cultural environment. Development, no less than evolution, works by indirection, building on behavioural outcomes of previous and often unrelated processes. The underlying mechanisms of adult behaviour can be understood only by examining the history of these processes.

To sum up, one of the main projects in cognitive science and cognitive philosophy has been to naturalise putative internal representations corresponding to the syntactic tokens of a physical symbol system as defined in classical AI. The natural kinds of such systems (objects, properties and events) have traditionally been derived by conceptual analysis performed on folk-psychological descriptions of adult human behaviour in tightly circumscribed and exhaustively specified task domains (Newell & Simon 1972; Minsky 1987). The informational problem has then been defined as that of establishing correspondences through a causal/informational account between such functionally specified internal representations and the objects, properties and events of the world. Natural selection has been seen as the best hope for legitimising such correspondences. Marr's theory of vision, leading to the discovery of separate neural channels for depth, movement, colour, etc. further recast the problem as one of informational "binding"—a problem of reassembling the various data-streams into unitary entities corresponding to entities in the world. Explanations of consciousness have emerged as by-products of such causal/informational accounts. I have argued that this model of unconscious processing is difficult to sustain if we accept that natural selection is our best hope for naturalising explanatory entities for human behaviour. In the remainder of this paper I shall propose a different conception of mental phenomena and argue that this provides better prospects for an explanation of phenomenal consciousness.

3 Mind as Interactively Emergent Patterns of Situated and Embodied Activity

In Hendriks-Jansen (1996) I put forward an alternative explanation of human behaviour that draws on situated robotics, ethology, and recent discoveries in developmental psychology. I suggest that human infants are born with species-typical activity patterns that have been selected for their power to engage the attention of adults and enable the infant to develop systematicity through interactions with cultural artifacts. These activity patterns are thus specifically adapted to an intentional and cultural environment. They have been favoured by natural selection because human caregivers interpret certain gestures and facial expressions as evidence of belief, desire, and purpose, and because the human environment is an environment of language and artifacts that requires and gives meaning to certain canonical forms of behaviour. There is now extensive evidence of such species-typical activity patterns, and of the role they play in setting up apparently meaningful "dialogues" with adults (Bullowa, 1979; Bruner, 1982; Fogel & Thelen, 1987; Miller & Jusczyk, 1989; Schaffer, 1977; Thelen, 1981; von Hofsten, 1984). The mechanisms involved depend on the fact that the caregiver is led to believe that her infant is already an intentional being, who has goals, beliefs, and desires that mediate his actions.

However, a scientific theory of the infant's behaviour does not require positing such mental states. Complex and apparently purposive behaviour can arise by interactive emergence from "mindless" activity patterns operating within the cultural and intentional environment by which they were selected, in the same way that complex behaviour like wall-following has been shown in situated robotics to emerge from the interactions of various low-level reflexes operating within a structured environment for which they were fine-tuned by the robot's designers (Hendriks-Jansen, 1993, 1994; Mataric & Brooks, 1990; Pfeifer & Verschure, 1992). Mothers are biologically and socially primed to interpret their infants' smiles, coos, and primitive gestures as meaningful signals and incorporate them into patterns of turn-taking that gradually develop into more elaborate "conversations" and games. Important developmental milestones such as protodeclarative pointing, shared attention to objects, "book-reading", and the development of holophrastic speech, can be shown to emerge within and from the dynamic "scaffolding" provided by such dialogues and games (Hendriks-Jansen 1996). Most of the early activity patterns that kick off these processes become submerged or disintegrate before the end of the first year. Their only reason for existence appears to be that they enable human infants to be "bootstrapped" into their cultural and intentional species-typical environment.

An evolutionary explanation of human behaviour and mental phenomena along these lines suggests that consciousness is not a unitary mechanism that can be given a singular adaptive explanation. There is no specific physical, neurophysiological, or "software" ingredient that human beings inherit through their genes and that makes them conscious. Nor is consciousness a matter of installing a virtual architecture in an exceptionally large and plastic brain (Dennett 1991). Consciousness of the specifically human variety emerged during the course of our evolutionary history, and it emerges during the early years of each individual's life, through interactions involving species-typical activity patterns and our specifically human environment. The mechanisms that enable us to be bootstrapped into an intentional and cultural world are likely to be implicated in the emergence of consciousness as well. In a very basic sense, the explanation for consciousness cannot be found in the head: it requires an historical approach that embraces the environment-infant-caregiver system as a whole.

The most fruitful descriptive framework for the spatial and temporal entities that are implicated in the type of explanation I have proposed is dynamical systems theory. In the dynamical approach (see Port and van Gelder 1995, Thelen and

Smith 1994), the cognitive system is assumed to comprise the body with its sensors and effectors as well as the mind or brain, and it is often considered helpful to the include the agent's species-typical environment within the same dynamical system. All of these components are assumed to be in continuous interaction, changing and evolving over time. Rather than being conceptualised as information that is input into the system and converted into internal representations to be processed and stored, the environment is said to "perturb" the system, altering the parameters that shape the creature's behaviour. The complex behaviour of a dynamical system results from the fact that it obeys a dynamical law or evolution equation, which in turn depends on its perceptual and behavioural history. Such a system may therefore be said to store "information" about viable forms of behaviour in its species-typical environment, but this information does not necessarily represent features or objects in the world, nor does the system's "use" of that information in real-time behaviour amount to "information processing".

Dynamical systems theory assumes that the order and structure of behaviour emerge only during execution. They are nowhere prescribed within the system, and although the species-typical activity patterns that kick off the processes of development are inherited, there is no description of them in the creature's genes (Oyama 1993; Thelen and Smith 1994). Spatial and temporal structure emerge spontaneously in dynamical systems through the interactions of low-level components that include the morphological, kinetic, and sensory characteristics of the creature's body, as well as regularities in its environment. To quote Thelen and Smith (1994):

Although behaviour and development appear structured, there are no structures. Although behaviour and development appear rule-driven, there are no rules. There is complexity. There is a multiple, parallel, and continuously dynamic interplay of perception and action, and a system that, by its thermodynamic nature, seeks certain stable solutions. These solutions emerge from relations, not from design. When the elements of such complex systems cooperate, they give rise to behavior with a unitary character, and thus to the illusion of structure. But order is always executory, rather than rule-driven, allowing for the enormous sensitivity and flexibility of behavior to organize and regroup around task and context (p. xix).

A developmental perspective alters our view of the final outcome. "Solutions" emerge first in specific contexts and in real time from the interactions of an embodied creature with its species-typical environment—they do not derive from some internal formulation of the "problem". Order is therefore executory rather than rule-driven. The fact that our horse-related behaviours and thoughts are so precisely and sensitively lined up with horses in the world may not require positing horses-in-the-head and their rule-like manipulation. A careful study of the development of these behaviours might uncover a multiple, parallel, and continuously dynamic interplay of perception and action that produces such regularities without the need for any rules or internal representations at all. The developmental approach obviates the need for a design stance, both as a means of determining functional components and as a means for grounding these components through natural selection. As I have argued elsewhere (Hendriks-Jansen 1996) and has been argued from various academic viewpoints (Elman et al. 1996; Johnstone 1982; Lewontin 1982; Oyama 1985), good explanations of development offer the only means of providing an evolutionary grounding for adult capacities like having the concept of a horse.

Knowledge is reconceptualised within this framework as the skill to act appropriately in all relevant situations. It thus becomes an interactively emergent, dynamical entity that "exists" only in the sense that it is apparent from an observer's point of view when the creature behaves appropriately in context. Knowledge does not exist as propositional content prior to and separate from behaviour, stored somewhere in the creature's mind or brain. The crucial problem with the traditional view of knowledge, as Thelen and Smith (1994) point out, is that it makes it difficult to explain how generic knowledge about the world is applied to concrete instances. Stored knowledge and the current task need somehow to be fused if knowledge is to be of any use. How can knowledge concerning classes of objects and events that has been accumulated from past experience and converted into propositional form be brought to bear on the specifics of the task at hand? Dynamical systems theory provides a straightforward answer to this problem. Since knowledge does not involve internal representations of facts that need to be retrieved, but is the interactively emergent ability to act appropriately in all relevant situations, it is always "on line". Expectations of up-coming events and the ability to recognise objects, properties, and events and respond appropriately are simply the continuation of the current trajectory through state space, which has been made into an attractor by past experiences in similar situations.

If the main problem with the traditional view of knowledge is that of explaining how generic knowledge held internally by a creature can be applied in specific, context-dependent situations, the main problem with the dynamical systems view is the converse one of explaining how propositional knowledge can be assimilated by a tightly-coupled, embodied system. Pedagogy depends on the transmission of knowledge by propositional means (Premack 1984). Adult human behaviour takes many forms that cannot be learned from spontaneous, tightly-coupled interactions with other human beings or artifacts. It is impossible to teach a person to drive in this way, let alone to transmit the laws of physics or the principles of business administration. In order that a student may learn to shift gears and handle the steering wheel appropriately, she needs to be given experience of the kinetics and dynamics involved. The mind and body have to be set moving in approximately the right manner, so that she may experience the perception-action loops that will eventually make the steering wheel and mechanism "transparent" and learn to hear and feel the speed at which an engine demands shifting to a higher gear. The appropriate attractors can only become established through the performance of embodied, context-dependent activity, and as Kuhn (1970) insisted, this applies to the acquisition of new paradigms in science as much as it does to learning when to shift gears. In order that the new paradigm may be internalised and truly understood, the student needs to work through a large number of exemplars: paradigmatic problems and experiments that give her a "feel" of what is correct and what is not. But the problem remains: the only way to get the student acting so that the mind and body can learn is by giving her explicit instructions framed in terms of objective, task-related facts. How does a dynamical system assimilate such formal descriptions and convert them into context-sensitive, embodied skills?

My suggestion is that this is what consciousness is "for". It allows propositional knowledge to make contact with the parameters and variables of the dynamical system. Consciousness provides the bridge between the explicit, atomic facts used as scaffolding for the acquisition of new knowledge and the situated, interactively emergent activity that takes over when the knowledge becomes incorporated as skill. It enables a creature to break free from species-typical perception-action loops and to learn radically new mind-body-environment attractors.

4 Consciousness as a Link Between Sensorimotor and Linguistic Attractors

One of the outstanding characteristics of subjective sensory experiences is that they involve active engagement with the environment. The main exceptions appear to be smell and hearing, but I suspect that closer inspection will reveal characteristic perception-action loops for these modalities as well. Vision is a highly active process. Eyes that are prevented from moving across a visual scene quickly lose all receptivity as the result of adaption (Yarbus 1967). Congenitally blind people can learn to "see" by means of tactile projections on the skin of their backs or midriffs, provided they have control of the focusing and panning mechanisms of the video camera that records the images to create the tactile projections (Back-Y-Rita 1972). In the absence of such control, they experience sensations on their backs or bellies, but when they are able to focus, pan, and zoom those sensation become "transparent", and they achieve conscious impressions of objects situated in the three-dimensional world "out there". Sighted people use saccades (voluntary and involuntary), smooth tracking, convergence and divergence of the eyes, and focusing of the lenses, as well as head movements to explore a visual scene (Yarbus 1967). Each of these activities involves complex integrations of afferent and efferent nerve impulses to produce muscle coordinations that work in tandem with visual processing

(Wolf 1984). Most of this exploratory activity is performed unconsciously.

Land (1977, 1986) has demonstrated experimentally that the subjective experience of colour is not correlated with specific wave-lengths of reflected light, but involves saccadic movements across the visual field and pair-wise comparisons of the intensities in three wave-bands at a large number of boundaries. The perception of colour constancy, like object perception, is an active process, with its own kinetics, dynamics, and attractors.

It has long been known that conscious perception of texture and proprioceptive awareness of one's own body involve characteristic patterns of movement (Katz 1925; Kreuger 1970). Katz pointed out that to experience the hardness and grain of a surface it is necessary to run one's fingers across it. Merely resting the hand on the surface does not produce the sensations by which specific materials and finishes are recognised. In a recent study Turvey and Carello (1995) showed that wielding utensils or tools and probing with an instrument to investigate various aspects of the environment may similarly be modelled as dynamical systems. These activities set up forces and movements that co-vary over time, but when we engage in them we do so with the aim of discovering invariant properties of the world or invariant body-movement relations. We shake a stick to gain a sense of its length and weight distribution relative to our grip; we "heft" a bag of flour to gauge its weight; we perform characteristic patterns of movement with our wrists and elbows to determine the size of a hole by using a probe.

In all these cases, the kinetics and dynamics of our actions are "transparent". Our conscious awareness is not of these time-locked movements and forces, but of the parameters of the dynamic attractors that are set up by our movements. Similarly, we are not aware of our eye movements as we probe the objects in front of us with our eyes to gauge their shape, size, and colour, and we are generally not aware of the movements of our hands as we explore the textures and details of surfaces. *Our conscious sensations in these modalities pick out the invariants of the dynamical systems that we set up by our characteristic investigative movements.* These parameters are nowhere represented inside the mind or brain. They emerge only when the exploratory activity is performed. But we do have public concepts, whose meanings have been established through the totally different class of activities involved in linguistic use, that correspond to these parameters picked out by subjective experiences.

In Hendriks-Jansen (1996) I argue that the development of language in human infants is made possible by a number of prelinguistic activity patterns that appear to be specifically adapted to serve as potential vehicles of content. Papousek & Papousek (1977) point out that mothers make a clear distinction between their infants' "fundamental vowel-like sounds" (cooing and grizzling) and their more advanced "syllabic sounds", which begin to emerge between the ages of twenty and thirty weeks. The former continue to be taken as signs of happiness or discomfort, requiring practical responses from the mother, while the latter are treated as occasions for proto-linguistic interactions with the child: "Parents often imitate such syllabic vocalisation, using the pauses between individual bursts and thus giving the interaction the semblance of a dialogue, pleasing to both partners. However, below seven to nine months the syllabic sounds bear the character of incidental and passing products of the developing speech organs and do not represent any objects or situations."(Papousek & Papousek 1977, p. 80)

Between nine and eighteen months, variations in melody, rhythm, and stress become clearly recognisable in the infant's vocal strings. Parents unhesitatingly attribute speech acts to their child, though his productions will at first contain no recognisable words at all. Games based on melodic sequences and particular syllables become established, producing proto-words associated with specific interactive situations.

Speech production and perception are thus made possible by a number of prelinguistic activity patterns that appear to be specifically adapted to serve as potential vehicles for content. From the beginning, the vocal behaviour that will eventually be appropriated for the production of contentful sentences is clearly differentiated from the vocal expressions of emotional and physiological state. A species-typical capacity to produce a variety of language-like sounds, which matures gradually during the first year of life and is exercised spontaneously by the infant, supplies the raw material from which the caregivers can shape primitive dialogues. These early species-typical activity patterns do not constitute anything like an innate ability to talk, nor can they be viewed as evidence of an underlying grammatical competence. They provide the means for initiating and sustaining vocal interactions with the caregivers, which serve as scaffolding that permits the infant to practice the production of speech acts. Interactive timing, clause separation, the rhythms, stresses and intonations associated with commands, statements and requests are all extensively practised before the child learns his first words. What sustains and shapes this activity is the interactive context of mother-infant dialogue.

The use of recognisable linguistic units begins with one-word sentences between the ages of twelve and eighteen months (the so-called holophrastic stage) The nature of the intended speech act (whether it should be interpreted as a command, a statement or a request) is conveyed by prosody and gesture, and it is clear that much of the meaning is supplied by the context in which the child performs them and by the interpretative skills of the parents. Nelson (1974) draws attention to the fact that the outstanding characteristic of the child's earliest words is "their reference to objects and events that are perceived in dynamic relationships." She points out that the world of the young child is not a static one of well-defined objects, properties, and features; it is made up of complex dynamic events. Theories of concept formation that assume that concepts are constructed from combinations of primitive, static cues need to explain how the child extracts such cues from the dynamic perceptual array before reassembling them into internal representations of concepts.

Nelson (1974) calls this the "abstraction theory" of concept formation. Classic abstraction theory posits that we detect similarities in objects, events and situations by abstracting from them the features they have in common. As I argued in Hendriks-Jansen (1996), such meaning primitives prove difficult to pin down. No predefined, closed set of atomic features is ever likely to capture all of the metaphoric uses for a specific term that human beings are able to think up. Nelson (1974) cites experimental evidence showing that young children perform poorly at concept formation under experimental conditions which, from the point of view of the abstraction model, ought to be ideal. On the other hand, they are notoriously clever at attaining concepts under "natural" conditions, which impose almost insurmountable obstacles when viewed in terms of that model. Early concept formation clearly requires a more dynamic and interactive explanation. What cognitive science calls "systematicity" (the ability to wield a concept in all appropriate instances that do not involve category mistakes) does not emerge originally as a result of correctly combining internally represented features; it begins from an ability to act appropriately in a variety of contexts involving the object, property, or relation that the public concept picks out.

Bruner (1976) describes the emergence of systematicity in early infant behaviour:

Much of the child's early mastery is achieved in oft-repeated tasks. The child spends most of his time doing a very limited number of things. There is endless time spent in reaching and taking and banging and looking, etc. But within any one of these restricted domains, there is a surprising amount of 'systematicity'. It consists of two forms of 'playful' activity: in one, a single act (like banging) is applied to a wide range of objects. Everything on which the child can get his hands is banged. In the second type, the child directs to a single object all the motor routines of which he is capable—he takes hold of the object, bangs it, throws it on the floor, puts it in his mouth, puts it on top of his head, runs it through his entire repertoire (Bruner, 1976, p. 200).

We can see here the emergence of loosely knit sets of action-perception loops that may be identified as the ultimate grounding of concepts. Holophrastic use of language acts as a bridge between concepts established in this way as attractors of an embodied system and concepts as proper linguistic entities. Before syntax and combinatorial semantics emerge, the single-word sentence uttered in a specific context provides a holistic means of referring to entire situations, with all the activities that are habitually performed in them. The one-word sentence is able to serve as a vehicle of content because the child and his parents have a shared history of experiences of the situations and associated activities, which is brought into the well-established interactive context of the performance of speech acts. But such holophrastic utterances still impose severe limitations on the speaker's ability to refer to anything beyond the immediate context. In order to move beyond this stage, the child must learn to detach the linguistic object from the tight embrace of its grounding, so that it may be used combinatorially as an atom of meaning, with abstract markers for the relations into which it can enter. Public language provides the scaffolding for this next stage of development. The public term, with its socially established meaning that is continually being renegotiated and reinforced by verbal interactions, acts as a point of reference for the situated skills of individual language users.

Language constitutes a continually evolving public resource that we all share and help to maintain. Linguistic terms and structures are like other human artifacts and tools: their shared public meanings have evolved by successfully eliciting co-operative interactions between speakers and interpreters. But each individual needs to develop the ability to use these terms in purely linguistic contexts. Millikan (1984) talks of "internal programs" that iterate the term in the context of "inner sentences". She posits that there exist internal programs that iterate terms from dictionary-type definitions (explicit intentions), and others that do so by working directly from perceptual data (implicit intentions). To save us having to test the validity of each individual term or sentence by trial and error in the real world we have, Millikan suggests, an in-built "consistency tester". She draws an analogy between this consistency tester for public terms and our ability to focus our vision. Infants must have an innate inclination to bring an object that appears in front of their eyes into focus, and an innate skill that enables them to do this. In the same way, human beings must have an in-built inclination to focus their concepts, and the mechanism for doing so is the consistency tester. We generate a variety of internal sentences containing the term, run them through the consistency tester, and in that way bring the corresponding concept into focus. Knowing how to focus on unities in nature is a skill that was put into us by natural selection, since we evolved to deal with the structure of the world.

I have argued that such a grounding for concepts is difficult to sustain. Far from starting out with an ability to focus on unities in nature, which then provides the basis for generating internal concepts corresponding to public terms, human infants need to *learn* to perceive objects, properties and natural events as spatial and temporal unities. Even the ability to focus the eyes on specific objects that Millikan assumes to be "innate" and uses as her analogy for the consistency tester has an intricate developmental history that almost certainly involves interactions with caregivers (Hendriks-Jansen 1996; Johnson 1993). Systematicity is acquired through situated, embodied interactions between early species-typical activity patterns and an intentionally and culturally structured world by which they were selected. There are no internal tokens or structures that correspond to pre-specified unities. The world is not a collection of task domains pre-registered into objects, properties and events. Similarly, there are no internal programs or inner sentences that enable the child to focus on the unities of her linguistic environment. Language, too, is developed in situated, interactive contexts. The consistency tester that establishes the concordances between linguistic entities defined in terms of their public use in "language games" and our private concepts as loosely knit sets of perception-action loops is phenomenal consciousness itself, conceptualised as the invariants of dynamical systems that are set up by our characteristic exploratory behaviour in the sensorimotor and linguistic domains.

Do the public linguistic entities "produce" our conscious experiences, in the sense that they draw our attention to and cause us to try to re-evoke the invariants produced by particular perception-action loops, or do the subjective experiences generated by the invariants of these activities teach us the "meanings" of public concepts? I believe that the actions between these two different classes of dynamical system are not one way. The essence of causal explanation in dynamical systems theory is multiple causality resulting in dynamic equilibria. Order and structure emerge through the interactions of many different components and processes, and various dynamical systems may interact to produce higher forms of emergent structure. The correlations that are set up between language and perception come about through the processes I described in an earlier section. We are able to develop into fully conscious human beings because we have species-typical activity patterns that draw us into tight coupling with other human beings and man-made artifacts. This cultural and intentional environment provides scaffolding for our exploratory activities and enables the correlations between perceptual and linguistic attractors to be set up. Fully developed consciousness does not, on this account, direct or cause behaviour. The causal mechanisms of behaviour are unconscious; they are the low-level interactions between the neurophysiological, sensory-motor, and environmental variables and parameters of our dynamical systems. But because consciousness plays a part in linking together our sensory and conceptual attractors, it makes possible the explicit propositional scaffolding that allows us to articulate and "debug" our own behaviour (Hendriks-Jansen 1996). Consciousness helps us to "keep an eye on the ball and follow through," as Dennett (1984) so memorably put it.

5 Conclusions

I have argued that the project to naturalise a causal/informational account of mind based on internal representations by appealing to natural selection runs into fundamental conceptual and methodological problems. Information processing does not provide acceptable explanatory entities for a naturalised theory of mind—it does not provide a satisfactory explanation even for the so-called "easy" problems of mind (Chalmers 1996). I have proposed an alternative, historical and developmental account that draws on situated robotics, dynamical systems theory, ethology, and recent discoveries in developmental psychology. This suggests that human infants are born with (or develop soon after birth) species-typical activity patterns that have been selected by a specifically human environment of man-made artifacts, language, and conspecifics who interpret behaviour in intentional terms. Complex and apparently purposive behaviour arises by interactive emergence from the simultaneous operation of these activity patterns within a dynamic developmental context. The most fruitful descriptive framework for the temporal and spatial entities that are implicated in this type of explanation is provided by a dynamical systems approach.

The complex behaviour of a dynamical system results from the fact that it obeys a dynamical law. It may therefore be said to contain "information" about viable forms of behaviour in specific contexts, but this information does not represent objects or properties of the world, nor does the system's "use" of such information in real-time behaviour amount to information processing.

One of the outstanding characteristics of phenomenal consciousness is its dependence on active engagement with the environment. Characteristic action-perception loops associated with various perceptual modalities set up forces and movements that co-vary over time. Our conscious awareness is not of these time-locked movements and forces, which tend to be "transparent" to the subject who performs them, but of the invariant parameters of the dynamical systems that are set up by these characteristic exploratory movements. These parameters are nowhere represented in the brain. They emerge only when the specific exploratory movements are performed.

On the other hand we have public language, whose terms derive their meaning from public use. The core ability to engage in linguistic interactions is developed as situated activity as described above. Interactive timing, clause isolation, the rhythms, stresses and intonations that characterise various speech acts, are all acquired before the infant learns his first word. Similarly, his personal concepts are grounded in the experience of concrete situations and the activities habitually performed in them. The holophrastic stage of language development acts as a bridge between personal concepts established in this way as attractors of the embodied system and concepts as public linguistic entities. Single-word sentences impose severe limitations on the speaker's ability to refer to anything beyond the immediate situation. They require a shared history of experiences with the interpreter to make sense of the context. The child needs to detach the linguistic entity from its sensorimotor context in order that it may be used in language games, where meaning is defined by the relation of the concept to other concepts and by combinatorial rules. Phenomenal consciousness provides the scaffolding to do this.

Such an account will not satisfy anyone who is looking for a material or computational substrate of consciousness—a definition that tells us what consciousness *is* in causal/informational terms I have discussed mainly what consciousness is *not*, and I have speculated what it might be *for*. It is *not* an added feature or ingredient of informational content. The problem of explaining phenomenal consciousness has nothing to do with getting subjective experiences or qualia out of functionally and/or causally defined information.

References

[1] BACH-Y-RITA, P. 1972. Brain Mechanisms in Sensory Substitution. Academic Press. New York.

[2] BODEN, M.A., Ed. 1996 The Philosophy of Artificial Life. Oxford University Press. Oxford.

[3] BROOKS, R.A. 1991b. Intelligence without representations. Artificial Intelligence 47:139–159.

[4] BRUNER, J.S. 1976. On prelinguistic prerequisites of speech. *In* R.N. Campbell & R.T.Smith, Eds. Recent Advances in the Psychology of Language: Language Development and Mother-Child Interaction. 199–214. Plenum Press. London.

[5] BRUNER, J.S. 1982. The organisation of action and the nature of adult-infant transaction. *In* M. von Cranach & R. Harre, Eds. The Analysis of Action. 313-328. Cambridge University Press. Cambridge, UK.

[6] BULLOWA, M., Ed. 1979. Before Speech: The Beginning of Interpersonal Communication. Cambridge University Press. Cambridge, UK.

[7] CHALMERS, D.J. 1996. Facing up to the problem of consciousness. *In* Hameroff, Kaszniak & Scott. 1996. 5–28.

[8] CRICK, F. & C. KOCH. 1990. Toward a neurobiological theory of consciousness. Seminars in the Neurosciences 2:263–275.

[9] DENNETT, D.C. 1969. Content and Consciousness. Routledge, Kegan Paul Limited. London.

[10] DENNETT, D.C. 1984. Elbow Room: The Varieties of Free Will Worth Wanting. MIT Press. Cambridge, MA.

[11] DENNETT, D.C. 1987. The Intentional Stance. MIT Press. Cambridge, MA.

[12] DENNETT, D.C. 1991. Consciousness Explained. Allen Lane, The Penguin Press. London.

[13] DENNETT, D.C. 1995. Darwin's Dangerous Idea: Evolution and the Meanings of Life. Allen Lane, The Penguin Press. London.

[14] DRETSKE, F. 1986. Misrepresentation. *In* R.J. Bogdan, Ed. Belief, Content and Function. Clarendon Press. Oxford.

[15] DRETSKE, F. 1988. Explaining Behavior: Reasons in a World of Causes. MIT Press. Cambridge, MA.

[16] ELMAN, J.L, E.A. BATES, M.H. JOHNSON, A. KARMILOFF-SMITH, D. PARISI & K. PLUNKETT. 1996. Rethinking Innateness: A Connectionist Perspective on Development. MIT Press.Cambridge, MA.

[17] FOGEL, A. & E. THELEN. 1987. Development of early expressive and communicative action: reinterpreting the evidence from a dynamic systems perspective. Developmental Psychology 23:6:747–761.

[18] HAMEROFF, S.R., A.W. KASZNIAK & A.C. SCOTT, EDS. 1996. Toward a Science of Consciousness: The First Tucson Discussions and Debates. MIT Press. Cambridge, MA.

[19] HAMEROFF, S.R. & R. PENROSE. 1996. Orchestrated reduction of quantum coherence in brain microtubules: a model for consciousness. *In* Hameroff, Kaszniak, & Scott. 1996. 507–540.

[20] HARDCASTLE, V.G. 1996. The Binding Problem and Neurobiological Oscillations. *In* Hameroff, Kaszniak & Scott. 1996.

[21] HENDRIKS-JANSEN, H.J. 1993. Natural kinds, autonomous robots and history of use. *In* Proceedings of the 1993 European Conference on Artificial Life. 440–450. Brussels.

[22] HENDRIKS-JANSEN, H.J. 1994. In praise of interactive emergence, or why explanations don't have to wait for implementations. *In* R.A. Brooks & P. Maes, Eds. Artificial Life IV. 70-79. The MIT Press. Cambridge, MA. *Reprinted in* M.A. Boden, Ed. 1996. The Philosophy of Artificial Life. 282–299. Oxford University Press. Oxford, UK.

[23] HENDRIKS-JANSEN, H.J. 1996. Catching Ourselves in the Act: Situated Activity, Interactive Emergence, Evolution, and Human Thought. MIT Press. Cambridge,MA.

[24] JOHNSON, M.H. 1993. Constraints on cortical plasticity. *In* M.H. Johnson, Ed. Brain Development and Cognition: A Reader. 703–721. Blackwell. Oxford.

[25] JOHNSTONE, T.D. 1982. Learning and the Evolution of Developmental Systems. *In* H.C. Plotkin, Ed. Learning, Development, and Culture. John Wiley & Sons.

[26] KATZ, D. 1925. Der Aufbau der Tastwelt. Zeitschrift für Psychologie:Ergänzungsband 11:270. Quoted by Kreuger, 1970.

[27] KREUGER, L.E. 1970. David Katz's Aufbau der Tastwelt (The world of touch): A synopsis. Perception and Psychophysics 7:6:337–341.

[28] KUHN, T.S. 1970. The Structure of Scientific Revolutions. 2nd ed. University of Chicago Press. Chicago.

[29] LAND, E.H. 1977. The Retinex theory of vision. Scientific American 237:108–128.

[30] LAND, E.H. 1986. Recent advances in Retinex theory. Vision Research 26:1:7–21.

[31] LEWONTIN, R.C. 1982. Organism and environment. *In* H.C. Plotkin, Ed. Learning, Development, and Culture. John Wiley & Sons.

[32] MARR, D. 1982. Vision. Freeman & Co. New York.

[33] MATARIC, M.J. & R.A. BROOKS. 1990. Learning a distributed map representation based on navigation behaviors. *In* Proceedings of 1990 USA-Japan Symposium on Flexible Automation. 499-506. Kyoto, Japan.

[34] MILLER, J.L. & P.M. JUSCZYK. 1989. Seeking the neurobiological bases of speech perception. Cognition 33:111–137.

[35] MILLIKAN, R. 1984. Language, Thought and Other Biological Categories: New Foundations for Realism. The MIT Press. Cambridge, MA.

[36] MINSKY, M.L. 1975. A framework for representing knowledge. *In* P.H. Winton, Ed. The Psychology of Computer Vision. 211-277. McGraw-Hill. New York.

[37] MINSKY, M. 1987. The Society of Mind. Picador. London.

[38] NELSON, K. 1974. Concept, word, and sentence: interrelations in acquisition and development. Psychological Review 81:4:267–285.

[39] NEWELL, A. & H.A. SIMON. 1972. Human Problem Solving. Prentice-Hall. Englewood Cliffs, NJ.

[40] OYAMA, S. 1985. The Ontogeny of Information. Cambridge University Press. Cambridge, UK.

[41] OYAMA, S. 1993. The problem of change. *In* M.H. Johnson, Ed. Brain Development and Cognition: A Reader. Blackwell. Oxford, UK.

[42] PAPOUSEK, H. & M. PAPOUSEK. 1977. Mothering and the Cognitive Head-Start: Psychobiological Considerations. *In* Schaffer, 1977. 63–85.

[43] PFEIFER, R. & P. VERSCHURE. 1992. Distributive adaptive control: a paradigm for designing autonomous agents. *In* F. Varela & P. Bourgine, Eds. Toward a Practice of Autonomous Systems. Proceedings of the First European Conference on Artificial Life. 21- 30. MIT Press. Cambridge, MA.

[44] PINKER, S. 1994. The Language Instinct: The New Science of Language and Mind. Allen Lane, The Penguin Press. London.

[45] PORT, R.F. & T. VAN GELDER. 1995. Mind as Motion. MIT Press. Cambridge, MA.

[46] PREMACK, D. 1984. Pedagogy and aesthetics as sources of culture. *In* M. Gazzaniga, Ed. Handbook of Cognitive Neuroscience. 15–33. Plenum Press. New York.

[47] SCHAFFER, H.R., Ed. 1977. Studies in Mother-Infant Interaction. Proceedings of Loch Lomond Symposium. Academic Press. New York.

[48] SHANNON, C.E. & W. WEAVER. 1949. The Mathematical Theory of Communication. The University of Illinois Press. Urbana.

[49] STERELNY, K. 1990. The Representational Theory of Mind. Basil Blackwell. Oxford, UK.

[50] THELEN, E. 1981. Rhythmical behaviour in infancy: an ethological perspective. Developmental Psychology 17:3:237–257.

[51] THELEN, E. & L.B. SMITH. 1994. A Dynamic Systems Approach to the Development of Cognition and Action. MIT Press. Cambridge, MA.

[52] TURVEY, M.T. & C. CARELLO. 1995. Some dynamical themes in perception and action. *In* Port & van Gelder, 1995.

[53] VON HOFSTEN, C. 1984. Developmental changes in the organisation of prereaching movements. Developmental Psychology 20:3:378–388.

[54] WOLF, P. 1984. Saccadic eye movements and visual stability: preliminary considerations towards a cognitive approach. *In* W.Prinz & A.F.Sanders, Eds. Cognition and Motor Processes. Springer. Berlin.

[55] YARBUS, A.L. 1967. Eye Movement and Vision. Plenum Press. New York.

Analysis of Consciousness in Vedanta Philosophy

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Vedanta philosophy was developed in ancient India by the Aryan seers, saints and scientists. Consciousness is considered here, as the very core of our existence. It is the Absolute Operator which exists in both animate and inanimate objects, causing projections, preservations and destructions. Nature is conscious. The state of Consciousness is the Absolute state. It can be attained by an individual only by applying the principle of detachment. In this article, these philosophical tenets have been analyzed mathematically. It has been found that many conjectures and conclusions of Vedanta are fully in conformity with recent scientific investigations. This concord is the output of a logical analysis conducted in this work.

1 Introduction

Mathematics is a mode of thought. It is symbolic logic—always precise, stringent and rigorous. Based upon a set of assumptions, a mathematician derives certain conclusions such that the assumptions are not violated. This is what mathematics is all about. In applied mathematics, however, both assumptions and conclusions are often required to be validated by scientific observations and experiments. Scientists from almost every discipline, apply mathematics to develop, solve and evaluate models and analyze conclusions and predictions with precision and accuracy. Recently, biologists and psychologists are applying rather advanced techniques of mathematics to conduct very systematic research on several unexplained phenomena in bioscience and psychoses. Many of these topics were almost untouched by mathematicians in the past. These are happening primarily because mathematics is possibly one of the most powerful tools of science and scientists strongly believe that if there exists any truth in any aspect of our existence, that should be brought to light—at least statistically—by applying mathematical logic. At the present time, mathematics is being used to penetrate mysteries even in the realms of metaphysics and religion. For example, by applying statistical analysis, doctors in a New York hospital have found that daily prayers have a positive role to enhance our health and happiness.

We all are aware of the fact that consciousness exists. But our knowledge on consciousness is quite limited and somewhat speculative and esoteric. The core of Vedanta philosophy is consciousness. Consciousness, according to Vedanta, is the real doer—causing all changes in nature. But at the same time it is detached from everything. The core of mathematics is a function. All change in nature is caused by a function which is detached from both cause and effect. This analogy should generate some interest to undertake a study of the tenets of Vedanta philosophy from the standpoint of mathematics. With this rationale in mind, the present research has been conducted.

There exists no absolute definition of Consciousness in psychology. Professor McConnell from the University of Michigan stated [1]: "There is possibly no term in psychology more difficult to define adequately than Consciousness.

At its simplest, it means awakeness, alertness, responsiveness". The special issue of *Journal of Consciousness Studies* [2], Vol. 3 No. 1, 1996, is dedicated to "Explaining Consciousness—The Hard Problem (HP)". According to Robinson [2], HP is a problem which cannot be solved "within our present conceptual framework". Shear [2] mentioned that "HP will require sophisticated scientific investigation of the subjective phenomena of consciousness". He further mentioned that "subjective methodologies akin to those developed in eastern cultures can be expected to play a role in any mature science of consciousness...".

Historians stated that more than 4000 years ago Aryans lived in India [18, 20]. They adored most a set of books known as the Vedas or books of knowledge. Literally, Vedanta means the end ("anta" in Sanskrit) of the Vedas. It contains the very essence of the Vedas and as such Aryan pundits considered it to be the highest form of knowledge or wisdom that one can acquire.

The philosophy of Vedanta is the philosophy of Consciousness presented not just as a cognitive science but as an experimental science in a sequence of books of antiquity. These are called the Upanishads [3, 19, 23, 31, 33, 35]. There are many Upanishads, and each one deals with various aspects of one essential topic: Cosmic Consciousness—the union of all fragments of manifestations of Consciousness of the universe which is again the union of all objects of this visible universe and an invisible universe. Aryans called it a Cosmic Universe and declared that the Cosmic Universe and the Cosmic Consciousness are essentially one and the same. We live in a world with myriads of relative truths attached to relative realities. But behind this scene, Consciousness hovers as the Eternal Witness, the Absolute Truth and the Absolute Reality. Once this state is attained, all relative realities lose their glitter and glamour, and appear to be illusions to those who seek the Truth. Seers of ancient India did not consider this to be just an idealistic philosophy. They called it the science of all sciences [22, 25].

Upanishads assume the existence of a fictitious entity and called it "Brahman". Brahman is the Absolute, the Omnipotent, the Omnipresent and the Omniscient—beyond time, space and causation—birthless, deathless, conserved and the Eternal. Who is Brahman?

Aitareya Upanishad, in RigVeda states: "Prajñānam Brahman" meaning Brahman is Consciousness. It further states: "Brahman is the origin ... whatever breathes here, whatever is moving on legs or flying in the air or unmoving, all is guided by Consciousness and supported by Consciousness. The basis of the universe is Consciousness." Śvetāśvatara Upanishad in Yajur-Veda declares: "The Self (meaning Brahman or Consciousness), smaller than the small, greater than the great, is hidden in the hearts of creatures...". Then it states: "It is not female, it is not male, nor is It neuter. Whatever body It takes, with that It becomes united." This means that Consciousness has no gender, and It exists even in inanimate objects. How is this possible? A logical explanation is investigated in this work.

In Chhandogya Upanishad, from Sam Veda, Consciousness is symbolized by "null" because it is invisible, and our mind cannot comprehend Its cosmic features. This forms the most significant characteristic of the native philosophy of ancient India. Several mathematicians like Halsted and Sanford [4] believe that the number "zero" was invented in India as a result of prevalence of the concept of "null". More on this are discussed later. The numbers 1, 2, 3, 4, 5, 6, 7, 8, 9 were found by observing the subtle characteristics of the phenomenal universe. Together with "null" or "Sunya" (in Sanskrit) these numbers form the decimal system [4]. Vedanta states that the entire cosmos has come out of Consciousness which is symbolically "null", and will merge with Consciousness. How an object of Nature emanates from "null" or Consciousness is primarily a philosophical topic. But when a person dies, he/she almost vanishes from our eyesight and becomes "null". In Markandeya Puran [23], three states of Consciousness have been mentioned. These are (i) Kāla Rātri (ii) Mahā Rātri and (iii) Maho Rātri respectively. Maho Rātri means the end of the life of an individual (like the death of a person), Mahā Rātri means the end of a universe or a galaxie. Kāla Rātri means the demise of time, space and causation—a total annihilation of the cosmos. These are different attributes of the same Cosmic Consciousness in which all objects—physical or metaphysical, tangible or intangible—of the phenomenal universe must slowly merge.

Thus the symbol "null" appeared as the last digit in any Hindu inscription.

Consciousness is not directly defined in Vedanta. Seers stated that Consciousness is beyond description and beyond the reach of human mind. Realization of the true nature of Consciousness can be achieved only through the principle of detachment. At that stage—sense-organs (Indriyas) which work as input/output devices for incoming/outgoing information, external mind (Manas) which works as the receptor/transmitter of the input/output information, nerves (Ida, Pingala) and internal mind (Citta) which carry all information to the intellect (Buddhi) for processing and carry the response or output back to the external mind which directs them to the sense-organs, and memory (Smriti) which stores both input and output information—all these biological and psychological instruments cease to function. Individual Consciousness transcends the universe and all of its attributes, and merges with the Cosmic Consciousness, the Absolute and the ultimate abode of supreme tranquility and bliss.

Regardless how mystic it sounds, it is cognizable, to a certain extent, by mathematical logic. In this work some statements and axioms found in the Upanishads have been simulated by mathematical equations. Rigorous step-by-step analysis was applied to draw conclusions maintaining consistency and precision. These conclusions have been validated by applying pure logic and/or scientific investigations. Vedanta philosophy revealed some of the most subtle aspects of modern physics. Let us first study what Consciousness is in the light of mathematics.

2 Mathematical Modeling of Consciousness

Before we look for a mathematical representation of Consciousness, we need to understand, in the most simplistic way, that It exists. In Vedanta, another name of Consciousness is "Self". Dr. Erwin Schrödinger [5], the Austrian Nobel Laureate in Physics, gave a simple demonstration to validate the existence of "Self" in us. He explained as follows: "Assume we take two human bodies A and B. Put A in a situation such that a garden is seen; put B in a dark room. Then let A and B interchange places. On the assumption that there are no distinct "Selves" in A and B, the interchange should make no difference. But if A is my body there is then no view of the garden. Therefore, besides the world, the "Self" must exist ...". This clearly implies that the "Self" or Consciousness in us makes us see a garden and generates pleasures in our heart—although It cannot be seen or touched or even felt. We are mostly unaware of Its presence in ourselves.

Aitareya Upanishad states that Brahman is the Inner Operator "by which one sees, by which one hears, also by which one smells and by which one utters and by which one tastes the sweet and the sour." Mandukya Upanishad states: "He is the Inner Controller". Praśna Upanishad states: ... "It (Consciousness) is that who sees, feels, hears, smells, tastes, thinks and knows." Kena Upanishad elaborates the concept of Consciousness with more scientific grace and mathematical fervor. It states: "That which cannot be expressed by speech, but by which speech is expressed—that alone is known as Brahman. That which mind cannot comprehend but by which mind comprehends—that alone is known as Brahman. That which cannot be seen by eyes, but by which eyes can see—that alone is known as Brahman. That which cannot be heard by ears, but by which ears can hear—that alone is known as Brahman. That which cannot be breathed, but by which breathing works—that alone is known as Brahman." Through these statements, Consciousness resembles a mathematical operator. Let us now understand it.

The central theme of mathematics is to study functions. A function is also called a mapping or an operator. When a cause is changed into an effect, symbolically it means that X is changed into Y. Mathematically, such a change is done by an operator F and is expressed as:

$$F : X \to Y$$

All changes—known or unknown, comprehensible or incomprehensible, seen or unseen, very minute or very massive—are all done by operators. An interesting property of F is that while changing X into Y, F is attached neither to X nor to Y. For instance, when clouds are changing into rains, it is done by an operator which is neither the cloud nor the rain.

Now let us analyze the statements in Kena Upanishad. "That which cannot be expressed by speech" means whatever "That" is, is detached from our expressions or beyond expression; "but by which speech is expressed" means "That" must activate our mechanism of speech—or those constituents of our body which set up the mechanism of speech. Thus, "That" which is our Consciousness is an operator which is detached from speech and beyond description, but which operates on the mechanism by which speeches are spoken. Mathematically let D_1 = the domain containing the constituents of the mechanism of speech and R_1 = the range, containing all the statements spoken by us. Let C = the Consciousness operator. Then, according to the first statement in Kena Upanishad

$$C : D_1 \to R_1$$

If we combine all the statements, in the Upanishads we get

$$C : \bigcup_{n=1}^{\infty} D_n \to \bigcup_{n=1}^{\infty} R_n$$

where

$\bigcup_{n=1}^{\infty} D_n$ = *the union of all the domains of all biological and psychological activities of ours which are countless*, and,

$\bigcup_{n=1}^{\infty} R_n$ = *the union of all the ranges consisting of the output from all the biological and psychological activities through the operation of consciousness.*

It should be noted that as Charlie Dey stated [14] "a function in mathematics may simulate Consciousness, but whereas Consciousness is very meaningful because of its very existence, irrespective of any simulation, a function—by itself—may not always be meaningful". Furthermore in mathematics, the "state" of a function is an undefined concept. In Vedanta, Consciousness is an operator, which defines its own "state" of existence which is the Absolute.

Thus Consciousness is neither a force nor a power or any form of energy. It simply activates all of them and generates flamboyance of vigor and vitality in Nature. How Consciousness operates and why the state of consciousness is the state of the Absolute will be our next topics of discussion.

3 Consciousness in Nature

Nature contains both animate and inanimate objects. If Nature is conscious, as Vedanta claims, then rivers, oceans, hills, mountains, stars and planets—all are conscious. How could this ever be possible? How could a piece of stone be conscious?

Vedanta derived the conclusion that Nature is conscious from the fundamental postulate that: "In the beginning there was but the Absolute Self alone" (Aitarey Upanishad, RigVeda). We will carefully analyze the logic applied in this derivation. To define mathematics, Dr. Richard Courant, the famous German Mathematician of the early 20th century once said that one can assume that the moon is green and is a square and derive certain results such that assumptions are not violated. This is mathematics. Thus we must examine the Vedantic axioms and examine whether they are logical and in conformity with the laws of modern science.

The principle of the conservation of energy states that the total amount of energy of the universe is always the same. If $a(t)$ = potential energy of the universe at a time t, and $b(t)$ = the kinetic energy of the universe at a time t, then,

$$a(t) + b(t) = K \tag{1}$$

where K is an absolute constant, independent of t. Let us now consider the time when there was no motion—the universe was not even born. In the absence of motion, time may be set equal to zero. At $t = 0$, $b(0) = 0$ (because kinetic energy cannot exist without motion). Therefore, from (1)

$$a(0) = K \tag{2}$$

At that moment, an operator definitely existed who later converted potential energy into kinetic energy (because energy cannot change itself) so that the universe may be born. Who is the Operator?

From the previous section it follows that Consciousness was considered to be the operator which enacts all physiological and psychological activities in us. From the point of view of physics, it means that Consciousness must preserve and generate potential energy and convert that into kinetic energy. We may understand it easily if we think that if Consciousness is taken out of a person, there will be no preservation or generation of potential energy and consequently no conversion of potential energy into kinetic energy—rendering the person stale, stiff and stagnant. Thus, Consciousness is the only operator that could preserve potential energy in a system. Therefore, at $t = 0$, before the creation of the universe, Consciousness must have existed as the preserver of the vast potential energy $a(0)$. Āgama-Prakarana of Māṇdukya Upanishad (from Atharva-Veda) states: "Turiya (Cosmic Consciousness) is for ever everything and the witness". This implies that at $t = 0$, together with $a(0)$, Cosmic Consciousness existed like a witness. In a human body various chemicals are being formed continuously and not all of them were there at the very beginning. A cell should float in water but instead, it is surrounded by liquid containing several chemicals like the radical species H, OH, e^-_{Aq}, molecular species O_2, O_2^-, H_2, H_2O_2 and possibly many more [6]. Like all other body functions, it is Consciousness who has set up all body chemistry, created chemicals in the body and maintains all chemical equations of reactions. Similarly minerals in our body are also generated by Consciousness and their growths are monitored by It. Following this logic we may comprehend why Vedanta states that it is Consciousness which generated out of Itself, micro matter—a union of "Akas" (micro mass) and "Prana" (micro energy). This union formed the micro atomic species as described in the reference [9] which must have been the constituent elements of $a(0)$. In the most simplistic form, the equation is:

$$\begin{aligned} \text{micro matter} &= \text{micro atoms} \\ &= (\text{micro mass} \cup \\ &\quad \text{micro energy} \cup \\ &\quad \text{Consciousness}) \\ &\subset (\text{Cosmic Consciousness}) \end{aligned}$$

Thus wherever we see matter, we really see mass and energy, guided by Consciousness. This is the essence of the dictum of Vedanta. Thus, according to Vedanta, the source of $a(0)$ is Cosmic Consciousness and $a(0)$ is one with It. Since Consciousness existed prior to the existence of $a(0)$, and at that moment nothing else existed, it must be the Absolute and thus the state of Consciousness must be the state of the Absolute. Since the measure of Consciousness is conserved, (Vedantic axiom is that Consciousness is changeless) mass of the universe must be conserved and so is "prana" or energy. Since "matter" is a combination of both, Vedanta declares that "matter" must be conserved. Talking about his works on Relativity, Einstein stated that he simply combined two conservation laws of physics (i) conservation of mass and (ii) conservation of energy into one law, namely, the conservation of matter [7].

According to physics, all forms of matter are continuously changing. Tiny atomic particles, beyond our vision, are always jumping up and down on all substances. Aryans called the universe "Jagat", which is a Sanskrit word derived from the verb "Gam", which means "to go", added to the suffix "kvip". The word "Jagat" means "the vast cosmos in perennial motion". Thus, potential energy is being continuously converted into kinetic energy, and this conversion can only be done by Consciousness. This suggests that Consciousness exists in inanimate objects. This immediately brings in a contradiction. If Consciousness exists in every object, then it should exist in a dead body. Therefore, a dead person is not dead. To answer this, we need to consider the degree of Consciousness present in an object.

Vedanta claims that the degree of Consciousness varies from one object to the other. This is only a quantitative difference not a qualitative one. In inanimate objects, quantitative measurement of Consciousness is substantially small, but not zero. This notion is clearly mentioned in the Bhagavad Gita [6, Bibhuti Yoga, Chapter 10]. Krishna identified himself with the personified Cosmic Consciousness and said that the universe "is a living whole, a vast interconnectedness, a cosmic harmony inspired and sustained by the One Supreme" (Cosmic Consciousness) [42]. However "While the Supreme is in all things He is more prominent in some than the others. There is an ascending order in the world" [42]. For example, He is more prominent in animate beings than in inanimate objects. Shree Ramakrishna, the great saint from India during the late 19th century also said that the degree of manifestation of Brahman (or Consciousness) varies from object to object

[25]. Swami Shraddhanandaji [26], my revered teacher and the head monk of the Vedanta Centre of Sacramento California clarified this point giving me a simple example. He said an ocean has many sizes of waves—big waves and small waves—but all belong to the ocean and all are one with the ocean. Brahman or Consciousness is that one "unity", one ocean—the Absolute and the Eternal—forming the underlying truth of existence of all objects from the galaxies, novas to the minutest elements of an atom, which are still beyond human vision and comprehension. This essence of the Upanishads may now be explained mathematically.

If $F(x_1, x_2, \ldots, x_n)$ is a potential function where $F : D_n \subset \mathsf{R}^n \to D_1 \subset \mathsf{R}^1$, $\mathsf{R}^n = n$ dimensional space, then if it acts upon an object moving it from the position A to B the amount of work done is

$$\left| \int_A^B \langle F_x, dx \rangle \right|$$

where $\langle F_x, dx \rangle$ is the scalar product of

$$\begin{aligned} F_x &= \left(\frac{\partial F}{\partial x_1} \frac{\partial F}{\partial x_2} \cdots \frac{\partial F}{\partial x_n} \right)^T \in \mathsf{R}^n \\ dx &= (dx_1\, dx_2\, \ldots\, dx_n)^T \in \mathsf{R}^n \end{aligned}$$

Definition: F is a weak operator on D if

$$\left| \int_A^B \langle F_x, dx \rangle \right| < \epsilon, \qquad \text{(for all } A, B \in D)$$

where $\epsilon =$ positive and arbitrarily small and the integral is independent of the locations of A and B.

F is also a weak potential function and as such it is able to do less work. In inanimate objects, Consciousness behaves somewhat similiar to F. However, Vedanta states that it is possible to transform F into G such that

$$\left| \int_A^B \langle G_x, dx \rangle \right| > M$$

where M is positive and arbitrarily large. Śvetaśvatára Upanishad states: "Know the embodied Self (Consciousness) to be a part of the hundredth part of the point of a hair divided a hundred times; yet it is infinite." This means Consciousness that exists in the minutest form has the potential to hold a vast source of energy. Einstein, evidently, put this principle into his famous equation:

$$E = mc^2$$

where $E =$ energy, $m =$mass, and $c =$velocity of light= 186×10^3 miles per second. This equation validates the Vedantic thought that from a minute particle, a vast amount of energy may be extracted.

Vedantists say that there exists a touch of Consciousness in a dead body, but It plays a part of a weak operator. When a person dies, the major part of the Consciousness leaves in a subtle body, and the biological organs each of which carries its individual Consciousness do not die simultaneously. They lose their consciousness step-by-step (Brihadāranyaka Upanishad, Yajur Veda). This has been validated by modern Medical Science. Transplantations of human organs are possible simply because when a person dies, some of the vital organs of the body may still be alive and well retaining their individual consciousness.

4 The Origin of the Universe

In the invocation of Iśa Upanishad (Yajur Veda) it is stated: "There exists a universe which is invisible, infinite and complete. Out of this universe, another universe has come out which is visible, infinite and complete. However, the invisible universe remains infinite." The invisible universe will be called the micro-universe and the visible universe will be called the macro-universe. This statement has some mathematical validity in the sense that if from a set A with infinite elements, a subset B with infinite elements is withdrawn, A still may have an infinite elements in it. For instance, let A be the set of all integers and B be the set of all even numbers, then the above statement is valid. The word "complete" means if X_0 is an event or an object, physical or metaphysical, of the macro-universe and it goes through a sequence of changes $X_1, X_2, \ldots$ then it attains a limiting point or final point ζ where ζ is also in the macro-universe. If a sequence of natural events—chemical, biological, psychological, etc.—end at a point which is a subject of observation and/or experiment, then it is an element of the macro-universe. For instance, a biological process associated with curing a disease ends when the disease is cured—which may be called a limiting point—in the statistical sense. This phenomenon may be observed and, as such, it is an element of the macro-universe. However, not every sequence of natural events may be kept under observation. For instance, a tree is an element of the macro-universe. If it is chopped down and reduced to blocks of woods, they are elements of the macro-universe. If they are now burnt and reduced to ashes, they are still elements of the macro-universe, even though, the heap of ashes may be blown away and the tree will seem to be totally nonexistent. In the Bhagavad Gita [8], the synopsis of all the Upanishads, the macro-universe is described having two parts: one part is manifest and the other part is unmanifest. In the statement: "Beyond this unmanifested there is yet another Unmanifested Eternal Existence which does not perish even when all existences perish" (Chapter 8, Akshara Brahma Yoga, Verse 20, Bhagavad Gita [8]), there are two "unmanifested" terms. The first one refers to some invisible objects of the phenomenal universe, and the Unmanifested Eternal Existence is the micro-universe, mentioned in the invocation of the Iśa Upanishad, which is the universe of Cosmic Consciousness. It is the Absolute state or the limiting point of all transformations. Analysis of the mathematical significance of this philosophical maxim is the topic of the next section (Section 5).

According to RigVeda, when the macro-universe was born out of the micro-universe, "Hiranya Garbha" was first manifest. In Sanskrit, "Hiranya" means "Golden" and "Garbha" means "womb". Therefore, when the macro-universe was born there was a vivid display of light. This obviously refers to the Big Bang in Physics. George Gamow [9] called it a "Universal Cooking Era." This material world came out after all the matter in the universe which consisted of a "natural abundance of atomic species"—forming micro-matter according to Vedanta—was [9] "squeezed to extremely high density and subjected to very high temperatures providing favorable conditions for all kinds of nuclear transformations." Since this is the very first manifestation of Brahman (Consciousness), Vedanta called Him "Brahma" and the Hindus still worship Him and call Him "The Creator." Since Consciousness is forever invisible, some scientists state that this universe has come from nothing. The truth is that something cannot come from nothing unless that nothing contains something which could be invisible or even incomprehensible. As we have seen before, Chhandogya Upanishad identified this "nothing" or "null", with the Cosmic Consciousness. From this "null", according to Vedanta, the macro-universe was born with nine distinct characteristics: Three modes of existence which are Projection, Preservation and Destruction; three factors of existence, namely Time, Space and Causation and three subtle, random natural inclinations or forces (Avyāktams), namely Sattva, Rajas and Tamas. This is how the doctrine of Vedanta led pundits of ancient India to invent the decimal system [4]. We will now study how Avyāktams work and how the state of Cosmic Consciousness may be attained.

5 Consciousness and the Law of Entropy

Katha Upanishad (Sam Veda) claims: "Whatever there is—the whole universe vibrates because it has gone forth from (the realization of) Brahman." How are these vibrations caused? Vedanta says that the three "Avyāktams" namely Sattva, Rajas and Tamas which are essentially, three subtle, random forces of Nature bombarding on every object continuously—cause vibrations. Sattva is the internal force, Rajas is the external force, and Tamas is the force which repulse both Sattva and Rajas. From the point of view of psychology, the force of Sattva is the force of conscience that leads a person to honesty and nobility. The force of Rajas is that which vitalizes a person to go for action, vigor and strenuous efforts. Induced by the force of Tamas, a person indulges into wickedness, dishonesty and stupidity. More descriptions about the effects of these subtle, random, natural forces on human psychology may be found in the Bhagavad Gita [8] in Chapter 14, Gunatraya Bibhaga Yoga. However, Krishna, the author of the Bhagavad Gita called these Avyāktams—Sattva, Rajas and Tamas—"Gunas" or inclinations. Thus according to Krishna, these "Gunas" or "inclinations" and their combinations form all the natural forces—subtle and gross—of this universe. In the theory of Relativity, Einstein said that all objects of the universe are inclined towards each other which resemble forces of various strengths causing changes of curvatures of their orbits in the space-time manifold. Vedanta claims that the Cosmic Consciousness, which is the source of all these inclinations, is however, unaffected by them. None of the three "Gunas", including Sattva—the one which makes a person virtuous—can touch the state of the Absolute, the Cosmic Consciousness, although they all have originated from It. Because the Absolute is beyond the macro-universe which contains the "Avyāktams". For example, the radiation from the sun turns water into vapor forming clouds which may put a veil around the sun, but cannot touch it. All forces in Nature are just combinations of these three forces (Gunas). They exist only in the macro-universe and they are never balanced. Mathematically, if three forces act on a particle and are not balanced, the particle vibrates. Thus from the minutest particle to the macro-universe itself, every object is vibrating. This matches with the fundamental concept of Quantum Mechanics. This vibration will exist so long the state of the Absolute is not attained. In the Chapter 9, Verse 7, Raja Vidya Rajaguha Yoga of the Bhagavad Gita [8], Krishna said that the macro-universe will stay manifest for one "kapla", unmanifest for one "kalpa" and will reappear at the beginning of the next "kalpa". This Aryan almanac, translated into the modern scientific language shows that one kalpa equals 4.32 billion years [10, Vol. 11, page 509]. Dr. Carl Sagan [11] a famous astronomer of this century has accepted the validity of the findings of Krishna. This prodigious vibration of the cosmos with a period of 8.64 billion years—an incredibly large amount of time—exists as a natural phenomenon because of the continuous bombardaments of Sattva, Rajas and Tamas. Contemplation on this majestic, splendid celestial phenomenon may hold most of us spellbound. But mathematically we can easily comprehend that behind any event in Nature—minute or massive—there exists an operator. Here, this operator is the Cosmic Consciousness. Since the entire cosmos—the time-space continuum—is enveloped by It, It must be beyond time, space and causation. Taittiriya Upanishad claims: "... all that exists is inalienable from Brahman (Cosmic Consciousness) in time and space, Brahman being the cause of time and space".

Avyāktams will cease to exist when the macro-universe will cease to exist and merge with Cosmic Consciousness. In the absence of Avyāktams—the disturbing forces—only a profound peace should prevail. Everything in this universe both animate and inanimate will disintegrate and be one with its true identity, its "Self" or "Consciousness" and all discord, disparity and difference will come to a sublime end. Once we used to think that all academic disciplines are unique and distinct from each other. Now we realize that this is not quite true. Vedanta stated that with the progress of knowledge, science, philosophy, art, music—all disciplines—will all be one and our analytical mind will proceed to seek the source of knowledge which is the limiting point of our very existence and that is Cosmic Consciousness. An individual may attain this majestic state making some personal efforts by conditioning the mind, which is generally very ill-conditioned. Let us discuss this now.

According to Vedanta, "Avyāktams"—Sattva, Rajas and Tamas—cause vibration not only in the physical universe, but also in the world of metaphysics. They often generate ill-conditioned patterns for the state of mind. It is needless to say, that this was also caused because of the existence of Consciousness in Nature, according to Vedanta philosophy. Vedantists call this phenomenon a celestial game which will go on until the mind is properly conditioned by yoga, meditation, proper food, education and noble association. A simplistic model representing the transformation of an ill-conditioned system into a well-conditioned system is the logistic equation.

Let us consider the iterative system:

$$x_{n+1} = kx_n(1 - x_n)$$

which generates a sequence $\{x_n\}$ with a known value of x_0. If $k = 4$, this system behaves in a very erratic fashion. For example with $k = 4$, if we choose $x_0 = 0.4$ and generate 20 values of x_n the last 5 values are respectively 0.1348, 0.4664, 0.9955, 1.7979×10^{-2}, and 7.0621×10^{-2}. Keeping k unchanged, if we change x_0 very slightly by choosing, $x_0 = 0.40001$, then the last 5 values become 1.7173×10^{-3}, 6.8573×10^{-3}, 2.7241×10^{-2}, 0.1060 and 0.3790 respectively. Thus the changes of the values of the elements of the sequence are quite drastic for almost a minor change in the value of x_0. Under such circumstances, a system is called an ill-conditioned system or a chaos.

However, if $k \leq 2.85$, the system behaves very well converging to one and only one point for any $x_0 \in (0,1)$. For instance, if $k = 2$ the sequence converges to 0.5 for all $x_0 \in (0,1)$ and if $k = 2.85$, it converges to 0.6491 for all $x_0 \in (0,1)$ etc. We may call k, a conditioning parameter.

This may form a very simple model for the human mind. When mind is not conditioned properly, then slight disturbances cause erratic changes of human behavior. But when mind is conditioned it stays focussed and all disturbances are damped out. In order to realize the state of Consciousness mind has to stay focussed, or in other words, mind must be conditioned.

6 Attainment of The State of Cosmic Consciousness

In the subtle state, Consciousness is the "Formless" like a true mathematical operator. In the gross state it is blended with the phenomenal universe with boundless beauties and bounties. It assumes forms. Is there a passage to attain the "Formless" from the "Form"? Vedanta says "Yes". It will then be a union of Cosmic Consciousness with the individual Consciousness—and at this juncture of realization of the Truth—body, mind and intellect do not even seem to exist. We will now study some mathematical presentation of this embellished, ethereal, exquisite epitome of Vedanta philosophy.

Attainment of the state of Cosmic Consciousness means being out of the bombardment of all natural forces, which means, from the point of view of Thermodynamics, that entropy has to be null at this point. The Bhagavad Gita, [6] the core of Vedanta, states that practicing intently the principle of detachment one should attain this royal state.

We will now develop a mathematical model to simulate the attainment of the state of Pure Consciousness. Like bubbles inside an ocean, thoughts are always being generated in our mind. Why? Because mind is being continuously bombarded by the "Avyāktams". Contents of these thoughts generally vary considerably. When we start concentrating on one idea or one object, we start getting detached from other ideas and objects. As thoughts start merging with one central theme, we may say, mathematically the difference between the contents of thoughts start to diminish.

Let M = The mind as an operator and x_0 = an initial thought taken up by the mind at some $t = t_0$. Let x_1 be the thought generated by mind (with the help of the Intellect) as it operates on x_0. Thus,

$$x_1 = M(x_0).$$

This is an iterative process, because one thought being acted upon by mind is always transformed into another thought.

Thus at some $(k+1)th$ iteration, x_{k+1} = the $(k+1)th$ thought is generated when M operates on x_k = the kth thought, giving

$$x_{k+1} = M(x_k).$$

If mind now concentrates on practically *anything*—any object or thought, for some $k > K$

$$|x_k - x_m| < \epsilon$$

where ϵ is positive and arbitrarily small and $|x_k - x_m|$ is the difference between two thoughts one at the kth iteration and the other at the mth iteration. These are the symbolic representations of a psychological phenomenon and not a numerical sequence which we see in mathematics. Nevertheless, mathematical logic is still applicable.

Obviously, $x_0, x_1, \dots x_k, \dots$ is a Cauchy sequence having a limiting point A, where

$$A = M(A).$$

"A" is also called the fixed point of M. The question is: What is "A"? Is "A" the object or the thought on which we are concentrating? The answer is "No". Let us analyze that. The psychological process leading to meditation or concentration on an object shows that as concentration gets deeper and deeper, ripples and bubbles generated by the mind (due to the random bombardment of Avyāktams), slowly and steadily decay. If an object or a thought stays in our mind that itself must cause ripples because when mind is stuck with an object of Nature, Nature must bombard the mind by three Avyāktams namely, Sattva, Rajas and Tamas because of the law of entropy. At the stage when the limiting point

"A" is reached, since mind behaves like an Identity operator ($\ddot{A} = M(A)$), there exists no ripple or bubble in mind, or in other words, mind must transcend Nature. The input and output being identically the same, mind is unable to act on "A". Thus the information of "A" makes mind mindless. Intellect which processes the information brought by mind becomes inactive and memory which stores the input and the output becomes nonfunctional. Why? Because, intellect processes only those information which are brought by mind. Since "A" is beyond mind, intellect cannot process "A". Also, memory stores only those information which have been processed by intellect. Since "A" cannot be processed by intellect, "A" cannot be stored by memory. Both mind and intellect being inactive, body seems to be paralyzed or motionless. In psychology it is called the state of "Trance". Vedanta calls it "Samādhi".

In the *vicinity* of A, body, mind and intellect are *weakly* active. Breathing barely exists. Those who have experienced the state of Samādhi said that near the vicinity of the state of "Samādhi" sense organs and mind still receive incoming information for processing by intellect. But when they were asked to tell their experiences in "Samādhi"—they said it was beyond explanation. Sree Ramakrishna, a saint from India (1836-1886), reached "Samādhi" and said to his disciples that at the state of "Samādhi" everything melts into Cosmic Consciousness (Brahman) just as a doll made of a chunk of salt loses its identity in the ocean. In Chhandogya Upanishad (in Sam Veda), Sanatkumar, the erudite scholar on "Samādhi", stated that this is a state "where one sees nothing else, hears nothing else, understands nothing else—that is the Infinite. Where one sees something else, hears something else, understands something else—that is Finite. The Infinite is immortal, the Finite mortal". Later he said that this "Infinite" is the "Self" or Conciousness. In the equation $A = M(A)$ "A" is that changeless "Self" not perceived by mind or processed by intellect. It must denote a transcendent state which should be the state of the Absolute. Since Cosmic Consciousness also denotes the state of the Absolute, and there cannot be two states of the Absolute, "A" must be identically the same as the state of the Cosmic Consciousness.

The phenomenal universe is being rampantly bombarded by subtle random natural forces and this bombardment increases in time. This is the law of entropy in Thermodynamics. At the state of "A", mind and body are no longer receptors of any information, thus all disorder subsides and temperature becomes a constant and in the absence of any heat exchange entropy reduces to zero, at least for the time being. At "A" all irreversible processes of existence suddenly appear to be reversible. A person feels that he has started his journey from "A" and has come back to "A". Vedanta states that the phenomenal universe originated from the Cosmic Consciousness and will merge with It (Māndukya Upanishad). Thus, in the neighborhood of "A" the universe will be in a quasi-static process in the terminology of Thermodynamics. The state of "A", however, is the state of perfect equilibrium. Absence of work also implies absence of heat flux which in turn implies that entropy is zero. Brihadaranyaka Upanishad states: "In this state a father is no more a father, a mother is no more a mother, the worlds are no more the worlds, the gods are no more the gods, the Vedas are no more the Vedas...a thief is no more a thief ... a monk is no more a monk, an ascetic is no more an ascetic". "This form is untouched by good deeds and untouched by evil deeds, for he is then beyond all the woes of his heart". Because attainment of the state of Cosmic Consciousness means attainment of equilibrium which implies cessation of all works. Neither body, nor mind or intellect could be active. The vedic statement quoted above also means that at the state of the Absolute the concept of dualism is totally nonexistent. In order that a "father" may exist, a "child" must exist; which implies that at least two objects must exist—which is a contradiction when the state of the Absolute is attained. Thus at this stage "a father is no more a father". But why Vedas—the books of Supreme Knowledge of the Aryans—must also cease to exist? Because all knowledge is absorbed by the state of the Absolute and all books of knowledge—whose only purpose is to reveal truths—lose their significance and merge with the Absolute state. Since (from the section 4) Consciousness is the state of the Absolute, the knowledge from the Vedas must merge with Consciousness when this Absolute state is attained and as such they are not needed anymore. Thus at the state of the Absolute, analysis of mathematics and metaphysics, physics and philosophy, biology and psychology all must converge into one aesthetic harmony, one Eternal Knowledge, one Absolute Truth.

7 The State of Consciousness as Sat-Chid-Ananda

The concept Consciousness is not esoteric, it is scientific and as such it is universal. It seems that "ordinary consciousness is an exquisitely evolved personal construction 'designed' for the primary purpose of individual biological survival" [12]. Although we call the expressions of our analytical mind as expressions of consciousness, consciousness itself it quite different from all thoughts and deeds for our day-to-day survival. Ornstein nicely stated that [12, page 38] "Our thoughts are transitory, fleeting, moving from one idea, object, image to another; yet it is always the same consciousness that flows from experience to experience". This is a Vedantic assertion. There are other researchers who expressed similar ideas through their own perception of Consciousness. William Blake [12] stated "If the doors of perception were cleansed, man would see everything as it is—infinite". This refers to the state of Consciousness—one eternal, infinite and holistic. William James [13] stated: "Our normal waking consciousness, rational consciousness as we call it, is but one special type of consciousness, whilst all about it, parted from it by the filmiest screens, there lie potential forms of consciousness entirely different. We may go through life without suspecting their existence; but apply the requisite stimulus, and at a touch they are there in all their completeness ...". Mathematically, this perception of James may be expressed as

$$C = \bigcup_{n=1}^{\infty} C_n$$

where C_1, C_2 ... are manifestations of various aspects of one Consciousness "C" as displayed in Nature some of which are too subtle to be grasped by human comprehension. Vedanta says that all the diverse appearance of Consciousness is truly an illusion. The truth is that It is just one and the complete just like there exists only one sun with many reflections in lakes, rivers and oceans. However, James had also the feeling that each aspect of Consciousness is complete—meaning that it must be infinite by its own existence—which is very similar to what we see in Vedanta. Each object of Nature reveals Consciousness and as such finite is essentially infinite. It is because of our ignorance we are unable to perceive this truth. In our daily life we think that we see only fragments of Consciousness—and we do not see its holistic mode of existence.

Aryan seers in ancient India developed both sophisticated scientific investigation and subjective methodologies to reveal Consciousness as The Absolute Reality attainable through the principle of detachment and claimed that such a process is an experimental science. Although they did not define Consciousness directly, stating that the Absolute cannot be delineated in any language, enough information may be found in the Upanishads—the collective research works of Aryan saints and scientists at various times of antiquity—which indicate that a mathematical definition may be formed out of these scientific and philosophical works. The definition will be:

If motion does not exist

$$C : a(t) \rightarrow a(t), (t \text{ being crystallized})$$

else,

for all t, $$C : a(t) \rightarrow b(t) \quad \text{and}$$
$$C : b(t) \rightarrow (a(t) \cup b(t))$$

where

$$C = \text{The Consciousness Operator}$$
$$a(t) = \text{Potential Energy}$$
$$b(t) = \text{Kinetic Energy}$$
$$t = \text{time}$$

This definition is valid, if and only if, generation of potential energy from some source, has taken place which according to Vedanta is Consciousness.

When t does not exist—implying the Universe being motionless or even nonexistent—the Consciousness Operator C behaves like an Identity operator and is called "Nitya" or "The Everlasting". When motion begins and t is present, C

is called "Lila" or "The Playful One". Vedanta says that the same Consciousness has two different aspects. This operator Itself defines Its own majestic state which is open only to the one who practices detachment with unequivocal, unfeigned dedication and determination. Many Aryan saints, kings and queens attained this royal state as could be found in the history of ancient India. Janaka, Krishna and Buddha are some of them. In the 15th century, Mirabai, the queen of Rajputana, a Northwestern province of India—attained this state. During the same time, Mr. Viśvambhara Misra from Bengal, India practiced the principle of detachment and attained the state of Pure Consciousness. In the World of Vaisnavas, he is known as Chaitanyna Mahaprabhu (The Lord united with Cosmic Consciousness). Recently, in the late 19th century Ramakrishna attained this state. There are many others like them whose names may not be recorded by the historians. Hindu saints strongly believe that Christ also attained the state of Cosmic Consciousness.

Realization of the state of Cosmic Consciousness is the highest state of Knowledge. At this stage, all states of existence and all states of motion of mind and matter together with why and how any particular event driven by Consciousness may change, become known. This is the entire world of science and philosophy. In Chhandogya it is written that by knowing one nugget of gold, everything made of gold is known; similarly the knowledge of Consciousness is that knowing which one knows everything—because the core of everything is Consciousness. All objects are either Consciousness personified, Consciousness petrified and/or Consciousness in motion. Consciousness is the predominant potentate in this vast cosmos. Furthermore, since at the state of Cosmic Consciousness entropy is zero, body, mind and intellect are free from the bombardment of subtle, random natural forces (Avyāktams). Therefore, a person enjoys a sense of profound peace and tranquility. Vedanta calls this Absolute state: Sat-Chit-Ananda or the state of The Absolute Existence, The Absolute Knowledge and The Absolute Bliss, or the state where "mortals become immortal" (Katha Upanishad). This certainly resembles the concept of "eternal life" in Christianity or "Nirvana" in Buddhism.

8 Discussions

Thousands of years ago, Vedantists made a bold comment that man must conquer Nature, which consists of the external world and the internal world. Nothing is beyond the efforts of man. History has been following the remarkable annals of victory of man over Nature since the dawn of civilization—from the epoch-making discovery of agriculture to the spectacular landing of a man on the moon. Man is now ready to undertake the most adventurous intergalactic travel to search for intelligent beings in other planets—perhaps in other galaxies. Therefore, there exist some groups of men and women who are highly motivated, thoroughly focussed and immensely dedicated to reveal scientific truths which could be represented in the sole language of science which is mathematics. Although the Absolute is beyond expression, an approximation of the Absolute—the vicinity, which is the least affected by the law of entropy—may be described scientifically and modelled mathematically.

During the early days of civilization, almost all elements of Nature—trees, fire, oceans, rivers, mountains, sun, moon, stars, planets, even some birds and animals—were objects shrouded by mysterious ideas and thoughts of man. They were often worshipped as emblems of God. But with the progress of science, these veils of mystery were slowly uncovered and truths were established.

Scientists are now searching for more detailed information about consciousness. Harnessing consciousness is possibly the biggest challenge for the next century. We all know that it exists, therefore we ought to know how to establish a scientific process to comprehend its existence and figure out how it works not just qualitatively, but also quantitatively. According to Rig Veda, the first manifestation of Consciousness is "Hiranya Garbha" or heat, out of which the material world was born. Thus, consciousness may be invented, when scientists will discover how matter was formed. Upanishads called consciousness a form of light with tremendous energy which is invisible. Scientifically it has been proved that as the wave length of light tends to zero, energy (it carries) tends to infinity. Isaac Newton once raised a question "Are gross bodies convertible into light?" [7]. The answer is "Yes". Thus when matter will be converted into light with zero wave length, according to the Upanishads, consciousness may be discovered. This is certainly an ideal situation. Realistically, as matter will be converted into light with smaller and smaller wave lengths, scientists should understand the features of consciousness statistically. The next natural step will possibly be the artificial simulation of consciousness. Like artificial intelligence, artificial consciousness should revolutionalize the world of computers for the next century. If this is done, according to Charles Dey [14] "nano robots may be manufactured and scattered in the vast space, and as they float, they may transmit relevant information about planets and stars of this cosmos. The space research will be then at its climax." Thus computerizing consciousness may not be beyond the reach of human endeavor, once we know how it works.

All jobs that we perform—directly or indirectly, knowingly or unknowingly—are all tied to processing information. Thus any flux of energy in Vedanta may be considered as a flux of information. One of the most interesting texts in the science of information theory is the reference [40]. The concept of information, both in theory and in practice are the primary topics in this text. Mathematically, the flow of information—in any gross or subtle form—must be done by an operator. Looking at a human form, we realize, that this operator is Consciousness. I am very much indebted to Professor Zeleznikar with whom I had direct discussions on this topic at Lujbljana. During our conversation Professor Zeleznikar clarified it to me that he has the idea to develop artificial consciousness to be used in our future computers [41].

9 Conclusion

The analysis of Vedanta Philosophy given in this article has led to conclusions which are mathematically accurate. Scientifically, no phenomenon contradicting Vedantic findings has yet been found by observation and/or by experiment. Several discoveries unfolding the advents of Nature as stipulated by the Aryan pundits over 4000 years ago still hold scientists of the 21st century speechless and spellbound. Future researchers in Vedanta may reveal many more hidden scientific truths which modern science will learn in its timeless passage towards searching for the Truth.

Appendix: The Aryans in India

Historical evidences found from archeology and logical analysis of events recorded in the books of antiquity relate to the fact that Aryans who were in India about 4000 years ago were probably very handsome and highly intelligent people and their complexion was white. In Rig Veda, one of the most sacred books of the Aryans in India it is written [17] "the praises of Indra (an Āryan God) are sung for rending the dasas' (dark-skinned people, later it meant slaves) fortresses 'as age consumes a garment' ...". In the book "Dhyana Yoga" [15, page 48] Mr. Shivānanda Sarasvati, a well-known Ayurvedic doctor from India who did an extensive research on the medicines used by the Aryans in ancient India stated that Krishna (the historic personality whom Hindus worship as Lord Krishna) was a tall, white person just like "any other typical Aryan". During the mid nineteenth century, Chatterjee [27] applied the Principle of "Precision of the Equinoxes"—a well known phenomenon in Astronomy and derived mathematically that the revered Hindu text on Science and Philosophy—The Bhagavad Gita—was composed around 1440 B.C and Krishna, the author of this text was born around 1510 B.C. In the Bhagavad Gita [6, Samkhya Yoga, Chapter 2, Verse 2] Krishna charged Arjuna that he (Arjuna) should not show any lack of courage or despondency like a "non-Aryan" in the battlefield of Kurukshetra. This also implies that both Krishna and Arjuna were full-blooded Aryans. In the Ramayana, which is the record of India's glorious past, the great sage Valmiki stated [16, Ādikanda] that Rama, the prince of Ayuddha, was tall with broad chest and shoulder, long hands and bright beautiful eyes with a white complexion. Then he wrote: "Ārya sarvasamashchaiba sadaiba priyadarshana", which literally means "he (Rama) was always a handsome person just like all other Āryans". These two names Rama and Krishna are worth mentioning in this article because they were Vedanta personified, two most lustrous examples of Indian history showing that Vedanta could be rendered as a very practical tool for the betterment of body, mind and intellect leading to the highest state of enlightenment—the state of the Absolute, the cosmic Consciousness. In the Bhagavad Gita [6, Chapter 154 Purusottama Yoga, Verse 15] Krishna proclaimed: "I am the knower of the Vedas and the author of Vedanta". This is indeed true, because the essence (as stated by the reviewer) of all the Upanishads—the books of antiquity which expound the philosophy of Vedanta—was spoken by Krishna in the Bhagavad Gita [6].

In [18, page 176] Childe stated in his recent investigations on the Aryans, that the first appearance of the Aryans took place in Northwestern India (Punjab), Central Asia and almost all Eastern Europe. Frawley [20, page 249], an authority on the Vedic culture, stated that "the Vedas possess a much greater antiquity than imagined by modern scholars and the Aryans were in India at a very early point in history (by 6000 B.C)." Rig Veda "relates the origin of Vedic peoples from across the sea ...". Frawley believes that "some of them (Aryans) escaped by sea to India, up the river to the Himalayas and then down again at safer times". He seemed to agree with most European scholars that "Vedic people were primarily a light-skinned, perhaps blonde, alpine or nordic type like the Europeans". In this article it is indeed immaterial to discuss the color of the Aryans. Their code of conduct and mode of life were exemplary to all of us. Frawley [20, page 245] wrote "The Vedic Aryan is a culture of spiritual or yogic values". The very foundation of this culture is their philosophy of life and existence and that is the philosophy of Vedanta. Vedanta bestowed upon them an abundance of spiritual wealth and bounty which did enhance their physical health and beauty. In Sanskrit the word Aryan means "noble" or "pure", because their culture was based upon "the rules of the seers, men of spiritual realization" [20, page 244]. These rules were primarily derived from the teachings of the Vedas. Most Hindus strongly believe that the Aryans who composed the Vedas and developed the philosophy of Vedanta were in India "since the Ice-Age" [28]. This was also substantiated by the works of the famous Hindu scholar swami Vivekananda [24]. One primary reason for such a strong assertion is that the entire encyclopedia of the Vedic texts—Vedas, Vedangas, Upanishads, Upavedas—were all found in India. For millenniums, one after another, Hindus treasure these books most, uphold the significance of these books most and truly believe that anything good and noble inherent in great culture of India has emanated from the dictum of the Vedas.

References

[1] McConnell, J.V. 1974. Understanding Human Behavior. An Introduction to Psychology. Holt, Rinehart & Winston, Inc. New York.

[2] Journal of Consciousness Studies 3:1. 1996. ISSN 13558250. Imprit Academy. Virginia Commonwealth University.

[3] Nikhilananda, Swami. 1962. The Upanishads. Bell Publishing Company,. New York.

[4] Dey, S.K. 1997. Invention of Zero. Proc. Mid-West Conference on History of Mathematics. University of Wisconsin. LaCross.

[5] Moore, W. 1992. Schrödinger Life and Thought. Cambridge University Press.

[6] Chatterjee, A., J.L. Magee & S.K. Dey. 1993. The role of homogeneous reactions in the radiolysis of water. Radiation Research 96:1–19.

[7] French, A.P. 1968. Special Relativity. W.W. Norton & Comp. Inc. New York.

[8] Chidbhavananda, Swami. 1991. The Bhagavad Gita. Tamil Nadu.

[9] Gamow, G. 1952. The Creation of the Universe. The New American Library.

[10] Encyclopedia Britannica. 1967.

[11] Sagan, C. 1980. Cosmos. Balentine Books. New York.

[12] Ornstein, R. E. 1972. The Psychology of Consciousness. W.H. Freeman. San Francisco.

[13] James, W. 1950. The Stream of Consciousness. The Principles of Psychology. Dover Publication. New York.

[14] Dey, C. 1997. Computer Scientist. Mecco Inc. Paris, IL. Priv. comm.

[15] SHRIBANANDA, SARASVATI. 1992. Dhyan Yoga. Umachal Prakashani. Kamakhya, India.

[16] AMALESH, BHATTACHARYA. 1989. Ramayan Katha. Arya Bharati. Calcutta, India.

[17] CRAVEN, R.C. 1983. A Concise History of Indian Art. Oxford University Press. New York.

[18] CHILDE, V.G. 1993. The Aryan. Barnes and Noble. New York.

[19] RADHAKRISHNAN, S. 1994. The Principal Upanishads. Harper Collins P. India.

[20] FRAWLEY, D. 1991.Gods, Sages and Kings, Vedic Secrets of Ancient Civilization. Passage Press. Salt Lake City, UT.

[21] CHETANANDA, S. 1990. Vedanta. Voice of Freedom. Vedanta Society of St. Louis.

[22] SHRADDHANANDA, S. 1996. Seeing God Everywhere. Vedanta Press. Hollywood, CA.

[23] JAGADISHVARANANDA, S. 1977. Shree Shree Chandi. Udbodhon Press. Calcutta, India.

[24] VIVEKANANDA, S. 1964. Thoughts on Vedanta. Udbodhon Press. Calcutta, India.

[25] NIKHILANANDA, S. 1976. Gospel of Shree Ramakrishna. Calcutta, India.

[26] SHRADDHANANDAJI, S. 1996, November. Private communication, Sacramento Vedanta Centre.

[27] CHATTERJEE, B.C. 1850.Krishna Charitra. Sahitya Sansad. Calcutta.

[28] WOLPERT, S. 1991. India. University of California Press.

[29] ZIMMER, H. 1951. The Philosophies of India. Pantheon Book. New York.

[30] ISHERWOOD, C., Ed. 1945. Vedanta for the Western World. Vedanta Press. Hollywood, CA.

[31] HUME, R.E. 1931. The Thirteen Principal Upanishads. Trans. Sanskrit. Oxford University Press. London.

[32] KEITH, A.B. 1925. Religion and Philosophy of the Veda and Upanishads. Harvard University Press. Cambridge, MA.

[33] MASCARO, J. 1965. Upanishads. Penguin Classics. Harmondsworth.

[34] GRIFFITH, R. 1976. The Rig Veda. Motilal Banarsidass. Delhi, India.

[35] MÜLLER, F.M. 1884, 1879. The Upanishads, Sacred Books of the East. Vol. I, II.

[36] DEUSSEN, P. 1908. The Philosophy of the Upanishads. Clarke. Edinburgh.

[37] DEY, S.K. 1994. Indian Philosophy and Its Impact on Mathematics. Midwest Math-History Conference V. University of Indianapolis. Indianapolis, IN. Oct. 14–15.

[38] BURTON, D.M. 1997. The History of Mathematics: An Introduction. McGraw Hill.

[39] NEUGEBAUER, O. 1969. The Exact Sciences in Antiquity. Dover P.

[40] ŽELEZNIKAR, A.P.1990. On the Way to Information 1. The Slovene Soc. Informatika. Ljubljana.

[41] ZELEZNIKAR, A.P. 1997. Private communication. University of Ljubljana. June 23rd.

[42] RADHAKRISHNAN, S. 1993. The Bhagavad Gita. Harper Collins Publishers. India.

Information: Description, Cognition, Invention

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Juxtaposing the work of Baars, Chalmers, Scott, Varela, and others with a detailed analysis of historical case studies, this paper uses a multilevel and multilateral model to explore how information, consciousness and culture interpenetrate. This model formally demonstrates that what we mean by information exchange must be a key component of consciousness studies if we are going to adequately acknowledge that how we build informational bridges connecting personal, cultural, and intergenerational perceptions cannot be separated from our living as individuals and cultures in time and space. Particular attention is given to illustrating that while information itself may be personal or impersonal, our conclusions about the processing of information must address consciousness, experience, exchange, and feedback multidimensionally. I conclude that the key phenomenological concern we must probe when combining consciousness and information studies is what communication is, what information exchange implies, and why theoretical analyses must address the significant difference between information that is primarily descriptive and information that actually enlarges the scope of our communication process and includes some measure of cognitive development.

1 Introduction

It is commonly acknowledged that consciousness has eluded even the most deliberate efforts to contain it. In this paper I analyze why consciousness evades our grasp through an explanation into how we build informational bridges connecting personal, cultural, and intergenerational perceptions. My focus on informational bridges stems from my assumption that consciousness cannot be separated from our living as individuals and cultures in time and space.

The overall analysis is divided into three parts. In the second section, entitled *Description: one-dimensional models,* I correlate the work of Bernard J. Baars with historical examples of cognitive insights to illustrate some of the problems inherent in unified phenomenological theories. Section three, *Cognition: subjective and dualistic descriptive consciousness,* shows that dualistic models, like Chalmers, share some of the foundational problems found in traditional unification models. *Invention: symbolic creation,* the fourth section, presents a model incorporating Alwyn Scott's ideas about emergent consciousness and offers an alternative approach to traditional modeling limitations. In the fourth section I also
(1) show that computers have the capacity to illustrate emergence through their facility in managing, analyzing, and illustrating large amounts of data, and
(2) compare emergent models with informational processing systems, connective approaches to information modeling, and computer generated images to demonstrate particular differences among these modes.
My conclusion is that the key phenomenological concern we must probe when combining con-

sciousness and information studies is what communication is, what information exchange implies, and why theoretical analyses must address the significant difference between information that is primarily descriptive and information that actually enlarges the scope of our communication process and includes some measure of cognitive development.

I am defining information broadly. In other words, my use of the terms acknowledges that we have discovered that information, as a part of a larger selective system, is embodied in organisms, the mind, and cultures and is encoded in genes, ideas, and institutions. My use of the terms also attempts to address the *quality* issues within information models due to our inability to comprehensively model how communication (exchange) meshes with second-order consciousness (human awareness of the human capacity to be aware) in molding the nature of *memes*.[1] Overall, the perspective I am presenting asserts that we must acknowledge that *memes* and genes interpenetrate and we must also acknowledge that it is not whether information is impersonal and primarily concerned with the difference between signal and noise[2] that is important. Rather, I will be proposing that the two critical factors we must address are

(1) how we handle all that is apparent and invisible relationally and

(2) whether our analyses merely sustain forms of information exchange we have already learned or actually enlarges our scope of knowledge and experience.

Description: One-dimensional Models

One-dimensional models offer an excellent starting point for probing these areas and effectively illustrate why there is a need to review traditional scientific and phenomenological studies of consciousness. In this discussion I am defining one-dimensional models as unification models and asserting that the very closure this kind of model portends to provide mitigates that living dynamics and consciousness are an ongoing part of scientific evolution. This is a *quality* difficulty and it is perhaps most apparent when people acknowledge the modeling challenges we encounter when illustrating the convergence between *how* something akin to poetry *with* reason. I will be asking throughout this paper whether we could do better acknowledging that alternatives have repeatedly emerged when reason and something inexplicable (often defined with terms like subjective, poetic, and imaginative) combined. Can we somehow recognize that many of these alternatives have led many of us to re-conceptualize how we define the world? Can we somehow reframe the question of whether something we can reify informs these changes?[3]

[1]The idea of *memes,* first developed by Richard Dawkins, was offered as a cultural analogy to the idea of the biological gene. *Memes* are units of information that sustain the culture. Language, numbers, theories, songs, recipes, laws, and values are all memes that we learn, revise, and pass on to our children.

[2]This of course refers to information theory as invented in the 1940s by Claude Shannon of the Bell Telephone Laboratories. According to Shannon's theory, information is what communication and radio transmissions carry. This information is impersonal and can make sense or be nonsense. In addition, information is something *measured* by engineers and mathematicians and something that can be transmitted and tested for accuracy. There are two key points here. First, the shape of the theory is hardware determined and thus its nature is measured (in terms of bits). Second, this information has nothing to do with concepts, words, or numbers. It also has nothing to do with ideas, learning, knowledge, or embodied meaning. David Chalmers writes, "Shannon (Shannon, 1948) was not concerned with a semantic notion of information, in which information is always information *about* something. Rather he focused on a formal or syntactic notion of information, where the key is the concept of a state selected from an ensemble of possibilities. The most important basic sort of information is the *bit,* which represents a choice between two possibilities. ... What is important, on Shannon's account, is not any *interpretation* of these states; what matters is the *specificity* of a state within a space of different possibilities." (Chalmers, 1996, p. 278).

[3]Perhaps the most intriguing oversight in consciousness studies is that innovative scientists, among them reductionistic scientists working in consciousness studies today, often challenge and revise basic scientific understandings in congruence with their work. Their work, of course, is motivated by their desire to know more about how what is within us "works" as well as how to better understand the patterns surrounding us. Nonetheless, while their investigations may be "objectively" presented and attempting to unify disparate elements, they still contain a personal motivation, a personal commitment, and a personal experience that has contributed to their so-called objective presentation, especially in the early and more private stages of inquiry. The mathematician Pierre-Claude Daunou (1761–1840) clearly expressed what I am trying to say when he noted, "In sciences, even the most rigid ones, no truth is born of the genius of an Archimedes or a Newton without a poetical emotion and some quivering of intelligent nature"

2 Baars and the Workspace of the Mind

The questions I am posing clarify to a larger degree when we look at Baars' Global Workplace (GW) theory. The GW theory associates conscious experience with a rather simple architecture of the psychological system and has three basic constructs: a global workspace, a set of specialized unconscious, and a set of unconscious contexts that serve to shape, evoke, and define conscious contents (Baars, 1988). According to Baars, the central workspace is much like the central staging area of a theater and the idea is that the detailed workings of the brain, like the cells of the human body, are widely distributed. Therefore, there is no centralized command that tells the neurons what to do. Rather the doing is an ongoing exchange similar to actors, audience, and director. Nonetheless, I am postulating a one-dimensional limitation arises. Why?

I am asserting that this limitation is inbreed with the approach. More specifically, despite the theoretical intention to include the knowledge that there is no single point in the brain where everything comes together (Baars, 1996), the theory lacks an adequate means to address the homunculus[4] problem and non-conscious[5] possibilities in a real (as opposed to a theoretical) way. The limitation in this is that Baars does not adequately address how the interaction among audience, players, and director expands beyond the modes known to components of the theater group. There is also the question of how all of our theaters ("brains")—not just the working of one theater (brain)—come together in a multi-lateral environment, where new life continually enters the picture. Even more important to this discussion is how does the theater transform beyond its own limitations?

Let me stress that Baars understands that the issues within the dynamic create these questions but simply fails to find a clean way to address them. For example, in his book, em In the Theater of Consciousness: The Workspace of the Mind (Baars, 1996) Baars notes that conceptual breakthroughs have made the difference as science has evolved and Baars affirms the need to surmount some of the conceptual difficulties that have plagued historical studies of consciousness.[6] Yet, in turning to contrastive phenomenology to address this difficulty he simply side-steps the issues. He defines phenomenology as the study of consciousness based on subjective experience and then claims that contrastive phenomenology allows the involvement of private experience to be emphasized in a scientific way because its technique of combining experiment, subjective experience and conscious events allows people to actually report on conscious events while unconscious ones (sic) can be inferred and studied indirectly and simultaneously (Baars, 1996). Baars then asserts the importance of variable modeling techniques and attempts to show that his combination of experiment, experience, and events brings a variable perspective to consciousness studies. This variable positioning, however, is a mode that barely permits experimenters to evaluate and indirectly "see" into consciousness (Baars, 1996). Let me clarify this. The variable is assumed to be present because information is derived from more than one mode (e.g., brain imaging techniques with reports of psychological and subjec-

(Hadamard, 1973, p. 10). In other words, when something akin to poetical emotion combines with a quivering of an intelligent nature the mix has the capacity to remove conceptual difficulties within science.

[4]The homunculus idea infers that there is a director ultimately orchestrating consciousness. Of course, Baars disputes this (see above). In addition, according to Baars, all unified theories of cognition today are theater models (Baars, 1996). I believe this is why people like myself, as well as Daniel Dennett and Marcel Klinsbourne, have maintained that Baars view is a Cartesian Theater view that ultimately suggests that consciousness involves a single point center, often called the homunculus (Baars, 1996).

[5]I am using the term non-conscious to refer to whatever may not be connected to the mind at all. This would include what will be in the future, thus assuming an open-ended evolutionary process. Non-conscious differs from the unconscious, the unconscious being something one is not conscious of now or something repressed. Whatever the brain automatically brings to our experience could fit within either category.

[6]"In the long history of the sciences it is vital to remember that *conceptual difficulties are the rule whenever we encounter truly new territory, not the exception.* Historically we do not allow the appearance of paradox to stand in the way of sensible study of the evidence. Gravity was a great philosophical paradox in 1650, the roundness of the earth was conceptually bizarre in 1400, and in 1900 space flight was inconceivable to some of the foremost physicists in the world. Good science requires two legs, the leg of thinking and the leg of evidence. In consciousness studies, we have tried all too often to walk on the conceptual leg alone. It is not a good idea." (Baars, 1996, p. 234).

tive experience as recorded by subjects), yet its limitations are global ones.

For example, while the tests are credible and testable, they are very unconvincing if we are speaking about variables in real time (e.g. life). The falsification parameter (try it yourself) is culture-bound[7] and the underlying assumptions exclude non-conscious and evolutionary possibilities. What we have is experimentally limited to information about how we perform certain kinds of tasks that are actually so remote from the input we get in living dynamics that one must conclude the tests and the results merely *parallel* conscious experience. My point is that testing individuals on their ability to retain particular numbers in their minds while trying to read or being asked to read a combination of Mary has a little lamb and words without any recognizable context is testing them in ways that are contextually empty of life. To be sure, the results can be replicated by many of us should we try the experiment, but validating the experiment does not invalidate the problems of a one-dimensional perspective, as I will show when I discuss emergent consciousness.

In sum, the multi-lateral nature that informs a multi-lateral and living consciousness is missing in the simplicity of this kind of one-dimensional modeling. The larger problem is that this kind of model is trying to define consciousness as if it is a measure of some "whole-thing" despite the fact that this kind of "whole-thing" definition does not measure how we extend beyond the "whole-thing" actually addressed. This kind of "universal" boundary has plagued reductionistic science (as well as both holistic and phenomenological studies I might add) since the beginning, a point I will address directly in the section on invention and emergence.

[7]Baars writes: "Concepts and percepts both need to be internally consistent ... *Mary had a little lamb* makes a coherent understandable conscious flow, while a scrambled sentence like *had lamb little Mary a* does not. Conscious events obey an *internal consistency constraint.*" (Baars, 1996, p. 128). Clearly they offer some measure of internal consistency, but only if you are familiar with their particular "sense."

3 Historical Counterpoints: Galileo and Harriot

3.1 Introduction

Baars' rationale in using a variable approach, as I noted earlier, is that it allows phenomenological modeling. He also asserts that contrastive phenomenological modeling fits within historic scientific modeling techniques. To be sure, scientific history does demonstrate that bracketing information has served science well. History, however, also shows that *discovery* is not a bracketing technique, but an activity of conceptualizing variables that were unseen previously. This conceptualization is not merely a new modeling technique, but a re-conceptualization that entirely alters the scope of inquiry.

Historical discoveries clarify what reconceptualization is and illustrate some of the shortcomings in the kind of modeling Baars calls contrastive phenomenology. Let me emphasize that these historical examples demonstrate that a *new* concept is *not* a rearrangement, a bracketing, or re-integration of how some "whole-thing" is described but a re-cognition that adds explicit information to the explanation. The new explanation in turn includes information that changes our information and thus shows the shortcomings within previously *unquestioned* assumptions.

Comparing the stories of Thomas Harriot (1560–1621) and Galileo Galilei, (Holton, 1996; Van Helden, 1995) illustrates what I mean by recognition. These two historical figures demonstrate that actually enlarging assumptions of what had earlier captured the cultural imagination necessitates both implicit and explicit reorientation. Briefly, each of these men saw a different moon when looking through his telescope in 1609.[8] Thomas Harriot, a mathematician, cartographer, and astronomer, lived in London. Galileo, who is generally credited with changing how people in those days saw the moon and planetary objects in general, was a professor of mathematics

[8]The word telescope actually was not invented until 1611. Galileo referred to his instrument as a spyglass and I have been unable to determine the name Thomas Harriot actually used although spyglass seems to have been the common term at that time. Some excellent resources on the changing of the moon's image, complete with illustrations, can be found in (Galilei, 1957/1610; Holton, 1996; Van Helden, 1995).

at the University of Podua.[9] What is fascinating here is that both men observed the moon repeatedly and both also wrote extensively in their journals about what they saw. When Harriot saw the moon, he commented on its "strange spottedness," and sketched a jagged edge, but made no notation about this edge in his notebook. It was as if he *saw* the moon, copied what he *saw,* and did not see it at all because he could not incorporate the visual anomalies with his Aristotelian-based worldview, which held that the moon was an unchanging and perfectly smooth sphere. Galileo, on the other hand, directly addresses the difference between what he saw and the Aristotelian belief system in his book *Sideous Nunicus* (1610). Galileo writes,

> I have been led to the opinion and conviction that the surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and the other heavenly bodies) to be, it is uneven, rough, and full of cavities and prominences, being not unlike the face of the earth, relieved by chains of mountains and deep valleys (Galilei, 1957/1610, p. 31.).

In his recent book *Einstein, History, and other Passions,* Gerald Holton (Holton, 1996) looked at the reactions of Galileo and Harriot and raised some questions I believe are critical to apply to experimental information as we apply it to our investigations of consciousness, especially if we want the conclusions we draw about people who are "normal" (i.e., show no evidence of brain damage or impairment) to be open-ended. Why is it that Galileo is able see the moon is qualitatively similar to the earth and Harriot cannot? Why is it that Galileo can calculate the shadows cast by peaks and valleys that Harriot could not even see? Why does Galileo feel confident with what he sees despite the fact that it contradicts the prevailing Aristotelian worldview? Why is it that after Harriot read Galileo's book he, too, was able to see mountains and craters? Holton asserts that the difference lies in their training in visualization and how they had learned to use their eyes as a tool of *imagination.*

Galileo was raised in Renaissance Italy where the discovery of linear perspective had captured the imagination of all intellectuals. In fact, the first job Galileo ever applied for was a position to teach geometry and perspective at the Florence Academy of Design (Holton, 1996). Clearly his familiarity with the mathematical techniques used by painters to render three-dimensional phenomena on a two dimensional plane enabled him to translate the image he saw through the lens. More specifically, Galileo could *see* the rocky terrain because he had studied how bodies cast shadows on different surfaces. Harriot, on the other hand, lived in the verbal English culture where people like Shakespeare, rather than visual artists, were setting the tone of the times. Thus Harriot, unlike Galileo, did not have the tools to envisage the overall look of what he saw.

The personal quality that allowed Galileo to see and explain what he saw is unlikely to be captured in Baars' laboratory. It was Galileo's conceptual relationship to the phenomena that made the difference. Galileo was able to look through the telescope with a qualitatively different informational foundation than Harriot and since Galileo's body of knowledge, like his perceptual understanding of how things fit together, *had advanced beyond the implicit and learned cultural perceptions,* he saw a totally different image. The variation cannot be attributed to sensation or intelligence per se. Nor does it speak of abnormality, a form of essential consciousness, or subjectivity per se. It does, however, reflect some quality of consciousness. Moreover, if an experimenter who shared Harriot's cultural perspective set up this experiment, Galileo's responses could easily be statistically normalized or tossed aside as "bad data" (because they did not conform to the communal norm). Of course, others eventually confirmed what Galileo saw, so the experiment could possibly be "corrected" and this reinterpretation might even be correlated with evidence of increased neural activity that appeared while Harriot learned to appreciate the alternative. One could also stretch "qualia"[10] theories to explain why there had initially been some level of difference between what each perceived.

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[9]It should be noted that Harriot, not Galileo, has the first moon observations on record (Van Helden, 1995). It should also be noted that historical records indicate that many people had looked at the moon through lenses even before the spyglass was invented (Van Helden, 1995).

[10]"Qualia" are generally defined as qualities that are intrinsic to our subjective feelings, like the redness of a rose or the smell after the rain.

What these *eventual* explanations fail to address clarifies when we add the story of Johannes Kepler to the historical story. Kepler's realization of elliptical planetary orbits is an innovation that articulates why describing the model using explanations like qualia and neuron activity provides an unsatisfactory solution.[11] In Kepler's case the story we know speaks of how it took Kepler six to ten years to deduce the pattern that he used to create the elliptical formula.[12] It was not "in the air" when Kepler lived. Quite the contrary. Kepler derived the elliptical formula after studying data about the physical world complied by the astronomer Tycho de Brahe over twenty years of observing the movements of the planets. I might add that Kepler did not know the formula he derived was that of an ellipse.[13]

Even still, once Kepler perceived the elliptical formula he was able to use the information to empirically, logically, and efficiently define a self-consistency in the cosmic pattern. This simplified pattern included much that had previously not fit together in any kind of logical way. Thus Kepler was the author of the kind of conceptual breakthrough that really did turn a paradox into a relationship. It was a breakthrough precisely because he was able to concisely correlate what had previously been only a massive amount of *unrelated* information. The exceptional aspect of this is that while the old circular models adequately *described* phenomena and actually matched our sensory perceptions more accurately than the revision (for example, it does look as if the sun circles the earth), the elliptical model more accurately describes phenomenal mechanics. Let me emphasize that the elliptical model was a *radical departure from the principle of uniform circular motion which had been considered self-evident and inviolable from the earliest times.* This reversal of an *implicit* truth cannot be emphasized enough. Nor can the precision it brought to the overall picture of celestial and terrestrial phenomena.

> The numerous observations made by Tycho Brahe, with a degree of accuracy never before attained, had in the skillful hands of Kepler revealed the unexpected fact that Mars describes an ellipse . . . the genius and the astounding patience of Kepler had proved that not only did this new theory satisfy the observations, but that no other hypothesis could be made to agree with the observations, as every proposed alternative left outstanding errors, such as it was impossible to ascribe to errors of observation. Kepler had, therefore, unlike all his predecessors, not merely put forward a new hypothesis which might do as well as another to enable a computer to construct tables of the planet's motion; he had found the actual orbit in which the planet travels through space (Dreyer, 1953, p. 392).

Let me also emphasize that the conceptual innovation was mathematically-based and did include some measure of "internal involvement," as is evident when we look at Kepler's reaction to his discovery.

> I thank thee, Lord God our Creator, that thou allowed me to see the beauty in the work of creation; I exult in the works of thy hands. See, I have completed the work to which I felt called; I have earned interest from the talent thou hast given me.I have proclaimed the glory of thy works to the people who will read these demonstrations, to the extent that the limitations of my spirit would allow (Davis & Hersh, 1981, p. 111).

Again, three points stand out. First, *once the implicit pattern*—the pattern that none had previously perceived—*became explicit,* the elliptical idea was able to change cosmological assumptions and enter human consciousness. What had not even existed in a metaphysical context, now became defined in relation to the physical world. Again, *once* the explicit description was evident, the possibilities expanded to include ideas on or-

[11]Of course, another advantage to adding Kepler to the discussion here is that he, like Galileo, has traditionally been used to explain how the conceptual framework of what we tend to think of as Newtonian science took form in the west.

[12]Einstein used Kepler's discovery of elliptical rotations to articulate how knowledge cannot advance from experience alone—for it builds on how the inventions of the intellect correlate with observed patterns (Einstein, 1973).

[13]"After six years of incredible labour, he held the secret of the Martian orbit ... *But he still did not realize that this formula specifically defined the orbit as an ellipse.* Nowadays, a student with a little knowledge of analytical geometry would realize this at a glance; but analytical geometry came after Kepler. He had discovered his magic equation empirically, but he could no more identify it as the shorthand sign for an ellipse than the average reader of this book can; it was nearly as meaningless to him. He had reached his goal, but he did not realize he had reached it." (Koestler, 1959, p. 337.)

bits that are not circular.[14] Second, the explicit ideas were accompanied by a change in Kepler's internal consciousness. Clearly, the fact that one can appreciate the beauty of Kepler's insight even without any awareness of his emotional response to the discovery does not mean that his perception was disembodied. His words show the insight was embodied and underline that the *complexity* of human consciousness is hard to fit with the *traditional* reductionistic model of science and philosophy, where experience and insight are nullified. Finally, once Kepler was able to re-present and explain an alternative in greater detail others could go through an exercise he had intuited and also perceive how the pattern fit the picture. This repeatability made it possible for the information to be exchanged - despite the fact that it was a radical departure from *all* solutions being considered at that time in regard to the cosmological picture.

These examples illustrate the limitations within our presentation of what science is, especially in regard to unification models. My point is that innovation must be easily fit into the modeling process. This need not mean some kind of religious and spiritual adjustment within science, so much as the need to re-evaluate our history, our intentions, our behavior, our evolution, and our information.

3.2 Cognition: Subjective and Dualistic Descriptive of Consciousness

David Chalmers is one who has often pointed out that we need to re-evaluate the limitations of traditional reductionistic science in our scientific models of consciousness. His philosophical explanation of this is in terms of the now infamous "hard problem." The hard problem, as Chalmers poses it, is that we have no way to model how subjective experience emerges from neural processes. The limitation within this position that I want to address is that Chalmers ultimately relegates consciousness to a modality where reification is the essential rubric. This then leads him to conclude that only dualism can actually grasp the whole nature of consciousness.

Chalmers' dualism[15] allows him to relate a network of activity and connectedness to consciousness, to use the underlying "whole-thing" closure that Baars uses, and to accommodate that human knowledge cannot define the "whole thing." But it is because Chalmers' sees no rationale in valuing an ongoing, changing cognitive function that he *solves* the problems of living experience by stating it is unsolvable. His tactic, proving we can never *completely* account (i.e. reify, explain) subjective experience, leads to the underlying paradox that is used to provide a logical explanation for our inability to define *all* of the pieces *all at once.* The problem in concluding there is a paradox![16] is that Chalmers highlights our inability in accounting for subjective experience in a way that simultaneously discounts the value of learning as a conscious experience of enlargement. This is a major inadequacy, stemming from how the model is constructed. It also reveals a major flaw in the "hard problem paradox"—this being that the combination of insight and intelligence always has

[14]For example, initially David Fabricus, a clergyman and amateur astronomer who maintained a correspondence with Kepler from 1602 through 1609, (Dreyer, 1953) wrote Kepler, "With your ellipse you abolish the circularity and uniformity of the motions, which appears to me the more absurd the more profoundly I think about it. . . . If you could only preserve the perfect circular orbit, and justify your elliptic orbit by another little epicycle, it would be much better" (Koestler, 1959, p. 353).

[15]"To capture the spirit of the view I advocate, I call it *naturalistic dualism.* It is naturalistic because it posits that everything is a consequence of a network of basic properties and laws, and because it is compatible with all the results of contemporary science. And as with naturalistic theories in other domains, this view allows that we can *explain* consciousness in terms of basic natural laws ... Some might find a certain irony in the name of the view, but what is most important is that it conveys the central message: to embrace dualism is not necessarily to embrace mystery" (Chalmers, 1996, p. 128).

[16]Chalmers writes, "The existence of phenomenal judgments reveals a central tension within a nonreductive theory of consciousness. The problem is this. We have seen that consciousness itself cannot be reductively explained. But phenomenal judgments lie in the domain of psychology and in principle should be reductively explainable by the usual methods of cognitive science. There should be a physical or functional explanation of why we are disposed to make the claims about consciousness that we do, for instance, and of how we make the *judgments* we do about conscious experience. It then follows that our claims and judgments about consciousness can be explained in terms quite independent of consciousness. More strongly, it seems that consciousness is *explanatory irrelevant* to our claims and judgments about consciousness. This result I call the *paradox of phenomenal judgment*" (Chalmers, 1996, p. 177).

the *potential* to change invisible information into information that is more accessible personally and interpersonally—and history shows this has happened on an ongoing basis.

In sum, leaving learning out results in a static perception and it is one that ultimately overlooks we have the capacity to bring disparate relationships together in a more unified fashion. In fact, the very activity of doing so has led to what we call the tradition of excellence in science. Excellence, in my opinion, is less likely when we adopt Chalmers' fundamental solution. Solutions like this discourage an open stance in regard to information processing, for they do not sufficiently probe into why individual insight, discovery, and invention emerge and converge on an ongoing basis. The closed logic that Chalmers presents is unsatisfactory in assessing why history shows that convergent moments have emerged and resulted in informational modes that have *resolved* what had previously *appeared* paradoxical.

Thus, in sum, it should not be the question of whether or not we can *resolve* the enigma of consciousness, despite how this idea often guides our inquiry, but the recognition that human learning always uses information to comprehend information. More important, resolutions and convergence are an ongoing part of the process of human experience, from birth onward. Finally, as history shows, convergence has changed fundamental dualisms (like Chalmers' naturalistic dualism) into clearly evident conceptual unities repeatedly.[17] When this happens it is not because scientists are using deft Chalmers-like logic to create fundamentals and universals that supply placebo-like metaphysics. Instead, the practice of science works in the opposite fashion. Science, in practice, excels in bringing what had been defined supernaturally or metaphysically into the natural domain. Therefore, science is not logically-based in the way Chalmers suggests.

[17]Of course, the Newtonian insight that one set of laws could apply to the terrestrial and celestial domains is one of the best examples of this.

4 Invention: Symbolic creation

4.1 Informational Processing Models

Placing the concerns I have raised above in a broader context reveals that mathematical constructions have often been a key aspect of conceptual evolution and information exchange. For example, the revisions of the implicit assumption that planetary orbits were circular came about through creating the symbolic means to capture the data in a mathematical form. This ability to capture information in a novel way is a symbolic creation and may account for why Western science and philosophy have a mathematical bias. What I want to emphasize is that this mathematical modeling is a part of what we now call the history of science.

Platonic-Pythagorean ideas were foundational to this orientation. These ideas included a mathematical bias and an underlying dualism that stated the world of matter was a secondary and lesser domain. Both the bias and the dualism were merged into Christianity where the perceived duality (i.e. all paradoxes) was united in God, the Creator of the world of nature and the designer of all that appears inexplicable to us. Then, people like Newton and Descartes used their belief in God to establish what we now call the Newtonian and Cartesian frameworks. More to the point, the idea of a God-created unity left science and philosophy unified, (Ione, 1995) for the belief in God sufficiently explained away all that was inexplicable in nature (Ione, 1995). Eventually, however, people like Nietzsche realized that science had effectively nullified God's role, for there was no need for Him if we lived in a mechanistic universe. When enough people declared that the emperor had no clothes (i.e. "God was dead") new forms of dualism arose to offer the means to bridge the paradoxes so often apparent in our theoretical and epistemological conclusions about who we are, why we are, why there is something rather than nothing. Today Chalmers "hard problem" and ideas that have developed out of quantum complementarity are among the solutions.

The critical point here is that many contemporary mainstream variations continue to be formulated within this traditional scope. Thus the models favor unified theories, the "purity" of physics, and the "underlying causation" perspective. Overall these ingredients have provided a recipe that has unsuccessfully wrestled with the need to accommodate the biological "messiness" of life. Contemporary difficulties reflect historical ones, and thus we continue to wrestle with the physics-based Platonic duality. This orientation inclines to theoretical ideals because the pristine reality that is valued is one devoid of time. The model has proved to be incredibly cumbersome to integrate into cultures, where continual change takes place in the world of time.

Returning to history illustrates that this bridging problem led the Platonic assumptions to play out like an informational processing model. On the whole, each stage of the historical story held an ideal in place while registering information from a preceding stage. Thus in most stages we find the cultural imagination sustained an ideal while the particulars were rearranged. For example, if we start with Plato, we find that while it *can appear* as if a Western focus on phenomena was born as the Greeks watched the puzzling motions of the wandering planets and categorized the world they knew. In actuality this was not the case. Greek logic, even Aristotelian logic, was based on mental construction and it was this reverence for mental construction that was first adopted by pagan and Christian culture and came to be the theoretical foundation of Western science (Ione, 1995).[18] This kind of mental construction remains a part of the Western mind today and, as I will demonstrate now, is reflected in information processing models and consciousness debates about the mind.

More specifically, Plato believed well-constructed metaphors could help others conceptualize the purity of a domain beyond our understanding.[19] Essentially Platonic metaphors were not intended to *function* as a tool in our lives so much as a means to *reveal* something we could discover with the mind's eye. Thus the metaphors were used to help us remember the pre-existent, archetypal Truth. They were tools dependent on reason and mathematics, the modes that enabled the mind to perceive what lies behind the sensory world, the world of appearances. Plato explains how this works using astronomy.

> [W]e must use the blazonry of the heavens as patterns to aid in the study of these realities, just as one would do who chanced upon diagrams drawn with special care and elaboration by Daedalus or some other craftsman or painter. For anyone acquainted with geometry who saw such diagrams would admit the beauty of the workmanship, but would think it absurd to examine them seriously in the expectation of finding in them the absolute truth. [Socrates to Glaucon, Book VII, 529e, *Republic* (Plato, 1989)].

In Plato's case astronomy was used for a geometrical design and the design could be categorized as a part of the larger study of cosmology. The cosmological approach that Plato adopted was a radical departure form earlier ones. Plato, though fully aware of the impressive astronomical observations made by the Babylonians and Egyptians, emphasized that they had no underlying or unifying theory and no explanation of the seemingly irregular motions of the planets. Eudoxus, who was a student at the Academy took up the problem of creating a unified theory in order to 'save the appearances.' Let me emphasize that Eudoxus' answer is the first reasonably complete, emphasis or so-called *complete,* astronomical theory known to history in the sense that it tried to do more than simply collect data and describe planetary

[18] It is ironic that by the time of Augustine (354–430), Bishop of Hippo in Africa, Plato's reverence for mathematics had been replaced by a scorn evident in the words of the esteemed Augustine himself. According to Augustine, "the good Christian should beware of mathematicians and all those who make empty prophecies. The danger already exists that the mathematicians have made a covenant with the devil to darken the spirit and to confine man to the bonds of Hell" (Kline, 1967, p. 1).

[19] Baars (1996) has noted that metaphor can be very misleading. "The history of science is filled with metaphors that explained some observations but then blocked further thought. Psychologists are familiar with the use and abuse of the "steam vessel" metaphor or emotion, which seems to guide many amateur psychotherapists. We know that "blowing off steam" has a ready interpretation when someone expresses suppressed anger with great intensity; it is often followed by a feeling of relief. But Freud's idea that a psychic equivalent to a steam vessel provides all the energy for bodily motion is no longer taken seriously, and there is indeed hard evidence that cultivating the habit of expressing anger does *not* lead to a more peaceful mental life. Just the opposite. The clinical researcher Seymour Feshback established some years ago that frequent deliberate practice in expressing anger only teaches people to express anger *more* often. In this respect the steam kettle metaphor actually leads to *less* adaptive behavior, when it is used for more than obtaining a moment of relief.

movement (Kline, 1982 , p. 24). The endeavor to correlate movement with planetary relationships resulted in a design so solidly built it lasted for 1500 years. But this astronomical model did not tell the whole story, much like information processing models today are limited.

Christopher Zeeman, a British mathematician, conveys that the limitations I am speaking of translated into the culture much like informational processing model. (This quote was a speculation on how the model lasted for so long in an article discussing the Antikythera mechanism.[20])

> First came the astronomers observing the motions of the heavenly bodies and collecting data. Secondly came the mathematicians inventing mathematical notation to describe the motions and fit the data. Thirdly came the technicians making mechanical models to simulate these mathematical constructions. Fourthly came generations of students who learned their astronomy from these machines. Fifthly came scientists whose imagination had been so blinkered by generations of such learning that they actually believed that this was how the heavens worked. Sixthly came the authorities who insisted upon the received dogma. And so the human race was fooled into accepting the Ptolemaic System for a thousand years" (Stewart, 1989, p. 7).

Let me reiterate that this complexion of change correlates with informational processing models if we define an informational processing model as a model where information is processed through a series of stages, each of which performs unique operations, registers information from a preceding stage, processes it, and then passes it along to another stage.

4.2 Connective Models

Connective models (e.g., see Varela, Thompson & Rosch, 1991) have been offered as an alternative to this conveyor belt type of information processing model. In my opinion, the connective model does not solve all of the problems we find in informational processing models. What the connective model does do is add content to the information that passes from stage to stage. Within this, the notion of operational closure is often used to define all life as a web of connections and capture the idea that of all is re-constituted on an ongoing basis.

> A system that has operational closure is one in which the results of its processes are those processes themselves. The notion of operational closure is thus a way of specifying classes of processes that, in their very operation, turn back upon themselves to form autonomous networks. Such networks do not fall into the class of systems defined by external mechanisms of control (heteronomy) but rather into the class of systems defined by internal mechanisms of self-organization (autonomy). The key point is that such systems do not operate by *representation.* Instead of representing an independent world, they enact a world as a domain of distinctions that is inseparable from the structure embodied by the cognitive system (Varela et al., 1991, p. 139–140).

Autopoiesis (auto – self and poiesis – making) is the term applied to the idea of ongoing reconstitution. The word was first introduced in 1973 by Humberto Maturana and Francisco Varela to refer to self-production and self-renewal of living systems. Let me emphasize that a living system is not a Platonic abstraction divorced from change and time. Nor is it an informational processing model, although it can include this mode in its description. Rather, an autopoietic network is self-bounded, self-generating, and self-perpetrating. It is a living system and includes the system's extension, a boundary, that is an integral part of the network. The key point here is that the system's production processes continue *over time,* and as they continue, all components are continually replaced by the system's processes of transformation. Thus the network and all components—including those of the boundary—are produced by processes within the network and all of the parts are replaced continually as the system itself continues. The most striking feature of an autopoietic system is that it pulls itself up by its own bootstraps and becomes distinct from its own dynamics, in such a way that both things are inseparable (Maturana & Varela, 1992, pp. 46–47).

This view adds to the informational processing construct by virtue of offering a means to explain that a mechanistic system is neither detached from its activity nor the kind of alternative offered by nineteenth century vitalism. On the contrary,

[20]This mechanism of thirty-two gear wheels found in 1900, may have been used by the early Greeks to compute the relationships between the sun and the stars.

the self-organizing mechanism of autopoiesis is a natural re-organization of the components which exist in relationship to one another and their environment. In addition, since mechanism infers an organization and the autopoietic system is a self-organization, it is not the non-biological Clockwork of a Cartesian system because, simply put, the autopoietic system is notprimarily concerned with the properties of components.

What the connective model cannot explain is how we reconceptualize patterns of organization. Context alone is not sufficient here. For example, our minds and our sense experience agree that that the sun circles the earth, rising in the east each morning and then setting in the west, just as the informational processing-like Ptolemaic model describes it. Yet we have learned that this earth-centered perception is an incomplete picture of the overall pattern of organization. Moreover, when combined with implicit assumptions, like the idea that only circles could explain planetary orbits correctly, the historical record shows that the combination of experience and intelligence had difficulty in formulating other options. Thus, information was re-organized and often embodied but neither of these modes necessarily upgraded the quality of our information.[21]

4.3 Emergent Models

The beauty of emergent models is that they acknowledge the value in upgrading the quality of our information and excel in clarifying the differences between description, context, and enlargement. It is because information processing models can overlap with emergent models that the Ptolemaic model can be seen as both an informational processing perspective and can be used to illustrate an emergent perspective.

To reiterate, Eudoxus invented the foundational geometry about 370 BCE. In doing so, he did not *merely* manipulate pre-existent data (code). Instead, something new was added to the previously known code. This addition extended human understanding of the relationships involved (in this case the relationships being planetary movements). I am terming this kind of innovation "emergent" and asserting that *emergent* consciousness, because it is emergent, has the capacity to address some of the problems theorists to date have had in intertwining science, sensation, perception, information, and consciousness.

Alywn Scott captures the quality of an emergent variable when he speaks of consciousness as emergent in the sense that our cognitive experiences do not simply pass from one level to the next, like climbing from one step on a stairway to the next one above or below it. According to Scott, it is more accurate to say that the components on each level are qualitatively different from those on the next level.[22] In other words the nature of consciousness is not (a linear) problem to be solved so much as a problem of framing how to consider several steps of the stairway together. (Scott, 1995). Scott writes,

> In taking a emergent view of consciousness—a view in which the phenomenon must be understood by examining many layers—I fully recognize that it is not an entirely orthodox or widely held position. Reductive materialists, in fact, insist on precisely the opposite view. And for many well-entrenched adherents of the reductionist school, with a fair degree of success in other scientific quests, it is difficult to concede that their swords are perhaps too blunt to cut consciousness down to size. Those who support a hierarchical perspective are fewer, if no less persuasive ... Part of the hesitancy to abandon the reductive tradition, I suspect, is rooted in a fear of disrupting certain articles of faith that go back many centuries (Scott, 1995, p. 160).

Of course, we have disrupted articles of faith and ideas repeatedly, often through innovative mathematical constructions. The mathematician Henri Poincaré once said mathematical constructions only become interesting when placed side-by-side

[21] It does, however, attempt to address the sterility of many laboratory models. *For example, although neurons in the visual cortex do have distinct responses to specific features of the visual stimuli, these responses occur only in an anesthetized animal with a highly simplified internal and external environment. When more normal sensory surroundings are allowed and the animal is studied awake and behaving, it has become increasingly clear that stereotyped neuronal responses become highly context sensitive* (Varela et al., 1991, p. 93).

[22] This is a key point for two reasons. First it is important to realize what it means to say that qualitative differences exist from level to level. As Scott points out, we can say that water's wetness and high dielectric constant are emergent properties because water does not share these properties with hydrogen and oxygen.

with analogous constructions (Poincaré, 1952). The intriguing factor that he is referring to aligns with Scott's idea of the stairway. In both examples the correlations do not compel us to descend to another level but leave us at the same level—with more information. Thus they allow us to be on several steps of the stairway together.

> Mathematics may, therefore, like the other sciences proceed from the particular to the general ... [Mathematicians] proceed 'by constructing,' they 'construct' more complicated combinations. When they analyze these combinations, these aggregates, so to speak, into their primitive elements, they see the relations of the elements and deduce the relations of the aggregates themselves. The process is purely analytical, but it is not a passing from the general to the particular, for the aggregates obviously cannot be regarded as more particular than their elements ... For a construction to be useful and not mere waste of mental effort, for it is to serve as a stepping-stone to higher things, it must first of all possess a kind of unity enabling us to see something more than the juxtaposition of its elements. Or more accurately, there must be some advantage in considering the construction rather than the elements themselves (Poincaré, 1952, pp. 14–15)

Since the historical goal has been to model the "truth" as if it is out there somewhere traditional models do not adequately address the difference between a model that is analogous to what is known—and a model that intends to give us more information than we already have. The difference between these two modes is a critical one that must be addressed in information and consciousness studies, for both modes are possible and bear different results. The important point is that the most effective models have the breadth to address the real need to continually educate new generations to cultural definitions and help then define their own perceptions of knowledge, truth, reality, and consciousness.

Thus, our definitions must have the capacity to use information to learn about information—especially if future generations are to *learn, expand, evolve,* and *exchange* on their own. This means that when we address how perception, sensation, phenomena, information, community, and consciousness actually fit together we must also address that each individual and each generation will re-think and re-form their own understanding of how all of the above are related. Each will learn cultural responses and in turn form their own responds to the scientific and cultural conclusions presented by the cultural at-large.

4.4 Computer Modeling Techniques

Computers have offered a means for gaining perspective on the possibilities discussed above. As machines that have the capacity to create analogous constructions and to use both serial and parallel processing, computers have shown they have the capacity to demonstrate what development on many levels is. More specifically, computers demonstrate we can develop the ability to quantitatively express information that we cannot yet explain.[23] One way computers do this is by modeling patterns and dynamics that simulate information and visually display apparently unrelated information. Finding the means to model what appears to be unrelated information relationally is in fact one way we bracket information. The beauty of this exercise of articulating the relationships is that it allows us to use information to reach beyond epistemological and ontological information.

In terms of consciousness studies these computer generated constructions can be defined as *phenomenological models* since they are models that have the capacity to combine information gained about human experience with the enhanced information management capabilities offered by the computer. What must be stressed is that these phenomenological models differ from theoretical and epistemological models by virtue of their ability to comprehensively bracket and *simulate* what real social, economic, and psychological behavior is in a quantitative and descriptive way. Of course, these computer-generated correlations cannot directly "tell" us about consciousness, for they *cannot* state the reasons *why* the apparent correlations exist. Nonetheless, this

[23] The idea that we can quantitatively represent information using computers has actually been in practice since the early 1980s, when computer graphics changed the general perception of mathematics by making the beauty of mathematical equations visual for all to see. Some of the names which are associated with the visual mathematics are fractals, strange attractors, chaotic dynamics, and complex dynamics. All of these names correspond to novel ways to define phenomena, consciousness, and information.

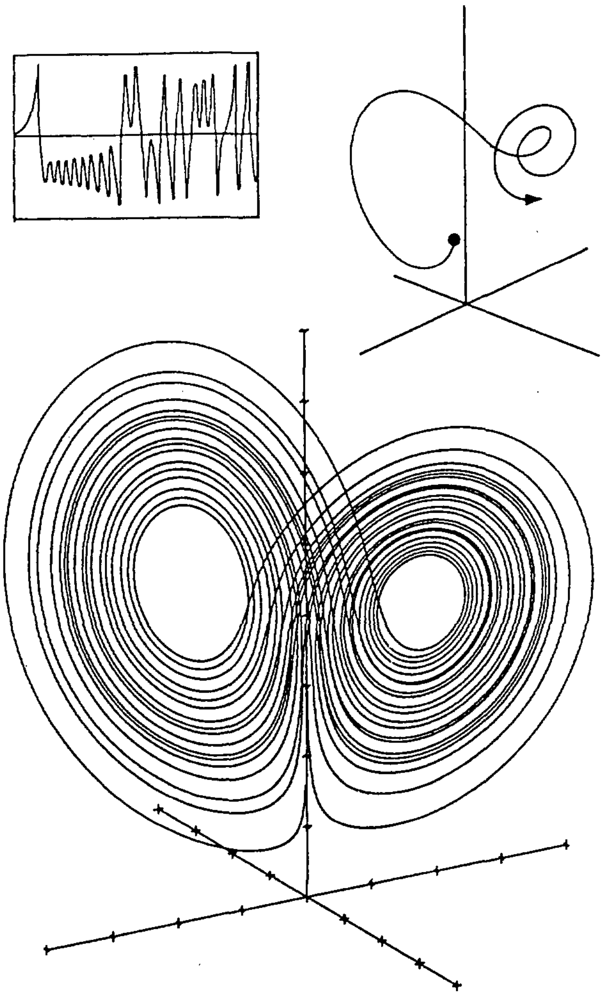

Figure 1: *A strange attractor.*

kind of quantitative modeling does effectively illustrate how information is—and becomes—a part of a larger selective system.

This idea of phenomenological computer modeling is useful in delineating the differences between self-organization and emergence, description and invention, consciousness and information. Being neither theoretical nor epistemological, computer models provide a *third* way of adducing information. It is a way that is enhanced by being able to simulate living dynamics. Thus, despite being non-biological, computers provide an innovative way of looking at human questions and it is a way that we could not even conceptualize using the traditional (and facing the traditional limitations) of the ontological and epistemological approaches.

The strange attractor (see Fig. 1) clarifies my point. The attractor is a phenomenological model in the sense that it offers a representation of a nonlinear system. This is a system where the rules were always unpredictable—like the weather.[24] The image itself is captured through combining computers and mathematics to model patterns of dynamics and fluctuation. What I want to emphasize is that the static representation on the page is a *picture* of the dynamic, it is not the attractor itself. The mapping, however, allows us to see how we can use coordinate points to bracket a dynamic in real-time. We can see visual evidence of a self-organizing pattern—and it is a pattern that appears chaotic without the plotting. What is most striking about this image is that the plotting holds the pattern of movement together as it changes in time, revealing details of the process. We can thus see the pattern emerge. We can see it takes form over time *and* we can see it never returns to a previous point. We can also see that the pattern shows an underlying order, despite its apparent non-linearity in the *real world.*

In sum, the strange attractor offers one example of how it is possible to model information that does not actually fit within either the traditional epistemological and ontological frameworks. The very existence of the attractor demonstrates we can invent alternative modeling possibilities. What makes the attractor relevant here is that it uses mathematical information and symbolic manipulation to show self-organization. In and of itself this does not suggest it also illustrates emergence. What makes this so is that the attractor is an invention that recently emerged.

5 Conclusion

Innovative multi-faceted symbol/metaphor creations, like the attractor, are innovations that allow us to challenge the closure offered by theo-

[24] The nature of weather systems, in fact, was one of the first areas where it became apparent that there were patterns in hard to predict systems and that these systems which appeared chaotic did so because they never exactly repeated the pattern and the points do not intersect with a historical pattern but loop around and around forever. Modeling the behavior of weather on a computer suggested a pattern self-organized with a bounded nonlinearity, and with it the ideas of some kind of *attractor*. The map displayed a kind of infinite complexity. It was a shape of pure disorder, and signaled a new kind of order (Gleick, 1987).

ries like Baars' unification and Chalmers' dualism. Conceptualizing the creative aspect within the attractor is critical to individual life and the culture at large if we want to engage with the kind of symbolic representation that can be used to enlarge our scope. More specifically, it is because our ongoing learning process is intergenerational that we will benefit in articulating that information in and of itself does not include an enlargement of scope. As the Ptolemaic model shows there are no guarantees as to how our symbols and our ideas will be revised and, if we view the possibilities only as conceptual ideas we miss their living quality.

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References

[1] BAARS, B.J. 1988. A Cognitive Theory of Consciousness. Cambridge University Press. Cambridge.

[2] BAARS, B.J. 1996. In the Theatre of Consciousness: the Workspace of the Mind. Oxford University Press. Oxford.

[3] CHALMERS, D.J. 1996. The Conscious Mind: in Search of a Fundamental Theory. Oxford University Press. New York and Oxford.

[4] DAVIS, P.J. & R. HERSH. 1981. The Mathematical Experience. Houghton Mifflin Paperbacks. Boston.

[5] DREYER, J.L.E. 1953. A history of astronomy. Cambridge: Dover Publications, Inc. Einstein, A. (1973). Ideas and Opinions. Dell. New York.

[6] GALILEI, G. 1957/1610. The starry messenger (in Discoveries and opinions of Galileo). Trans. Drake & Stillman. Doubleday Anchor Books. New York.

[7] GLEICK, J. 1987. Chaos: Making a New Science. Penguin Books. New York.

[8] HADAMARD, J. 1973. The Mathematician's Mind: the Psychology of Invention in the Mathematical Field. Princeton University Press. Princeton.

[9] HOLTON, G.J. 1996. Einstein, History, and Other Passions: the Rebellion Again Science at the End of the Twentieth Century. Addison-Wesley Publishing Company. Reading, MA.

[10] IONE, A. 1995. Nature Exposed to Our Method of Questioning. Master's. John F. Kennedy University.

[11] KLINE, M. 1967. Mathematics for the Nonmathematician. Dover Publications. New York.

[12] KLINE, M. 1982. The Loss of Certainty. Oxford University Press. Oxford.

[13] KOESTLER, A. 1959. The Sleepwalkers. Arkana. London.

[14] MATURANA, H.R. & F.J. VARELA. 1992. The Tree of Knowledge: the Biological Roots of Human Understanding. Shambhala. Boston & London.

[15] PLATO. 1989. The Collected Dialogues of Plato. E. Hamilton & H. Cairns, Eds. Princeton University Press. Bollingen.

[16] POINCARÉ, H. 1952. Science and Hypothesis. Dover Publications. New York.

[17] SCOTT, A. 1995. Stairway to the Mind: the Controversial New Science of Consciousness. Springer. New York.

[18] SHANNON, C.E. 1948. A mathematical theory of communication. Bell Systems Technical Journal 27:379–423.

[19] STEWART, I. 1989. Does God Play Dice?: the Mathematics of Chaos. Penguin Books. Cambridge.

[20] VAN HELDEN, A. 1995. The Galileo Project. Rice University. http://es.rice.edu:80/ES/humsoc/Galileo.

[21] VARELA, F. J., E. THOMPSON & E. ROSCH. 1991. The Embodied Mind: Cognitive Science and Human Experience. The MIT Press. Cambridge & London.

Anticipation, Perception, Language, Mind and Nonlinear Dynamics of Neural Networks

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It is considered how some mental phenomena can be imitated with the aid of neural networks. Representation of information in neural systems is discussed as well as two levels of their description ("hardware" and "software"). Perceptual, lexical and semantic spaces are introduced at the level of "software". Data on the meaning of phonemes, words and nonverbal signs are summarized in three theses, and ways of producing new meanings are considered. The conception is developed that perception consists of attempts to recognize the object and includes generation and verification of hypotheses. Any such a hypothesis being produced in advance yields a forecast of the future. Two mechanisms of such anticipation are discussed: (i) pre-excitation of attractors of the network dynamics; (ii) associative generation of information in the semantic space. Existence of different kinds of thinking and memory is explained. Reflection and self are considered as mathematical constructions in the semantic space. Consciousness is finally interpreted as a process of neural activity structured so that a hierarchy of attractors appears in the activity space. Nonlinear stochastic models of dynamics of neural activity are suggested. Their general properties are analytically studied: bounds of phase trajectories, global attractors, restrictions on the storage capacity and sizes of basins of attraction around stored patterns. Particular models are investigated as well. The learning problem is reduced to a standard form.

1 Introduction

One of the most fascinating problems concerning mental phenomena is to understand principles and dynamical mechanisms of *anticipation* of the future. It is considered that the ultimate purpose of the nervous system is to perceive signals (stimuli) from the surroundings and respond to them by some kind of activity on the basis of the probabilistic forecasting of future events. Even the simplest forms of behavior, the unconditioned reflexes, rely on certain "built-in" expectations based on regularities of events. Any such a reaction may serve for survival of the organism in so far as it produces activity which appears useful as the most probable course of events occurs in reality, otherwise the reflex action would be, at best, useless. The role of anticipation of the future increases greatly as one turns to more complex kinds of behavior such as conditioned reflexes (see Appendix A for more detail).

The first question arises naturally: what makes it possible to anticipate events? In principle, the answer is known: some groups of events of the world occur in a certain time order and, besides, their sequences repeat themselves in time. Such connections, *associations*, of events are fixed in the memory and serve as a basis for anticipation of the future.

The next question is at which stages of information processing (IP) anticipation occurs. It turns out that anticipation appears even in the process of *perception* of a stimulus (and may also accompany other, subsequent, steps of IP). Thus, the conception developed in the paper is that *perception is based on association of events in the past and appears to be anticipation of future events* [Bruner, 1957; Pribram, 1971; Sokolov, Vatkyavichus, 1989; Linkevich, 1994]. In other words, we suppose that the process of perception of an object consists of attempts to *recognize* the object and includes generation and verification of *hypotheses* what the object is. There are experimental observations (both from biology and from psychology) in favor of treating perception in such a way. This mechanism turns out to be effective and has certain advantages. In particular, (i) this is time- and energy-saving because usually, in most cases of everyday life, only a part of features are called from detectors and processed in order to recognize the object; (ii) hypotheses can be generated even *in advance*, before an object does really appear; this may be essential for survival. Any such a hypothesis being produced beforehand yields really a certain forecast of the future.

The question is, however, *how hypotheses can be generated.* A random production of variants proved to be exhausting. This became quite clear after attempts to realize such a strategy in artificial intelligence systems. It seems that the only possible way out is *associative generation of information*, i.e. producing patterns (pieces of information) that are close to some previous ones [Kapelko, Linkevich, 1996]. A hypothesis may only be plausible and promising if it is based on associations between events appeared in the past, but such events are close to each other as regards their meaning. Therefore stored pieces of information should be ordered in a way according their meanings.

Thus, we come to necessity to investigate *meanings* associated with patterns and this approaches us to a wide area of intriguing problems connected with *language*. This subject may also be essential because the use of language facilitates significantly production and verification of hypotheses. On the other hand, investigating semantic problems, we are faced with the eternal question "What is it?" as regards *consciousness, mind, thinking, will, self*, and we have to suggest, analyze and use some assumptions.

As a general basis of the study of the problems mentioned above, we take the principles of *connectionism* (or parallel distributed processing (PDP) approach) which represents a system (like the human brain) as a network of interconnected units (nodes) that evolve in time under control of their own dynamics and make influence on the state of each other (see, e.g., [Churchland, 1989; Cowan, Sharp, 1988; Farmer, 1990; Hopfield, 1982, 1984; Pineda, 1987; Rumelhart, McClelland, 1986; Rumelhart, Hinton, Williams, 1986; Smolensky, 1988]).

More specifically, our approach is close to the *attractor neural networks* paradigm [Hopfield, 1982, 1984] according which any stored piece of information (pattern) is represented by an attractor of the network dynamics, and information processing is associated with the network time evolution. Dynamics of a neural network (NN) can be treated as a decision-making process distributed both in space (each neuron takes its own decision) and in time (the decision is taken either in a series of steps if the state of the NN evolves in accordance with an iterated map, or during a time interval as differential equations describe time evolution of the NN) (for introduction into NN's see, e.g., [Amit, 1989; Frolov, Murav'ev, 1987, 1988; Hertz, Krogh, Palmer, 1991; Peretto, 1989; Vedenov, 1988]).

In contrast to the original NN's approach, we distinguish two levels of the description of the network dynamics given respectively by the time evolution of the *state* of the system and by the time evolution of *activity* of the NN, and any stored piece of information is represented by an attractor in an activity space so that the time evolution of the neural activity yields information processing (a more precise formulation of the approach adopted in our paper is given in the next section). Of course, the aim of the present paper is not to develop a theory of consciousness, mind, thinking, etc., but only to discuss how some mental phenomena could be imitated with the aid of NN's, and our primary concern is anticipation of the future.

A part of the results given in the paper were presented before, in a preliminary form, at meetings [Linkevich, 1994, 1996a, 1996b, 1997].

The paper is organized as follows. In the next section we discuss the question how information is encoded in neural systems and consider two levels of their description, viz. "hardware" and "software". A way to determine the meaning of words is examined in Sect.3 where three interconnected NN's (perceptual, lexical and semantic) are introduced and their activity spaces ("software") are interpreted as perceptual, lexical and semantic spaces respectively. Data on the meaning of phonemes, words and nonverbal signs are summarized in three theses in Sect. 4 where ways of generation of new meanings are considered as well. In Sect. 5 we suggest nonlinear stochastic models of dynamics of neural activity, and the learning problem is reduced for them to a standard form in Sect. 6. General properties of the proposed models are analytically studied in Sect. 7, whereas some particular models are investigated in Sect. 8. Anticipation in the process of perception is analyzed in Sect. 9 on the basis of a mechanism of pre-excitation of attractors. Sect. 10 contains a discussion of central points of mental phenomena: consciousness, reflection, self, thinking, memory. We complete by conclusions and discussion of some prospects and problems. Appendix A is devoted to an overview of some conceptions on the mind and behavior connected with anticipation of the future, while in Appendix B we give a brief account of data on the meaning of different signs.

2 Representation of Information in Neural Systems and Two Levels of Their Description

The first question that should be attacked is *how information is encoded in neural systems.* In the connection with the problem of information representation, it is discussed the role of successive action potentials (spikes) propagating along nerve axons. There are a broad spectrum of opinions from statements that spikes are irrelevant at all to theories in which the spike structure is essential. The reason of the controversies over internal representation of information is that the timing of spikes is highly irregular. There are two main candidates for neural codes: (i) information is encoded by the spike rate of neurons whereas the irregularity is stochastic and responses of many neurons must be averaged out [Adrian, 1928; Hopfield, 1982]; (ii) information is represented in the precise structure of individual spikes [Abeles, 1982; Softky, Koch, 1993].

It is mostly believed that information is mainly encoded by the neuron firing frequency. Recent experimental data apparently support this classical notion [Shadlen, Newsome, 1994] (for discussion of different ways of information encoding see [Bechtereva et al, 1985; Sokolov, Vatkyavichus, 1989; Freeman, 1992; Toulouse, 1992; Amit, 1994]). It is worth noting also that fractal structures were observed in spike patterns [Usher et al, 1994].

Taking into account data on the role of spikes we adopt the following outline [Linkevich, 1994]. Let us consider a neural network (NN) composed of N neuron-like elements such that the *state* of neuron i ($i = 1, \dots, N$) at time moment t is determined by a real M-dimensional vector $x_i(t) = (x_i^1(t), \dots, x_i^M(t))$ whose time evolution is governed by some differential equations or iterated maps. The state of the NN is given by the NM-dimensional vector $X(t) = (x_1(t), \dots, x_N(t))$.

In view of the role of spikes we introduce an additional variable $\omega_i(t)$ referred to as *activity* of neuron i at moment t. This is a real scalar nonnegative quantity that can be treated in one of the following ways: (i) the firing frequency of the neuron, or the current mean (average) rate of impulses (spikes); (ii) the probability of generation of the action potential by the neuron; (iii) the total (summarized) synaptic excitation of the neuron (see, e.g., [Frolov, Murav'ev, 1987]). Activity of the NN is given by the N-dimensional vector $\omega(t) = (\omega_1(t), \dots, \omega_N(t))$.

Thus we deal with the two following levels of description of a NN: (i) "*hardware*" of the system is given by the *state* of the NN described by the state vector $X(t)$; time evolution of the system is represented by the phase trajectory in the *state space* (X-space); (ii) "*software*" is given by *activity* of the NN described by the activity vector $\omega(t)$; time evolution is represented by the trajectory in the *activity space* (ω-space). *Connection* between them is determined by instantaneous input-output transfer functions of neurons $f_i(\cdot)$ such that $\omega_i(t) = f_i(x_i(t)), \quad i = 1, \dots, N.$

Commonly accepted assumption is that the firing frequency $\omega_i(t)$ of a neuron i depends only on its membrane potential $u_i(t)$ so that $\omega_i(t) = f_i(u_i(t))$ (see, e.g., [Freeman, 1992]). (Properties of the transfer functions are discussed in more detail in Sect. 5 below).

Now we can formulate our suggestion about *representation of information* in a NN. Any pattern (piece of information) stored in a NN is represented by an attractor (a set of non-wandering points) in the activity space of the NN (provided that the corresponding $\omega \neq 0$). Information processing performed by the NN is treated as time evolution of activity of the NN described by the vector $\omega(t)$.

3 Language and Neural Networks: Perceptual, Lexical and Semantic Spaces

As is known, a distinctive feature of the human being is the ability to use language in a number of ways. Therefore it is reasonable to begin with consideration how words and strings of words, sentences, that constitute language can come into play during IP [Linkevich, 1996a].

By words we will mean in what follows not only words by themselves, but also compound words, idioms and perhaps some collocations, set expressions, phrases and some other word groups that mean something different from the meanings of their separate words.

Let us address ourselves to ways *how to determine the meaning of a word.* In this work we deal mostly with the simplest approach, viz. *definitio ostentus*, i.e. definition by means of direct showing, familiarization of a learner with things, actions, situations, etc. This can be illustrated with the known Ogden - Richards [1938] triangle whose vertexes are (i) the name of a word; (ii) a denotation, i.e. an object (thing, action, etc.) that is actually named or described by the word; (iii) the meaning (sense) of the word.

To implement this scheme, we introduce three interconnected networks, viz. perceptual, lexical and semantic, and their activity spaces A_p, A_l, A_s will accordingly be referred to as *perceptual space* (PS), *lexical space* (LS) and *semantic space* (SS) (see Fig. 1). Our designations are summarized as

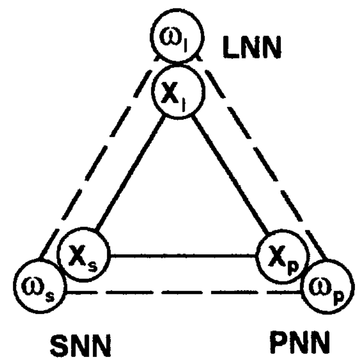

Figure 1: *Perceptual, lexical and semantic neural networks (PNN, LNN, SNN) for which the state is described by state vectors* X_p, X_l, X_s *respectively whereas activity is given by vectors* $\omega_p, \omega_l, \omega_s$. *Solid lines indicate connections between neurons of different networks while dashed lines mark associations between attractors in their activity spaces.*

follows:

– perceptual neural network (PNN)

state	$X_p(t) \in S_p \subset \mathbf{R}^{M_p N_p}$
activity	$\omega_p(t) \in A_p \subset \mathbf{R}_+^{L_p}$
attractors	$\xi^\kappa \equiv \tilde{\omega}_p^\kappa \in A_p,$
	$\kappa = 1, \dots, K_p;$

– lexical neural network (LNN)

state	$X_l(t) \in S_l \subset \mathbf{R}^{M_l N_l}$
activity	$\omega_l(t) \in A_l \subset \mathbf{R}_+^{L_l}$
attractors	$\eta^\lambda \equiv \tilde{\omega}_l^\lambda \in A_l,$
	$\lambda = 1, \dots, K_l;$

– semantic neural network (SNN)

state	$X_s(t) \in S_s \subset \mathbf{R}^{M_s N_s}$
activity	$\omega_s(t) \in A_s \subset \mathbf{R}_+^{L_s}$
attractors	$\sigma^\mu \equiv \tilde{\omega}_s^\mu \in A_s,$
	$\mu = 1, \dots, K_s$

Here, for any value of index q which stands for p, l or s (i.e. perceptual, lexical or semantic), one deals with the state vector of the NN $X_q(t) = (x_{q1}(t), \dots, x_{qN_q}(t))$ composed of the state vectors of neurons $x_{qi}(t) = (x_{qi}^1(t), \dots, x_{qi}^{M_q}(t))$, $i = 1, \dots, N_q$, and the activity vector

$\omega_q(t) = (\omega_{q1}(t), \dots, \omega_{qN_q}(t))$. We use the sign $\sim$ to denote attractors.

We suppose that (i) any *percept* (i.e. a mental image of an object as it appears in the mind after perception) is represented by some attractors $\xi^\kappa \equiv \tilde{\omega}_p^\kappa$ in the *perceptual* space (the activity space A_p of the perceptual NN); (ii) any *word* known to the neural system is given by an attractor $\eta^\lambda \equiv \tilde{\omega}_l^\lambda$ in the *lexical* space A_l; (iii) any *meaning* understandable to the system is treated as an attractor $\sigma^\mu \equiv \tilde{\omega}_s^\mu$ in the *semantic* space A_s.

A particular case will be studied below in more detail when attractors in all the activity spaces that correspond to stored patterns are stable fixed points.

As we deal with the three spaces, there are three kinds of topology and three kinds of associations between objects.

(i) Patterns close in the *perceptual* space represent, e.g., pictures that differ from each other in some details only. A known example is pictures (e.g., photos) of the face of just the same person, but with different shapes of eyebrows and lips (see Fig. 2). Names of words that describe emotions corresponding to such pictures are not close, however, to each other as well as their meanings.

(ii) The *lexical* space brings implementation of a vocabulary. As is known, any language contains a great many of words with close or even the same pronunciation and/or spelling (homonyms, homophones, homographs, and others) which can be used to denote different objects and different meanings.

(iii) Closeness in the *semantic* space is generated, in particular, by synonyms, i.e. words with the same or nearly the same meanings.

There are neurobiological data (see, e.g., [Bakhur, 1986; Bechtereva et al, 1985]) that can be treated in favor of our general scheme in which the neural system includes relatively independent subsystems like the PNN, LNN, SNN.

The learning of a system composed of the PNN, LNN and SNN may briefly be described as follows. During the learning stage a teacher provides input signals Φ^α and Ψ^α, $\alpha = 1, 2, \dots$, to the PNN and LNN respectively. As the synaptic couplings are appropriately adjusted, attractors ξ^α and η^α, $\alpha = 1, 2, \dots$, are formed in their activity spaces. Owing to interconnections between neurons of all the three NN's, attractors σ^α, $\alpha = 1, 2, \dots$, appear in the SS as well. Thus, associations between the patterns ξ^α, η^α and σ^α are produced. (Really a number of patterns $\xi^{\alpha_1}, \xi^{\alpha_2}, \dots$ correspond to any pair $\eta^\alpha, \sigma^\alpha$).

Performance of the system can be classified as follows.

(i) As an input signal $\tilde{\Phi}^\alpha$ close to some sample input Φ^α enters the PNN, its state converges toward the corresponding attractor so that the pattern ξ^α is retrieved. Besides, the lexical and semantic patterns η^α and σ^α associated with this ξ^α are restored due to interconnections between the NN's.

(ii) Similarly, as a signal $\tilde{\Psi}^\alpha$ appears close enough to some sample input vector Ψ^α, the corresponding pattern η^α and hence the associated patterns ξ^α and σ^α are given use to due to intrinsic dynamics of the interconnected NN's.

A kind of performance is also revealed due to appearance of an attractor in the no-signal condition. By appearance of an attractor $\tilde{\omega}$ we mean that due to IP (i.e. due to time evolution of the NN's) activity of the NN converges toward this $\tilde{\omega}$ when no input signal exists. Accordingly, we have the following two cases.

(iii) Appearance of a word (attractor) η^α produces the corresponding attractors ξ^α and σ^α.

(iv) If a state $\tilde{\sigma}^\alpha$ occurs close enough to some meaning (attractor) σ^α, convergence of activity toward this attractor σ^α takes place, and activities of the PNN and LNN approach the corresponding attractors ξ^α and η^α.

4 Some Properties of Semantic Space

A great deal of data concerning the meaning of phonemes, words and nonverbal signs were accumulated and used in a number of areas of human activity: science (semantic linguistics and hermeneutics, psychosemantics, phonosemantics, etc.), medical treatment, religion, art, etc. The data may be summarized in the following statements (which are briefly argued and illustrated in Appendix B by observations from various fields).

Thesis 1 *There exists a primary semantics, i.e.*

(i) there is a system of primary semantic factors (PSF's) which are the most general, leading, deep, initial meanings;

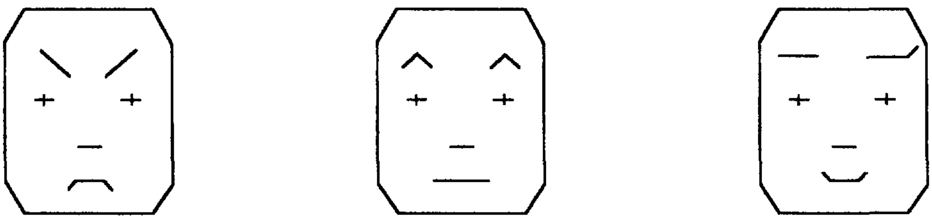

Figure 2: *Schematic faces expressing different emotions by distinguishing shapes of eyebrows and lips [McKelvi, 1973].*

(ii) this system is universal, i.e. the set of factors and the structure of connections between them are invariant with respect to language, culture, level of education, etc. of people (and even such a mental illness as schizophrenia does not disturb the system);

(iii) the system is invariant with respect to modality and kind of signs, i.e. the same for phonemes, words, visual images, etc. □

Thesis 2 *The meaning of a PSF is associated with the state and reaction of the organism after the action of stimuli (signals) that possess this semantic feature.* □

In more detail, roots of PSF's may be explained as follows.

Obviously, different stimuli (sounds, light, colors, etc.) may result in different states and reactions of the organism (emotions and feelings, changes of physiological parameters, reflexes, actions, etc.). However, at least a part of stimuli can be broken down into several large groups according to similarity of states and reactions produced by them. For any such a class of stimuli, the system of common features of states and reactions produced by all of them is just what is referred to as a PSF as it is embodied in the organism. More precisely, a PSF gives rise to a *connotative meaning* of a sign, i.e. a certain state of an individual that follows perception of the sign and precedes any conscious operations with it [Osgood, Suci, Tannenbaum, 1957].

Thesis 3 *PSF's are inborn or at least predisposed. (A baby can also recognize phonemes without any learning). All the other meanings are formed on that basis due to the learning for all the life. An adult human being has a hierarchical multilayer system of meanings.* □

Experimental studies in semantics revealed the three main PSF's : *appraisal, strength* and *activity* (see [Osgood, 1952, 1962, 1966; Osgood, Suci, Tannenbaum, 1957; Bentler, LaVoie, 1982; Petrenko, 1988; Zhuravlev, 1991] and Appendix B for more detail). (In addition, other PSF's were found in some studies).

The *strength* and *activity* of a phoneme is generated by its acoustic properties rather than by meanings of any words. Namely, it is phonetic features of sounds listed below that determine how a phoneme is perceived:

consonants:	hard	—	soft;
	voiced, sonant	—	voiceless;
vowels:	long	—	short;
	high-pitched	—	low-pitched.

The revealed regularities are rather universal, mostly the same for different languages. Linguistic and national features hardly manifest themselves in contract to the third PSF, *appraisal.*

The *appraisal* of a phoneme is determined not only by its acoustic properties, but also by specific features of the phonetic structure of the language. A number of phonemes in different languages have similar positions, but there are also sharp differences. The less phonetic similarity of the languages under comparison is, the greater is the number of differences. The SF in question is rather human, psychological than physical. The *appraisals* are rooted in emotional reactions: positive (pleasant) emotions and feelings is the background of positive (approving) *appraisals.*

In studies in semantics, any semantic factor (SF) is represented as a scale in some semantic space (SS) (e.g., good—bad, bright—dark, simple—complex, etc.) and a primary semantic factor (PSF) is treated as a group of close scales, or as a dimension of the SS (see Appendix B for more detail). Then new meanings may appear only due to generation of new dimensions of the SS, which seems to be an obvious disadvantage of the approach[1].

In contrast, the attractor neural networks paradigm brings a scheme in which a SF is represented by an attractor in the SS of the NN in such a way that close, in a sense, SF's are mapped into close attractors. Then one can indicate following ways of generation of new meanings:

(i) "Building onto pyramids", i.e. producing such multilayer structures that an attractor of a higher level has associations (correlations) with attractors of lower levels, and production of new meanings is building new attractors onto the "pyramid" of the attractors that correspond previous meanings (similar ideas were discussed in [Nicolis, 1986]).

(ii) "Gardening the phase landscape" when higher-level attractors are embedded into lower-order attractors, i.e. a set of fine attractors are formed inside the basin of attraction of a former attractor so that a hierarchical system of attractors (meanings) may be produced. The level of the hierarchy at which the system operates depends upon the level of noise in the NN. The lower is the level of noise, the finer structure of attractors are "seen" by the NN. In turn, the level of noise is reduced as efforts are undertaken to increase attention; one can write symbolically that *noise* $\sim 1/$*attention*.

(iii) New attractors (meanings) may also be produced by a dynamical mechanism of the associative generation of information based on the transition *fixed point* $\to$ *chaotic attractor* $\to$ *new fixed point* [Kapelko, Linkevich, 1996].

[1]Notice that the notion of the semantic space (SS) in the studies above mentioned differs from that in the approach adopted in our paper.

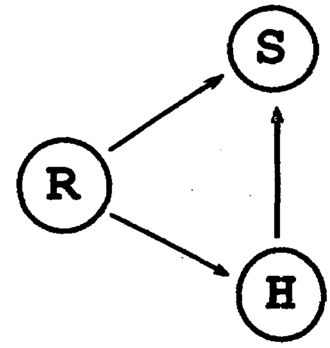

Figure 3: *Different ways of obtaining models of neural activity: R—a real biological neural system (a part of the brain); H—a model of "hardware" of the NN, i.e. a model of dynamics of the state of neurons; S—a model of "software" of the NN, i.e. a model of dynamics of activity of neurons.*

5 Models of Dynamics of Neural Activity

Let us address ourselves to the question how time evolution of activity of a NN can be described mathematically. There are, in principle, two ways of obtaining models of neural activity as illustrated by Fig. 3. We will go by the way $\mathbf{R} \to \mathbf{S}$, i.e. from the *real* biological neural system toward a model of *"software"* of the NN, although the transition $\mathbf{H} \to \mathbf{S}$ from a model of *"hardware"* of the NN toward a model of *"software"* could be of interest especially taking into account that a closed self-consistent description of the "software" dynamics may not be achieved for any process and any phenomenon (see, e.g., Sect. 9). (Examples of H-models can be found in papers [Hodgkin, Huxley, 1952; FitzHugh, 1961; Nagumo et al, 1962; Hindmarsh, Rose, 1982, 1984; Rose, Hindmarsh, 1985; Hopfield, 1984] whereas S-models are considered in [Wilson, Cowan, 1972, 1973; Frolov, Murav'ev, 1987, 1988; Pineda, 1987; Grossberg, 1988; Braham, Hamblen, 1990]).

We assume that activity of a NN obeys the following (stochastic) differential equations

$$\dot{\omega}_i = F_i(\omega) \equiv a_i(\omega_i) + b_i(\omega_i)\, f_i(u_i), \quad i = 1, \dots, N \tag{5.1}$$

where a real nonnegative variable $\omega_i \in \mathbf{R}_+$ describes impulse *activity* of neuron i. The real function $a_i(\omega_i)$ determines dynamics of activity of neuron i in the case when this neuron is not affected by other neurons nor by external input signals, while the function $b_i(\omega_i)$ is associated with a change of activity due to interaction with other neurons and external influences; $f_i(u_i)$ is the instantaneous input-output transfer function of neuron i. The membrane potential of the neuron

$$u_i = \sum_{j=1}^{N} T_{ij}\,\omega_j + I_i + \xi_i \qquad (5.2)$$

depends, generally speaking, upon activity of all the neurons of the NN due to interneuronal (synaptic) couplings. The synaptic efficacy T_{ij} determines the strength of the influence of activity of neuron j on the rate of change of activity of neuron i. An external (e.g., sensory) input signal entering neuron i is given by the quantity I_i, and $\xi_i = \xi_i(t)$ is a real stochastic variable. We will present in Sect. 7 an analytic investigation into some properties of the system (5.1) under rather wide conditions imposed on the functions $a_i(\cdot), b_i(\cdot), f_i(\cdot)$ while, here we consider specific forms of these functions.

We begin with *dynamics of activity of a single isolated neuron* described by the first term of Eq. (5.1):

$$\dot{\omega} = a(\omega)$$

The simplest, *linear model*, is given by the equation (see Fig. 4a)

$$a(\omega) = -\alpha\,\omega + \beta \qquad (5.3)$$

with $\alpha, \beta = const$, $\alpha > 0$ (commonly $\beta = 0$) and considered in [Wilson, Cowan, 1972, 1973; Frolov, Murav'ev, 1987, 1988; Pineda, 1987; Grossberg, 1988; Braham, Hamblen, 1990].

The above model seems, however, too simplified. Therefore we introduce the *cubic model* in which

$$a(\omega) = -\alpha\omega^3 + \beta\omega + \gamma \qquad (5.4)$$

and $\alpha, \beta, \gamma = const, \alpha > 0$ (see Fig. 4b). This choice is brought on by the FitzHugh model [FitzHugh, 1961], the known Prigogine theorem [Nicolis, Prigogine, 1977] and its extensions [Dyljudenko, Krot, 1996] while, the biological motivation is that the function $a(\omega)$ should contain a negative resistance region which is essential for the maintenance of oscillations in bursting neurons [Wilson, Wachtel, 1974].

Yet another form of the function $a(\omega)$ that reproduces the remarkable N-like shape with a negative resistance region is given by the *piecewise - linear model* (see Fig. 4c)

$$a(\omega) = \begin{cases} -h\,\omega + (q+h), & \omega \geq 1 \\ q\,\omega, & -1 < \omega < 1 \\ -h\,\omega - (q+h), & \omega \leq -1 \end{cases} \qquad (5.5)$$

where q and h are positive constants. For the FitzHugh model, such a parametrization was used in [Abbott, 1990; Kepler, Merder, Abbott, 1990] and proved to be providing even better asymptotic description of experimental data on the neuron current as a function of the membrane potential than a cubic form.

As regards the function $b(\omega)$, we will deal in what follows with the simplest choice $b(\omega) = 1$.

Let us turn to the neuron input-output transfer function $v = f(u)$. The main properties of this function essential for our consideration are supposed to be the following (see Fig. 5a):

(i) there is a threshold value u^0 such that $v = 0$ for all $u \leq u^0$;

(ii) the function $f(u)$ is bounded from above, i.e. there is such a constant C that $f(u) \leq C$ for all $u \in \mathbf{R}$. Without loss of generality we set $C = 1$. Then from (i), (ii) we have that $0 \leq f(u) \leq 1, \quad \forall u \in \mathbf{R}$;

(iii) the function $f(u)$ is monotone nondecreasing.

These conditions are in agreement with experimental data (see, e.g. [Freeman, 1992]).

As a specific choice of the transfer function that meets the above requirements, one can take the Freeman [1987, 1992] form (see Fig. 5b)

$$v = \Phi(u) = \\ = \begin{cases} \tilde{v}\left\{f_1 - \exp\left[-\frac{\exp(f_2 u) - f_3}{f_4}\right]\right\}, & u > u^0 \\ 0, & u \leq u^0 \end{cases} \qquad (5.6)$$

where $u^0 = \frac{1}{f_2}\ln(f_3 - f_4 \ln f_5)$ and $\tilde{v}$, f_1, f_2, f_3, f_4, $f_5 = const$. This parametrization provides us with a reliable description of experimental data on electroencephalograms when $f_1 = 2, \quad f_2 = f_3 = 1, \quad f_4 = Q, \quad f_5 = 1 + 1/Q$ and the parameters $\tilde{v}$ and Q are adjusted. In our studies, the Freeman function $\Phi(u)$ was mainly used with $\tilde{v} = \kappa(1+\kappa)^{-1}, \quad f_1 = f_5 = 1 + 1/\kappa, \quad f_2 = f_3 = 1, \quad f_4 = \kappa$ and the parameter κ was varied from 1 to 10.

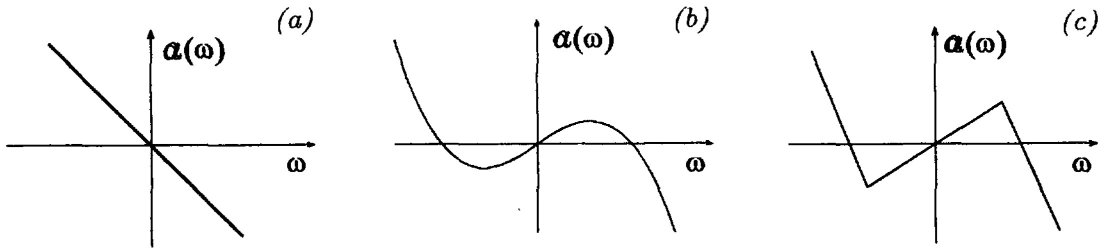

Figure 4: *Different forms of the function $a(\omega)$ which determines dynamics of a single isolated neuron: (a) the linear model given by Eq. (5.3); (b) the cubic model (5.4); (c) the piecewise-linear model (5.5).*

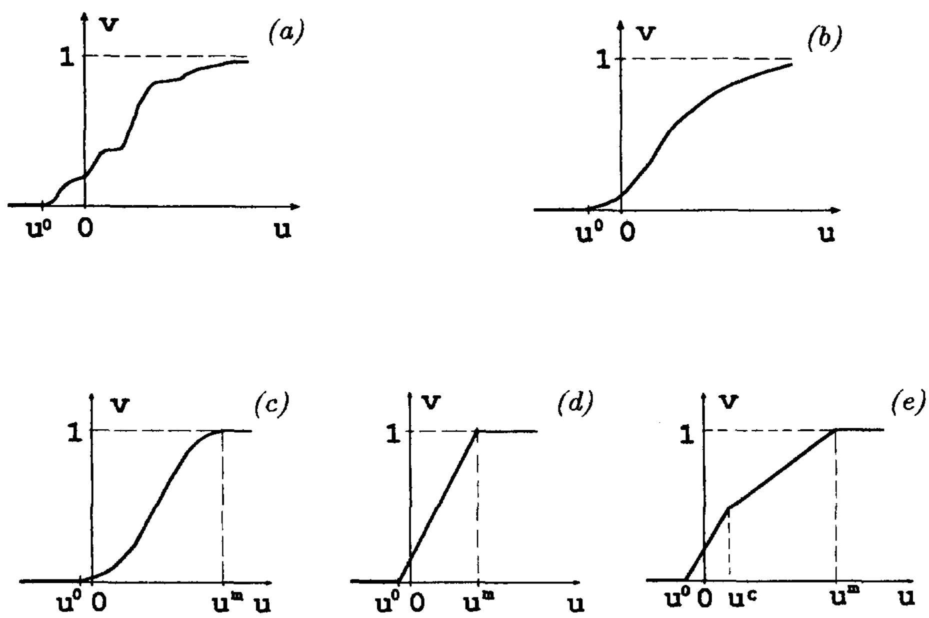

Figure 5: *Different forms of the neuron transfer function $v = f(u)$: (a) a function of a generic form with the threshold value u^0; (b) the Freeman [1987, 1992] parametrization (5.6) of data on electroencephalograms; (c) the sin-function (5.7) due to Braham [1989]; (d), (e) the piecewise-linear forms proposed in [Michel, Si, Yen, 1991] and [Linkevich, 1996b] respectively.*

A more simple form was proposed in [Braham, 1989] (see Fig. 5c):

$$v = \begin{cases} 1, & u \geq u^m \\ \frac{1}{2}\left[1 + sin\left(\pi \frac{u-u^0}{u^m-u^0} - \frac{\pi}{2}\right)\right], & u^0 < u < u^m \\ 0, & u \leq u^0 \end{cases} \quad (5.7)$$

Here u^0 and u^m are constants.

Piecewise-linear functions were used as well [Michel, Si, Yen, 1991; Linkevich, 1996b] (see Figs. 5d, 5e).

Yet another description of the connection between the "software" and "hardware" levels is a non-instantaneous input-output transformation governed by the differential equation

$$\tau\dot{\omega} = -\omega + f(u) \quad (5.8)$$

with a time scale τ [Linkevich, 1993c]. Then the instantaneous approximation corresponds to the limit $\tau \to 0$.

A discrete-time counterpart of the dynamical equations (5.1) is given by the iterated map ($t = 0, 1, \dots$)

$$\omega_i^{t+1} = a_i(\omega_i^t) + b_i(\omega_i^t)\, f_i(u_i^t), \quad i = 1, \dots, N \tag{5.9}$$

with appropriately redefined functions $a_i(\omega_i)$, $b_i(\omega_i)$, $f_i(u_i)$. For them, one can use the forms given above, but values of the parameters become different.

6 Learning and Retrieval of Patterns

As is indicated in Sect. 3, we suppose that any pattern (piece of information) μ to be stored in the system is encoded by a FP $\tilde{\omega}^\mu = (\tilde{\omega}_1^\mu, \dots, \tilde{\omega}_N^\mu)$ in the activity state of the NN taken in the deterministic limit (i.e. all $\xi_i = 0$) so that from Eq. (5.1) it follows

$$\begin{gathered} a_i(\tilde{\omega}_i^\mu) + b_i(\tilde{\omega}_i^\mu) \;\; f_i(\textstyle\sum_j T_{ij}\, \tilde{\omega}_j^\mu + \tilde{I}_i^\mu) = 0, \\ i = 1, \dots, N, \quad \mu = 1, \dots, p \end{gathered} \tag{6.1}$$

where p is the number of memorized patterns (MP's). The above system of equations holds also for the discrete-time models (5.9) after an appropriate redefinition of functions $a_i(\omega_i)$.

If activity of the NN at the initial time moment t^0 is close enough to a MP $\tilde{\omega}^\mu$, then, due to intrinsic dynamics of the system, the activity vector $\omega(t)$ should converge to the FP $\tilde{\omega}^\mu$, i.e. the distance $d\,(\omega(t), \tilde{\omega}^\mu)$ between the points $\omega(t)$ and $\tilde{\omega}^\mu$ vanishes as $t \to \infty$. If the time evolution of activity obeys differential equations, then $\omega(t)$ is a continuous function, and an infinitely large time interval is necessary to achieve exact coincidence of activity $\omega(t)$ with the desired point $\tilde{\omega}^\mu$. However, this is not actually required because all real computations are performed with a finite accuracy. It is sufficient therefore to demand that the network activity reaches a prescribed ε-neighborhood of the FP $\tilde{\omega}^\mu$, i.e. there exists such a time moment t_ε that $d\,(\omega(t), \tilde{\omega}^\mu) \le \varepsilon$ for all $t \ge t_\varepsilon$. We will say in such a case that the MP $\tilde{\omega}^\mu$ has been retrieved by the NN with the accuracy ε after the time instant t_ε and that activity of the NN is in the vicinity of the attractor (FP) $\tilde{\omega}^\mu$. To achieve the desired behavior of the NN, the synaptic matrix should be appropriately adjusted by making use of a learning algorithm (LA).

Here we have to impose certain conditions on patterns to be memorized. Namely, we require that $b_i(\tilde{\omega}_i^\mu) \neq 0$ for all the values of i and μ. Further we suppose that the quantities $\tilde{u}_i{}^\mu = \sum_j T_{ij}\, \tilde{\omega}_i^\mu + \tilde{I}_i^\mu$ are greater than the threshold values u_i^0 of the transfer functions $f_i(u_i)$ so that $f_i(\tilde{u}_i^\mu)$ can be inverted, i.e. there exist $f_i^{-1}(\tilde{u}_i^\mu)$ for all i and μ. Then Eq. (6.1) may be recast in the form

$$\sum_j T_{ij}\, \tilde{\omega}_i^\mu + \tilde{\eta}_i^\mu = 0, \;\; i = 1, \dots, N, \;\; \mu = 1, \dots, p \tag{6.2}$$

where

$$\tilde{\eta}_i^\mu = \tilde{I}_i^\mu - f_i^{-1}\left(-\frac{a_i(\tilde{\omega}_i^\mu)}{b_i(\tilde{\omega}_i^\mu)}\right)$$

Eq. (6.2) is nothing but the standard form of the learning problem and different LA's can be used to solve it.

As the above system (6.2) is linear, its general solution T is expressed through a particular solution R and a solution H of the corresponding homogeneous equation so that $T = R + BH$ where B is an arbitrary $N \times N$-matrix. To obtain the matrixes R and H, we use the following LA's:

(i) The projection learning rule [Linkevich, 1993a, 1993b; Kartynnick, Linkevich, 1994; Kapelko, Linkevich, 1996] yields the equation

$$\begin{gathered} R_{ij}^\mu = R_{ij}^{\mu-1} + \\ (\textstyle\sum_k r_k^{\mu-1}\, \tilde{\omega}_k^\mu)^{-1} \cdot (\tilde{\eta}_i^\mu - \sum_k R_{ik}^{\mu-1}\, \tilde{\omega}_k^\mu)\; r_j^{\mu-1} \end{gathered}$$

and an analogous formula for the H_{ij}^μ ($\mu = 1, \dots, p$). Vectors $\mathbf{r}^\mu$ should obey the conditions $\sum_k r_k^\alpha\, \tilde{\omega}_k^\alpha = 0$, $\alpha = 1, \dots, \mu$, and $\sum_k r_k^\mu\, \tilde{\omega}_k^{\mu+1} \neq 0$. They can be computed with the aid of outer products of vectors $\tilde{\omega}^1, \dots, \tilde{\omega}^\mu$ and are expressed through a set of free parameters given explicitly.

(ii) The optimization LA [Linkevich, 1996a] consists of minimizing the functionals

$$F(R) = \sum_{\mu=1}^{p} \|R\, \tilde{\omega}^\mu + \tilde{\eta}^\mu\|, \quad G(H) = \sum_{\mu=1}^{p} \|H\, \tilde{\omega}^\mu\|$$

with respect to the matrixes R and H. Notice that such a minimization can be performed by making use of NN's.

(iii) The "surgeon" LA [Linkevich, 1996a] is direct changes ("by hands") of values of parameters of neurons and synaptic couplings in an appropriate manner.

7 Some Properties of Dynamics of Neural Activity

7.1 Upper and Lower Bounds of Phase Trajectories and a Global Attractor

Let us analyze what regions of the network activity space are visited by trajectories during evolution of the system. As indicated in Sect. 5, we suppose that for every value i, the transfer function $f_i(\cdot)$ is bounded: $0 \leq f_i(\cdot) \leq 1$. Then we can write

$$F_i^-(\omega_i) \leq F_i(\omega) \leq F_i^+(\omega_i) \tag{7.1}$$

where

$$F_i^{\pm}(\omega_i) = a_i(\omega_i) + q_i^{\pm}\, b_i(\omega_i), \quad q_i^- = 0, \quad q_i^+ = 1 \tag{7.2}$$

From Eqs. (5.1), (7.1) it follows that

$$\omega_i^-(t) \leq \omega_i(t) \leq \omega_i^+(t), \quad \forall t \geq t^0, \quad \forall i = 1, \dots, N \tag{7.3}$$

where the functions $\omega_i^{\pm}(t)$ obey the following system of uncoupled differential equations

$$\dot{\omega}_i^{\pm} = F_i^{\pm}(\omega_i^{\pm}), \quad i = 1, \dots, N \tag{7.4}$$

They can easily be recast into the form

$$t - t^0 = \int_{\omega_i^0}^{\omega_i^{\pm}} \frac{d\,\omega_i^{\pm}}{F_i^{\pm}(\omega_i^{\pm})} \tag{7.5}$$

Thus, we have a lower bound $\omega_i^-(t)$ and an upper bound $\omega_i^+(t)$ of phase trajectories of the network.

Let us assume now that there exist finite limits

$$\lim_{t \to \infty} \omega_i^{\pm}(t) = \Omega_i^{\pm} < \infty \tag{7.6}$$

This condition is usually satisfied for attractor neural network models due to their dissipativity. (More certain statements concerning validity of the above assumption require a precise definition of a dissipative dynamical system and a more subtle analysis of their behavior. Some sufficient conditions under which the limits (7.6) and consequently a finite global attractor (7.7) exist have been found in [Kartynnick, Linkevich, 1995] by making use of a different technique).

From Eqs. (7.3), (7.6) we conclude that all possible phase trajectories of the network terminate in the hyperparallelepiped

$$P = \prod_{i=1}^{N} [\Omega_i^-, \Omega_i^+] \tag{7.7}$$

Accordingly, all attractors of the NN including FP's associated with MP's $\tilde{\omega}^1, \dots, \tilde{\omega}^p$ lie inside this hyperparallelepiped. Such a region is referred to as a global attractor (see, e.g., [Temam, 1988]) if the rest part of the phase space $\mathbf{R}^N \setminus P$ is the basin of attraction for the region P, i.e. any trajectory starting somewhere outside the hyperparallelepiped P reaches this domain after a finite time.

Let us consider the linear model described by Eqs. (5.1)–(5.3). In this case, Eqs. (7.2), (7.5) yield

$$t - t^0 = \int_{\omega_i^0}^{\omega_i^{\pm}} d\,\omega_i^{\pm}\,(-\alpha_i\,\omega_i^{\pm} + \beta_i + q_i^{\pm})^{-1}$$

and after integration we find the bounds of phase trajectories:

$$\alpha_i\,\omega_i^{\pm} = \beta_i + q_i^{\pm} + (\alpha_i\,\omega_i^0 - \beta_i - q_i^{\pm})\,\exp\{-\alpha_i(t - t^0)\} \tag{7.8}$$

It is easy to find the limits (7.6)

$$\Omega_i^{\pm} = (\beta_i + q_i^{\pm})/\alpha_i \tag{7.9}$$

and recast Eq. (7.8) so as

$$\omega_i^{\pm} = \Omega_i^{\pm} + (\omega_i^0 - \Omega_i^{\pm})\,\exp\{-\alpha_i(t - t^0)\} \tag{7.10}$$

If the initial state ω^0 lies inside the hyperparallelepiped P (7.7), i.e. $\omega_i^- \leq \omega_i^0 \leq \omega_i^+$ for all i, then from Eqs. (7.3), (7.6) and (7.10) it follows that

$$\Omega_i^- \leq \omega_i^-(t) \leq \omega_i(t) \leq \omega_i^+(t) \leq \Omega_i^+$$

for all i and all $t \geq t_0$.

For the cubic model defined by Eqs. (5.1), (5.4), we find from Eqs. (7.2), (7.5) that

$$t - t^0 = \Phi_i^{\pm}(\omega_i^{\pm}) - \Phi_i^{\pm}(\omega_i^0) \tag{7.11}$$

where

$$\Phi_i^{\pm}(\omega_i) = \frac{1}{2\alpha_i\,[3\,(\tau_i^{\pm})^2 - \beta_i/\alpha_i]} \cdot \left\{ \ln\left| 1 + \frac{3\,\tau_i^{\pm}\,\omega_i - \beta_i/\alpha_i}{(\omega_i - \tau_i^{\pm})^2} \right| + 3\,\Psi_i^{\pm}(\omega_i) \right\} \tag{7.12}$$

$$\Psi_i^{\pm}(\omega_i) = \begin{cases} \frac{1}{\sqrt{D_i^{\pm}}} \ln \left| \frac{2\,\omega_i + \tau_i^{\pm} - \sqrt{D_i^{\pm}}}{2\,\omega_i + \tau_i^{\pm} + \sqrt{D_i^{\pm}}} \right| & D_i^{\pm} > 0 \\ \frac{-2}{2\omega_i + \tau_i^{\pm}} & D_i^{\pm} = 0 \\ \frac{2}{\sqrt{-D_i^{\pm}}} \tan^{-1}\left(\frac{2\,\omega_i + \tau_i^{\pm}}{\sqrt{-D_i^{\pm}}} \right) & D_i^{\pm} < 0 \end{cases} \tag{7.13}$$

Here

$$D_i^{\pm} = 4\,\beta_i/\alpha_i - 3\,(\tau_i^{\pm})^2 \tag{7.14}$$

and the parameters $\tau_i^{\pm}$ obey the equations

$$\alpha_i(\tau_i^{\pm})^3 - \beta_i\,\tau_i^{\pm} - \gamma_i - q_i^{\pm} = 0 \tag{7.15}$$

7.2 An Upper Bound on the Network Storage Capacity and Sizes of Basins of Attraction Around Memorized Patterns

As found in the previous subsection, all attractors of the network dynamics including FP's which correspond to MP's lie inside the hyperparallelepiped P (7.7). This yields limits on the storage capacity of the NN and sizes of basins of attraction around MP's. Indeed, let us assume that a MP $\tilde{\omega}^{\mu}$ has a basin of attraction B^{μ} whose sizes are of the order $l_1^{\mu}, \dots, l_N^{\mu}$ so that the volume of the B^{μ} is of the order $\prod_{i=1}^{N} l_i^{\mu}$. Then the maximal number of patterns which can be placed inside the hyperparallelepiped P obeys the condition

$$p \lesssim \prod_{i=1}^{N} \{(\Omega_i^{+} - \Omega_i^{-} + L_i)/l_i^{\mu}\} \tag{7.16}$$

The quantities $L_i = \max_{P}\{l_i^1, \dots, l_i^p\}$ appear to take into account such MP's that lie inside the region P but their basins of attraction are partly located outside the P.

As we consider NN's treated as associative memory, it should be guaranteed that any MP $\tilde{\omega}^{\mu}$ can be retrieved by the system if the initial state occurs in a spherical neighborhood $S(\tilde{\omega}^{\mu}, \rho)$ of the $\tilde{\omega}^{\mu}$ with a prescribed radius ρ which determines the upper bound of a "degree of associativity" of pieces of information under computation. Under such a requirement, we have similarly to Eq. (7.16) the following condition

$$p \lesssim \prod_{i=1}^{N} \{(\Omega_i^{+} - \Omega_i^{-})/2\rho + 1\} \tag{7.17}$$

Thus, we have found an upper bound on the storage capacity of NN's described by Eqs. (5.1) given a certain value of the degree of associativity. On the other hand, given the number of patterns to be stored, one can estimate the maximal size of basins of attraction around them.

8 Dynamics of Neural Activity in Some Particular Models

8.1 A Deterministic Discrete-Time Model

Let us study dynamical behavior of a single neuron-like element described by the discrete-time piecewise-linear model with an additive term J:

$$\omega^{t+1} = a(\omega^t) + J^t \tag{8.1}$$

Here the function $a(\omega^t)$ is given by Eq. (5.5) and variable J can be viewed as an external input.

First of all, it is easy to prove that the interval $[-L, L]$ is mapped into itself where $L = (1 + 1/h)\,(1 + q/h)$. Therefore we restrict ourselves in what follows by the condition that the initial state $\omega^0 \in [-L, L]$, which ensures finiteness (boundedness) of the motion.

To find the Lyapunov exponent λ, we use its definition directly. So, for any iterated map $\omega^{t+1} = f(\omega^t)$, one has

$$\lambda = \lim_{t \to \infty} \frac{1}{t} \sum_{k=0}^{t-1} \log |f'(\omega^k)|$$

Let τ_c be the average time during which $\omega^t \in [-1, 1]$ and τ_p denote the average time during which $\omega^t > 1$ and τ_n stand for the time with $\omega^t < -1$, so that the total time under consideration is $\tau = \tau_c + \tau_p + \tau_n$. Then we obtain that $\lambda = \kappa\,q + (1 - \kappa)h$ where $\kappa = \tau_c/\tau$.

The simplest case is when $h = q$. This condition yields $\lambda = q$, and it is quite easy to predict type of behavior of the neuron:
(i) as $q < 1$, the only type of attractors is the fixed point;
(ii) if $q = 1$, a fixed point or a limit cycle can appear depending on value of the quantity J;
(iii) as $q > 1$, all attractors are chaotic.
Computer simulations confirm this finding (see Fig. 6). The above properties are kept in the case

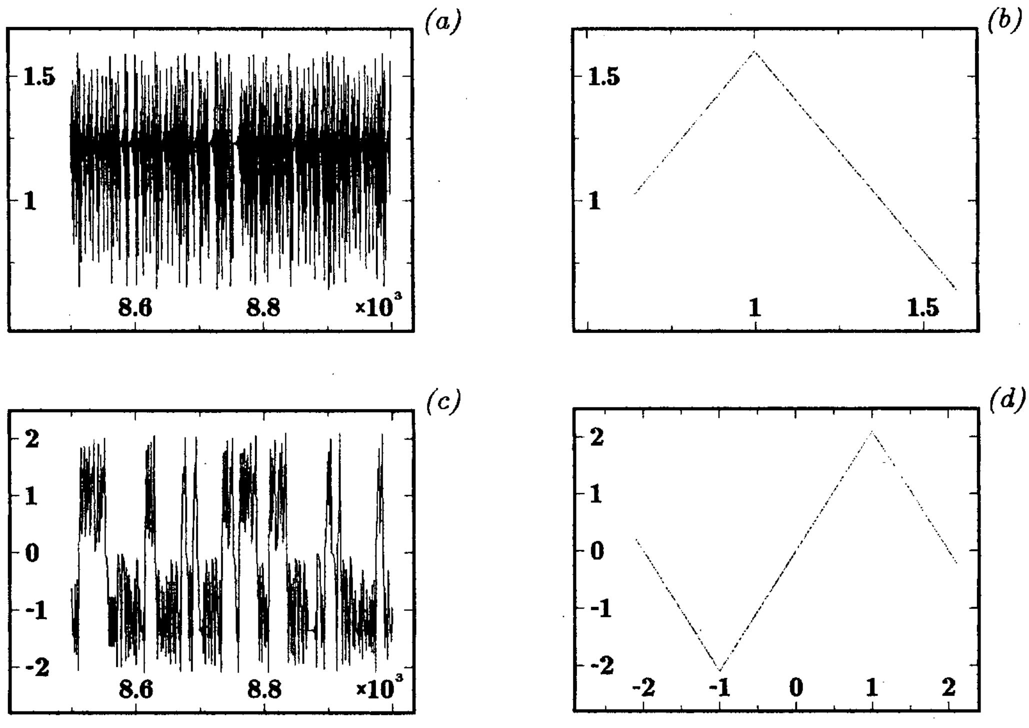

Figure 6: *Examples of chaotic behavior of a neuron described by the discrete-time piecewise-linear model (8.1) at* $h = q$ *and different values of* q*: (a), (b)* $q = 1.6$; *(c), (d)* $q = 2.1$. *Pictures in the left column represent time evolution of the state variable* ω^t *while the right column contains the corresponding phase portraits, i.e.* ω^{t+1} *vs.* ω^t.

$h \neq q$ for $q < 1$ and $q = 1$, whereas various kinds of dynamics are possible at $q > 1$.

Now consider a NN described by Eqs. (5.9), (5.5). To adjust the synaptic matrix T, we apply a projection learning algorithm in which vectors $\mathbf{r}^\mu$ are computed with the aid of outer products of vectors $\tilde{\omega}^1, \ldots, \tilde{\omega}^\mu$ (see Sect. 6).

To investigate stability of MP's, we use the local contracting maps method as described in [Kartynnick, Linkevich, 1994]. Namely, a FP $\tilde{\omega}^\mu$ will be stable if the following sufficient condition is satisfied: there are such $\delta \in (0,1)$ and $r > 0$ that $\|\mathbf{F}(\omega_1) - \mathbf{F}(\omega_2)\| \leq \delta \cdot \|\omega_1 - \omega_2\|$ for any $\omega_1, \omega_2 \in S(\tilde{\omega}^\mu, r) = \{\omega \in \mathbf{R}^N : \|\omega - \tilde{\omega}^\mu\| < r\}$. Here $\|\cdot\|$ means a norm, e.g. Euclidean, of the vector.

Computer simulations show that such values of the free parameters of the LA can be found that the above condition holds simultaneously for all the vectors $\tilde{\omega}^1, \ldots, \tilde{\omega}^p$ to be memorized. In all such cases, these MP's are indeed stable FP's. Therefore we conclude that the NN under consideration can, in principle, be treated as associative memory.

The most interesting observation is that the NN state can converge to a nearest FP even in such a case when neurons, being isolated from each other, exhibit chaotic behavior. To explain this phenomenon, let us consider a particular case when $\tilde{\omega}^\mu \in S(\mathbf{0}, 1)$ and $S(\tilde{\omega}^\mu, r) \subset S(\mathbf{0}, 1)$ for all $\mu = 1, \ldots, p$. Exploring a neighborhood of a FP $\tilde{\omega}^\mu$, introduce variables y_i^μ by means of the relations $\omega_i = \tilde{\omega}_i^\mu + y_i^\mu$. Suppose that the transfer function $f_j(\cdot)$ can be represented, in the given neighborhood, in the linear form as $f_j(\omega_j) = f_j(\tilde{\omega}_j^\mu) + b_j^\mu y_j^\mu$ where $b_j^\mu = const \quad (j = 1, \ldots, N)$. Then our map (5.9) can be written as $y_i^\mu(t+1) = \sum_{j=1}^N H_{ij}^\mu y_j^\mu(t)$ where $H_{ij}^\mu = q_i \delta_{ij} + T_{ij} b_j^\mu$, and the above sufficient condition takes the form $max_{ij}|H_{ij}^\mu| \leq \delta/N$. This was certainly satisfied in our simulations because, due to an appropriate choice of free parameters of the LA, we had: (i)

$b_j^\mu \sim 0.1$ for all μ and j; and (ii) $|T_{ij}| \sim 1$ for $i \neq j$, while $T_{ii} \sim -10$ and $q_i \in (1, 1.2)$. So, we see that chaotic oscillations of a neuron were suppressed by strong negative feedback.

Notice that the above effect can appear not only in piecewise-linear systems, but also in NN's with other forms of the functions $a_i(\omega_i)$ and $f_i(u_i)$. So, if we take a cubic polynomial for the function $a_i(\omega_i)$ and choose $f_i(u_i) = \tanh(g_i u_i)$, then an approximate compensation of the two contributions is possible because $\tanh(u) \approx u - u^3/3$.

8.2 A Stochastic Discrete-Time Model

Let us consider a simple particular stochastic model when $\tilde{a}_i(\omega_i) = 0$, $\tilde{b}_i(\omega_i) = 1$ for all i. Eqs. (5.9) take the form

$$\omega_i^{t+1} = f_i(h_i^t - \xi_i^t) \qquad (8.2)$$

where $h_i^t = \sum_{j=1}^{N} T_{ij}\, \omega_j^t + I_i^t$ and the change $\xi_i \rightarrow -\xi_i$ has been made for convenience The simplest model appears if the transfer function is taken to be a step function, i.e. $f(u) = \text{sign}(u)$ or $f(u) = \Theta(u)$, so that activity of a neuron is described by a binary variable: $\omega_i^t = +1$ if neuron i is active at time moment t, and $\omega_i^t = -1$ or 0 if neuron i is passive. Time evolution of activity obeys the rule

$$\omega_i^{t+1} = \text{sign}(h_i^t - \xi_i^t), \quad \text{or} \quad \omega_i^{t+1} = \Theta(h_i^t - \xi_i^t) \qquad (8.3)$$

It is easy to see that the probability p_i^{t+1} that neuron i will be active at time instant $t+1$ may be expressed as follows:

$$p_i^{t+1} \equiv \text{Prob}\{\omega_i^{t+1} = +1\} = \text{Prob}\{h_i^t > \xi_i^t\} \qquad (8.4)$$

Let us suppose that the random variables $\xi_1^t, \dots, \xi_N^t$ which affect different neurons represent independent Gaussian white noise with zero means $<\xi_i^t>= 0$ and autocorrelation functions $<\xi_i^t \xi_j^s>= 2\gamma_i\, \delta_{ij}\, \delta^{ts}$, $\gamma_i = const.$ Then Eq. (8.4) for the probability p_i^{t+1} is simplified:

$$p_i^{t+1} = \Phi\left(\frac{h_i^t}{\sqrt{2\gamma_i}}\right) \qquad (8.5)$$

where

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} dy\, e^{-y^2/2}$$

is the probability distribution for the standard Gaussian random variable. It is worth noting that the shape of the function (8.5) is similar to that of the distribution

$$\tilde{p}_i^{t+1}(\sigma) \equiv \text{Prob}\{\omega_i^{t+1} = \sigma\} = \tfrac{1}{2}\left[1 - \sigma \tanh(\beta h_i^t)\right] = \frac{1}{1+\exp(2\beta\sigma h_i^t)} = \frac{\exp(-\beta\sigma h_i^t)}{\exp(-\beta h_i^t)+\exp(+\beta h_i^t)} \qquad (8.6)$$

known as the Glauber equation for the state updating, or Gibbs (Boltzmann) distribution. The latter is widely used both in studies of the Ising model beginning with the paper [Glauber, 1963] and in investigation into NN's due to contributions given in [Little, 1974; Hopfield, 1982; Amit, Gutfreund, Sompolinsky, 1985].

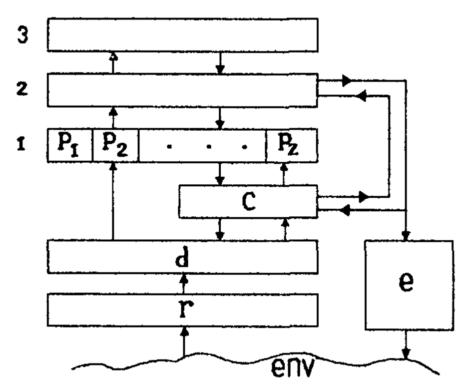

Figure 7: *The general architecture of the neural system which performs perception of stimuli on the basis of pre-excitation of attractors: env—environment; r—receptors; d—detectors; c—controller; 1—primary areas of mnemonic neurons (PAMN's) $P_1, \dots, P_Z$; 2—secondary area of mnemonic neurons (SAMN); 3—higher areas of neurons; e—effectors.*

9 Pre-Excitation of Stored Patterns and a Mechanism of Perception Incorporating Anticipation

Let us consider a scheme of perception developed in [Pribram, 1971; Sokolov, Vatkyavichus, 1989; Linkevich, 1994] (see Fig. 7). Any object O^α $\alpha = 1, 2, \dots$, of the environment which can be perceived produces some stimuli transformed into sensory signals by receptors. Detectors extract feature signals $\Phi_1^\alpha, \Phi_2^\alpha, \dots$ characterizing properties of the object which should be recognized by a set of primary areas of mnemonic neurons (PAMN's) $P_1, P_2, \dots, P_Z$, i.e. NN's described by state vectors $X_i(t) \in S_i \subset \mathbf{R}^{M_i N_i}$ and activity vectors $\omega_i(t) \in A_i \subset \mathbf{R}_+^{L_i}$, $i = 1, \dots Z$ (see Sect. 2 for designations).

Suppose that each NN P_i has a set of FP's $\tilde{X}_i^{\kappa_i}$, $\kappa_i = 1, \dots, K_i$ such that corresponding FP's in the activity space $\tilde{\omega}_i^{\kappa_i}$ encode features known to the system. A part of them may be inborn and correspond to simple important properties of the environment serving as marks for unconditioned (inherent) reflexes. The others are formed due to the learning.

Owing to incoming feature signals $\Phi_1^\alpha, \Phi_2^\alpha, \dots$ neurons of the PAMN's evolve in time under control of their intrinsic dynamics and some of the PAMN's can converge to FP's. Let us assume that signals $\Phi_1^\alpha, \Phi_2^\alpha, \dots$ have turned areas $P_{i_1}, \dots, P_{i_\alpha}$ in the vicinity of FP's $\tilde{X}_{i_1}^\alpha, \dots, \tilde{X}_{i_\alpha}^\alpha$ where the indexes $i_1, \dots, i_\alpha$ are some subset of $\{1, \dots, Z\}$. This means that the features encoded by activity vectors $\tilde{\omega}_{i_1}^\alpha, \dots, \tilde{\omega}_{i_\alpha}^\alpha$ have been recognized.

When the PAMN's are in the vicinity of FP's $\tilde{\omega}_{i_1}^\alpha, \dots, \tilde{\omega}_{i_\alpha}^\alpha$, the state of the secondary area of mnemonic neurons (SAMN) can converge to a FP $\tilde{X}_s^\alpha$. This means that the object O^α has been mapped into the image encoded by the activity vector $\tilde{\omega}_s^\alpha$:

$$\begin{array}{ccccc} O^\alpha & & & & \\ \downarrow & & & & \\ (\Phi_1^\alpha, \Phi_2^\alpha, \dots) & \longrightarrow & \{\tilde{X}_{i_1}^\alpha, \dots, \tilde{X}_{i_\alpha}^\alpha\} & \longrightarrow & \tilde{X}_s^\alpha \\ & & \downarrow \quad\quad \downarrow & & \downarrow \\ & & \{\tilde{\omega}_{i_1}^\alpha, \dots, \tilde{\omega}_{i_\alpha}^\alpha\} & & \tilde{\omega}_s^\alpha \end{array}$$

Plainly, this map is not a single-valued, but, instead, it depends upon parameters of the perceiving system and what signals were processed by the system in the past.

Now we examine the perception mechanism in more detail. Suppose that an object O^α has just been recognized. This means that the state vectors of PAMN's are in the vicinity of certain FP's $\tilde{X}_{i_1}^\alpha, \dots, \tilde{X}_{i_\alpha}^\alpha$ and the state vector of the SAMN is in the vicinity of an FP $\tilde{X}_s^\alpha$. Notice that the vectors $\tilde{\omega}_{i_1}^\alpha, \dots, \tilde{\omega}_{i_\alpha}^\alpha$ and $\tilde{\omega}_s^\alpha$ have non-zero components in view of our assumption concerning the way in which information is encoded in NN's (see Sect. 2).

Firing neurons send impulses to other neurons. This yields an increase of the membrane potentials of neurons receiving these impulses through excitatory synaptic connections. Hence, different sets of activity attractors $\{\tilde{\omega}_{j_1}^\beta, \dots, \tilde{\omega}_{j_\beta}^\beta; \tilde{\omega}_s^\beta\}, \beta = 1, 2, \dots,$ are pre-excited and become ready to be active to different extents. The degree of readiness of such a set β to be excited is determined by the strength of associations between the objects O^α and O^β produced due to the learning.

Suppose that after the object O^α has been recognized, a new object O^γ produces stimuli (instead of the O^α). They are processed by receptors and detectors, and feature signals $\Phi_1^\gamma, \Phi_2^\gamma, \dots$ enter the PAMN's. If these incoming signals are close enough to a set of FP's $\{\tilde{X}_{k_1}^\gamma, \dots, \tilde{X}_{k_\gamma}^\gamma\}$, then the PAMN's converge to these attractors and thereby the corresponding features have been recognized. However, if the input is a very partial or noisy version of a set of memorized features, then pre-excitation of activity attractors comes into play. The higher is the degree of pre-excitation of an activity attractor, the higher is probability that this attractor will be activated. If partial or noisy feature signals enter only neurons that have not been pre-excited, then the signals can turn out to be not sufficient for recognition of the pattern.

Thus pre-excitation of attractors in the activity space provides probabilistic anticipation of future events. This makes such situations possible when even weak signals produced by an expected object enable the system to recognize the object, while a similar piece of information does not allow it to recognize an unexpected object.

Plainly, operation of the PAMN's and SAMN does not always yield recognition of objects. kFor this reason, the perceiving system should include a controller to inspect whether the object is recognized or not, and to generate command signals to other blocks if the object can not be recognized. If attempts to improve performance of feature detectors turn out to be unsuccessful, then one has to generate new hypotheses on what the object is, i.e. to produce new distributions of pre-excitation of activity attractors. A possible dynamical mechanism of this is associative generation of information based on the transition *fixed point → chaotic attractor → new fixed point* [Kapelko, Linkevich, 1996].

To investigate the process of perception by the system represented in Fig. 7, we conducted computer simulations using the generalized FitzHugh–Abbott model [Linkevich, 1996c] in which the state of a neuron i is determined by three dynamical variables u_i, v_i, w_i whose time evolution is governed by the differential equations:

$$\begin{aligned} \dot{u}_i &= a_i(u_i) + a_2 v_i + a_3 w_i + a_4 + \\ &\quad \overline{I}_i + \textstyle\sum_{j=1}^{N} \overline{T}_{ij}\, f_j(u_j), \\ \dot{v}_i &= b_1 u_i + b_2 v_i + b_3 w_i + b_4, \\ \dot{w}_i &= c_1 u_i + c_2 v_i + c_3 w_i + c_4 \end{aligned} \tag{9.1}$$

Here, $i = 1, \ldots, N$; the function $a_i(u_i)$ is taken to be a piecewise-linear form similar to Eq. (5.5) (see Fig. 4c), $\overline{I}_i$ is a signal from detectors or other NN's. The synaptic efficacies $\overline{T}_{ij}$ were adjusted with the aid of the LA's described in Sect. 6, and the piecewise-linear form depicted in Fig. 5e was mostly used for the neuron transfer function $f(u)$. All the other parameters in the above equations are constants. We took the number of neurons N= 6,8 or 10 for every NN of the system and the number of patterns stored in each NN $p = 2$ or 3.

To verify the above mechanism of pre-excitation of attractors, we use the following procedure. We take the model (9.1) to describe time evolution of the state of a NN $X(t)$ but any pattern stored in the NN (such as an image of a single feature or an image of an object as a whole) is represented by a stable FP $\tilde{\omega}^\mu$ in the activity space of the NN. Notice that $\tilde{\omega}_i^\mu = f_i\ (\tilde{u}_i^\mu)$ for all μ and i.

Let a signal $\overline{I}_i$ bring the NN into some initial state $X(t^0)$. Then we calculate (for $t \geq t^0$) the two following quantities: (i) the distance $d_u^\mu(t) = d(u(t), \tilde{u}^\mu)$ between the current value of the vector of neuron membrane potentials $u(t) = (u_1(t), \ldots, u_N(t))$ and the stationary value $\tilde{u}^\mu = (\tilde{u}_1^\mu, \ldots, \tilde{u}_N^\mu)$ which corresponds to the MP $\tilde{\omega}^\mu$; (ii) the distance $d_\omega^\mu(t) = d(\omega(t), \tilde{\omega}^\mu)$ between the current value of the activity vector $\omega(t)$ and the stationary value $\tilde{\omega}^\mu$. We treat the distance $d_u^\mu(t)$ as a quantity that characterizes the degree of pre-excitation of the MP $\tilde{\omega}^\mu$ in such a way that the smaller is this distance, the greater is readiness of the MP $\tilde{\omega}^\mu$ to be excited. The distance $d_\omega^\mu(t)$ serves as a measure of closeness of the current activity to the target value.

We found that if the initial distance $d_\omega^\mu(t^0)$ was small enough, then the corresponding MP $\tilde{\omega}^\mu$ was asymptotically retrieved by the NN (in the sense described in Sect. 6) independent of the value $d_u^\mu(t^0)$. A more interesting situation appears, however, when the initial value $d_\omega^\mu(t^0)$ is not so small (for any value of μ). In such a case, the degree of pre-excitation characterized by $d_u^\mu(t^0)$ comes into play. Namely, if the latter distance is small enough, i.e. the MP $\tilde{\omega}^\mu$ is pre-excited (anticipated by the NN), then $\tilde{\omega}^\mu$ is indeed retrieved. In contrast, if $d_u^\mu(t^0)$ is large, i.e. the MP $\tilde{\omega}^\mu$ is not expected, the NN fails to retrieve $\tilde{\omega}^\mu$. Fig. 8 illustrates these two different scenarios for the model (9.1) in the most indicative case when there are two (or more) situations with different values of $d_u^\mu(t^0)$, whereas $d_\omega^\mu(t^0)$ is just the same for them.

It is worth noting that the effect described above takes place in so far as the neuron transfer function $v = f(u)$ has the threshold character, i.e. there is such a value u^0 that $v = 0$ for any $u \leq u^0$. In contrast, if we took instead such popular forms as $v = \tanh(g\, u)$ or $v = (1 + \exp(-g\, u))^{-1}$, then no pre-excitation of attractors would appear because of a single-valued relation between $d_u^\mu(t)$ and $d_\omega^\mu(t)$.

We reveal also that a complete self-consistent description of dynamics at the level of "software" solely is hardly possible for any type of IP. Instead, any model of "software" (S-model) has a restricted area of application and can be viewed as some kind of approximation of dynamics at the "hardware" level described by an H-model. Therefore the problem of reduction of H-models to S-models mentioned in Sect. 5 appears to be interesting.

10 Thinking, Reflection, and Self

To study linguistic aspects of mental phenomena, we introduced in Sect. 3 three interconnected NN's and treated their activity spaces as the perceptual, lexical and semantic spaces (PS, LS, SS) respectively. Each of these NN's is relatively independent of the others and can dominate in time evolution of the whole system playing the leading

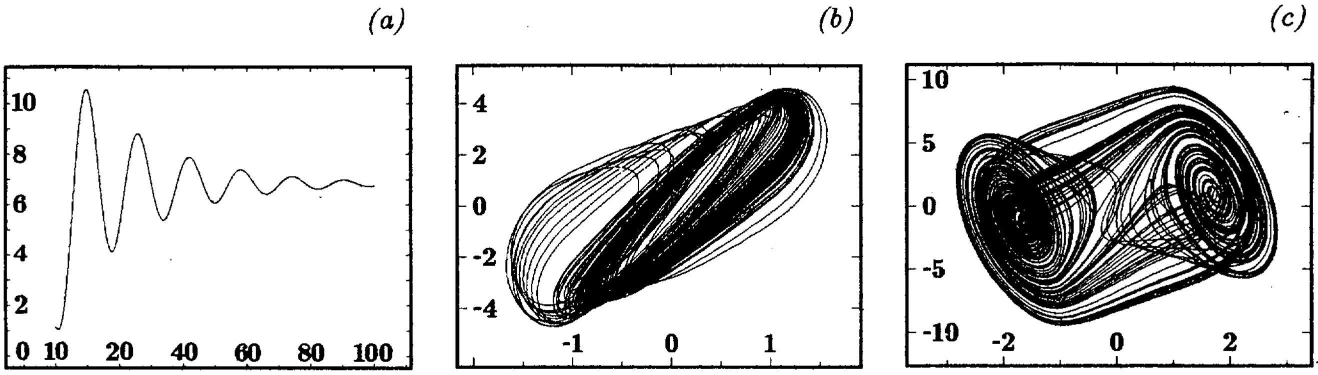

Figure 8: *Dynamical behavior of a neuron of the perceiving system described by Eqs. (9.1) and represented in Fig. 7 in two cases: (a) recognition of an expected object, i.e. relaxation toward a stored pattern; which is illustrated by time dependence of the neuron state variable u; (b), (c) phase portraits of chaotic wandering when an unexpected object is perceived (plots of the neuron variables u vs. v are depicted).*

role in IP performed by the system. Accordingly, there may be the three kinds of thinking:

(i) *Verbal*, or discursive, logical, thinking, i.e. such a type of thinking that the leading process is dynamics in the *lexical* space. Every normal adult human person knows what it is.

(ii) *Pictorial* thinking is chiefly determined by dynamics in the *perceptual* space (here a *picture* is a pattern, or a mental image, an image in the mind, etc.). Dreams, meditations, productive (creative) thinking bring us examples of such a kind. A well-known description of the pictorial thinking has been done by A. Einstein in his answers to questions of J. Hadamard [Hadamard, 1945] and discussions with M. Wertheimer [Wertheimer, 1945].

(iii) *Semantic* thinking is produced by dynamics in the *semantic* space. This type operates with meanings directly, but a person has no direct access to them and becomes aware of products (results) of this kind of IP only due to associations between attractors of the SS (meanings) and attractors of the LS and PS (words and mental images). The semantic thinking may be intimately connected with insights, intuition, creative thinking, meditations, prayers. At least the Würzburg school of psychology (the leader was O. Külpe (1862–1915), members were N. Ach, K. Bühler, K. Marbe and others) has concluded that thinking may not include any words, any pictures, any their associations [Külpe, 1893; Ach, 1905; Bühler, 1934; Selz, 1913, 1922, 1924]. This assertion was criticized by other schools because of disagreement in methods of studies, the conceptual background and even in the subject of psychology. It seems to be quite reasonable to return to results and conclusions of the Würzburg school and proceed experimental studies of different kinds of thinking.

It is worth noting that every kind of thinking, viz. verbal, pictorial, semantic, may be both conscious and unconscious (subconscious or superconscious, the later term is due to Simonov [1975, 1981]). Figuratively speaking, a thinking process is conscious if it is under light of attention, and is unconscious if it is in the dark, outside the area of neural activity illuminated by the attention beam. (Of course, the above statement may only be correct if we admit in principle, by definition, unconscious forms of thinking; otherwise the unconscious counterpart of thinking should be called e.g., quasi-thinking or something like this).

Every type of thinking (verbal, pictorial, semantic) should also be associated with a specific kind of memory. Besides, division of any kind of memory into short-term and long-term memories appears naturally in our approach. Indeed, any memorized pattern is represented by an attractor in an activity space, but inertia of the NN characterized by a finite value of the relaxation time results in that any attractor is practically held during a finite time. This produces the short-term memory. In contrast, the long-term memory stems from modifications of synaptic couplings. As the time scale of learning is greater than the time scale of evolution of the NN state, the learning process is relatively slow, but the memory is long.

Nalimov [1989] has proposed a map of consciousness in which the following components are distinguished: (1) the level of thinking (Aristotelian logic); (2) the level of pre-thinking (Bayesian logic); (3) "basements" of consciousness (contemplation of images); (4) the human body supporting consciousness; (5) the metalevel (cosmic consciousness); (6) "basements" of the cosmic consciousness (collective unconsciousness). As is seen, pre-thinking (or Bayesian logic, or probabilistic inference) is contrasted with thinking (or Aristotelian logic, or strict inference). On the contrary, in our approach there is no such a gap, the only difference between the so-called pre-thinking and thinking is in the level of noise.

Let us consider the contents of the perceptual space (PS) A_p (a part of its items may be conscious, while the others are unconscious). As is mentioned above, a perceived object O^α produces some mental image represented by an attractor $\xi^\alpha \equiv \tilde{\omega}_p^\alpha \in A_p$. Any such a pattern may be not only a picture of an object of the environment solely (i.e. a thing or a set of things of the external world), but also an image which includes (or even exclusively consists of) elements produced by the organism of the subject such as images of the hands, legs, other parts of the body; feelings created by the heart, stomach, breathing, etc.; sensed drives; etc.

Let $W = \{O^\alpha, \alpha \in \Pi\}$ denote the set of all objects O^α of the world (including the organism of the subject) that create images (attractors) $\xi^\alpha \equiv \tilde{\omega}_p^\alpha$ in the PS of the person as described above, and $\Omega_p = \{\tilde{\omega}_p^\alpha, \alpha \in \Pi\}$ the set of these images. Here Π is a set of the index values. Then one can introduce the map

$$\Phi_p : O^\alpha \to \tilde{\omega}_p^\alpha, \quad \text{or} \quad \Phi_p : W \to \Omega_p$$

and write $\Omega_p = \{\tilde{\omega}_p^\alpha \in A_p : \quad \tilde{\omega}_p^\alpha = \Phi_p(O^\alpha), \alpha \in \Pi\}$. Owing to associations (connections) between patterns (attractors) of the PS, LS and SS written symbolically as $\xi^\alpha \sim \eta^\alpha \sim \sigma^\alpha$ or $\tilde{\omega}_p^\alpha \sim \tilde{\omega}_l^\alpha \sim \tilde{\omega}_s^\alpha$ (see Sect. 3), the map Φ_p induces the two following maps:

$$\Phi_l : O^\alpha \to \tilde{\omega}_l^\alpha, \quad \text{or} \quad \Phi_l : W \to \Omega_l,$$

$$\Phi_s : O^\alpha \to \tilde{\omega}_s^\alpha, \quad \text{or} \quad \Phi_s : W \to \Omega_s$$

where Ω_l and Ω_s are defined just as Ω_p above. One can combine these three maps into the single one Φ_q with the index q standing for p, l or s.

A human being can operate with words in a variety of ways and produce, in particular, such sentences that correspond really to the map

$$\Phi_l^{(1)} : W_l^{(1)} \to \Omega_l^{(1)}$$

where $W_l^{(1)} = W \cup \Omega_l$ is the union (sum) of sets W and Ω_l. Then due to associations $\tilde{\omega}_p^\alpha \sim \tilde{\omega}_l^\alpha \sim \tilde{\omega}_s^\alpha$, one has also the maps

$$\Phi_p^{(1)} : W_p^{(1)} \to \Omega_p^{(1)}$$

$$\Phi_s^{(1)} : W_s^{(1)} \to \Omega_s^{(1)}$$

It may similarly be considered the map $\Phi_q^{(m)}$ of any order m:

$$\Phi_q^{(m)} : O^\alpha \to \tilde{\omega}_q^\alpha, \quad \text{or} \quad \Phi_q^{(m)} : W_q^{(m)} \to \Omega_q^{(m)}$$

Here $\Phi_q^{(0)} = \Phi_q$, $W_q^{(m)} = W_q^{(m-1)} \cup \Omega_q^{(m-1)}$ for $m \geq 1$, while $W_q^{(0)} = W$, and

$$\Omega_q^{(m)} = \left\{ \tilde{\omega}_q^\alpha \in A_q : \tilde{\omega}_q^\alpha = \Phi_q^{(m)}(O^\alpha), O^\alpha \in W_q^{(m)}, \alpha \in \Pi^{(m)} \right\}$$

In this way we meet the phenomenon known as *reflection*, i.e. (1) the ability of consciousness (or the mind, or the soul) to direct (to turn, to concentrate) itself on itself, on its own processes and products; (2) operations of the subject with his/her own consciousness that yield ideas about this consciousness [Teilhard, 1955; Lefebvre, 1982, 1990a; Slobodchikov, Isaev, 1995]. Reflection is considered as the central phenomenon of internal activity that distinguishes the human being from animals, as the key process of consciousness because the latter stems from an ability to contrast the self with the surroundings.

The intimate links of reflection with language implicit in our approach are easily observed by introspection investigated in connection with problems of education [Burns, 1982], and even such a question may appear whether reflection exists at all or this is only an illusion which stems from grammatical constructions of language [Lefebvre, 1990b].

It is worth noting also that although one can admit, in principle, reflectional maps $\Phi_q^{(m)}$ of any order m, really the maximal order is usually restricted by the value $m = 2$ because operations with $m \leq 2$ appear to be performed automatically, without efforts of consciousness, whereas reflections (self-appraisals) of higher orders make consciousness to exert itself and provide the subject with free will [Lefebvre, 1982, 1990a].

Now we approach the central item of consciousness - the *self*. Let us consider the set of all attractors in the SS

$$\Omega_s = \cup_m \Omega_s^{(m)}$$

and suppose that there exists a subset $\Omega_s^s \subset \Omega_s$ which is invariant with respect to any map $\Phi_s^{(m)}$, i.e. the subset Ω_s^s is mapped by $\Phi_s^{(m)}$ into itself:

$$\Phi_s^{(m)}(\Omega_s^s) \subset \Omega_s^s, \quad \forall m = 0, 1, 2, \ldots$$

This invariant subset of attractors Ω_s^s is treated as the *self* of the person. Attractors from the set Ω_s^s are associated with certain attractors in the PS (denote their set Ω_p^s) which represent sensory (perceptual) images connected with the person (a description of the contents of these images can be found in [Sechenov, 1961; Burns, 1982; Kratin, 1982]).

Attractors contained in Ω_s^s together with attractors $\pi_s^\kappa \in A_s$, $\kappa = 1, 2, \ldots$, associated with primary semantic factors (PSF's) constitute the set

$$\Omega_s^* = \Omega_s^s \cup \{\pi_s^\kappa \in A_s, \quad \kappa = 1, 2, \ldots\}$$

which determines the "skeleton" of the SS and consciousness. Namely, any attractor in the SS being produced makes influence on "geometry of dynamics" in this space in the sense that existence of any such an attractor is provided by appropriate values of synaptic couplings T_{ij}, but the latters enter dynamical equations, and thereby they determine time evolution of the activity vector $\omega_s(t) \in A_s$. Attractors of the set Ω_s^* have a special impact on the "geometry of dynamics" because they are most strong and steady and make a significant contribution to the values of the synaptic couplings.

Existence of the set of attractors Ω_s^* manifests itself in dynamics of neural activity by appearance of *order parameters.* Indeed, consider the distances

$$D_\omega^\mu(t) = d(\omega_s(t), \tilde{\omega}_s^\mu), \quad \tilde{\omega}_s^\mu \in \Omega_s^*$$

between the current value of the activity vector $\omega(t)$ and attractors $\tilde{\omega}_s^\mu$ from the set Ω_s^*. They should be slowly changing in time (or even practically constant) in comparison with the distances

$$d_\omega^\nu(t) = d(\omega_s(t), \tilde{\omega}_s^\nu), \quad \tilde{\omega}_s^\nu \notin \Omega_s^*$$

to any attractors $\tilde{\omega}_s^\nu$ which do not belong to the set Ω_s^*. The reason is quite clear: the quantities $D_\omega^\mu(t)$ represent the measure of closeness of meanings associated with the current percepts of parts of the organism, steady thoughts, attitudes, appraisals, etc. to the corresponding patterns fixed in the memory of the subject. In this way we treat $D_\omega^\mu(t)$ as slow variables and $d_\omega^\nu(t)$ as fast variables, and apply the slaving principle of synergetics [Haken, 1983, 1988, 1991] to dynamical equations for $D_\omega^\mu(t)$ and $d_\omega^\nu(t)$.

Thus, we meet the notion of reflection in two meanings of the word. Reflection (in the broad sense) can be defined as a transfer of control on parameters of the controlling system itself, or as such a building onto the "pyramid" of the controlling system that the process at a lower level of the pyramid becomes to be object of control for the higher level. Such phenomena can be observed for all the three NN's under consideration in our approach (PNN, LNN, SNN), both in their state spaces and in their activity spaces, as different time scales occur in time evolution of relevant variables and the synergetic slaving principle comes into play. In particular, hierarchical structures arise in a natural way in the semantic space of the neural system. This seems to be connected with reflection in the narrow sense of the word, i.e. awareness by a person of his/her own mental activity, or a map of consciousness into itself.

11 Conclusions

To conclude, we summarize first the key points of the work. The foundation of our approach is the description of a NN in two ways: (i) *"hardware"* is given by the *state* of the NN $X(t)$, while (ii) *"software"* is represented by its *activity* $\omega(t)$. Any *pattern* (a piece of information stored in the system) is treated as an *attractor* in the activity space of the NN, and information processing (IP) is considered as time evolution of its activity $\omega(t)$.

The conception developed in the paper may be formulated as follows. *Perception* consists of attempts to recognize the perceived object and includes generation and verification of hypotheses what the object is. Any such an assumption can be produced beforehand yielding really a certain forecast of the future. There are at least two mechanisms of such *anticipation* of future events: (i) pre-excitation of attractors of the network dynamics; (ii) associative generation of information in the semantic space of the NN when a new pattern is produced close to a previous one as regards their meanings.

To investigate meanings of words, we consider *language* and introduce three interconnected NN's so that their activity spaces A_p, A_l, A_s are referred to as perceptual, lexical and semantic spaces (PS, LS, SS) respectively because (i) any percept is represented by an attractor in the PS, (ii) any word known to the system is given by an attractor in the LS, and (iii) any meaning understandable to the system is treated as an attractor in the SS.

As there are the three interconnected NN's, each of them may give the dominating contribution to the time evolution of the system as a whole and play the leading role in mental processes. This gives rise to different kinds of IP including three types of *thinking*. Whereas the verbal and pictorial thinking are quite ordinary, the so-called semantic thinking is rather unusual and this is no wonder because a person has no direct ways to be aware of it. It is only connections (associations) between attractors (patterns) of different activity spaces that enable the person to make products of the semantic thinking to be available. However, this way, when the contents of the SS appear on the "screen of consciousness" of the subject in the form of associated patterns, hides the real origin of the produced pieces of information. It is apparently the most interesting outcome of the model developed here that there should be the three kinds of thinking, but the difficult problem arises, of course, how to verify existence of such forms of thinking that are not verbal nor pictorial.

The key points of consciousness—reflection and self—are considered as mathematical constructions arising rather naturally in the SS of a neural system. As the self is treated as a set of attractors in the SS, it is no wonder that a person meets difficulties to describe clearly what the self is, and as the SS is a certain *activity* space, it becomes quite obvious that it is hardly possible to find a location of the self (and consciousness in general) in the brain. Finally, one can say that consciousness is not a thing (a part of the brain), not a state (of the brain), not a property, but *consciousness is a process*, and this process exists in so far as there exist relevant configurations of neural activity (attractors in the SS). In other words, *consciousness is a process of neural activity structured in such a way that a hierarchy of attractors appears in the activity space of the neural system.*

To describe quantitatively the discussed class of mental phenomena, we have suggested nonlinear (stochastic) models of neural activity and reduced the learning problem for them to a standard form, which allows us to apply learning algorithms proposed earlier. We performed an analytic study of general dynamical properties of the models and have found bounds of phase trajectories in the activity space of a NN, existence of a global attractor which contains all the attractors of the system, certain restrictions on the network storage capacity and sizes of basins of attraction around stored patterns. Particular models were investigated as well.

Although our findings seem to be reasonable and promising, a great deal of work should still be done to achieve a complete quantitative description of the phenomena discussed at the qualitative level. This is quite natural, however, in view of the extreme complexity of the mental phenomena in question. As regards analytic investigation into the models considered above, one has to notice that application of usual tools of statistical physics, viz. the method of Fokker-Planck equations and the path integration approach, are in difficulty because of both nonadditivity of the noise $\xi_i(t)$ entering the dynamical equations and the threshold character of the neuron transfer function $f_i(u_i)$. Another direction of further studies is investigation into models refined in two respects: (i) the function $a(\omega)$ determining dynamics of a single neuron is taken to be a stochastic generalization of a form considered in Sect. 5; (ii) the synaptic couplings T_{ij} are treated as random variables.

In view of problems with the analytic description of neural activity, the role of computer simulations appears essential. They become particularly important as one goes deeper and wider into linguistic aspects of mental phenomena. So, in the present paper we dealt only with the simplest approach to the meaning of words, viz. the *definitio ostentus*. In contrast, the *verbal definition* yields the meaning of a word via its relations with other meanings expressed by some other words. There are a number of kinds of the verbal definition such as analytical, contextual, functional, genetic, nominal, operational, semantic, syntactic definitions, definition via abstraction, definition via genus and specific difference, etc. To embody such a way of determining the meaning of words in an artificial system, investigation into grammar is essential, and we began analyzing a number of languages from different families and groups and programming modules of the "transformers": $NE \sim TE - RELL - IL, \quad IL - RELL \sim TE$. Here the following abbreviations are used: NE - natural English, TE - "truncated" English, RELL - "regularized" English-like language, IL - internal language of an artificial system. The sign $\sim$ means that feedback (a dialog of the system with its user) may appear to be necessary. It is worth noting that attempts were undertaken [Miller et al, 1991] to implement the so-called regular languages [Chomsky, 1956, 1959, 1963, 1972; Chomsky, Miller, 1958] in NN's.

Yet another approach to imitate (or even to reproduce) mental phenomena is significantly based on (opto)electronic experiments. Indeed, as is argued above, the mind stems from operations with meanings, but meanings are embodied in the organism. So, primary semantic factors (PSF's) are determined by states and reactions of the organism due to the action of stimuli. Thus, we see that the human body produces the human mind and human intelligence.

Similarly, to obtain an artificial intelligence (AI), it is necessary to design an artificial body (AB) that produces an artificial mind (AM), and then an AI may appear as a form of the AM. Thus, the only thing that seems to be possible is the following scenario: AB $\to$ AM $\to$ AI, and AI may only be an emergent property of some AB.

A number of problems appears, of course, on this way: Are (opto) electronic meanings close to human meanings? What about (opto) electronic aims, targets, motives, drives, etc.? What kind of the artificial body is most suitable: electronic, optic, optoelectronic, molecular, etc.?

Finally, one can notice that all the consideration given so far lies in the framework of the reductionist approach to the mind-body problem which can be formulated in the form of the known Sherrington's alternatives (see, e.g. [Penfield, 1975]): (i) The mind is only a function of the brain activity. Special higher mechanisms of the brain generate the mind. (ii) The mind exists continuously and by itself, independently of the brain. The mind, being not connected with the brain, keeps silence, but it still exists during that time.

No alternative has been proved or rejected so far. Therefore it could be desirable to examine both possibilities, and our scheme enables us to model mental phenomena accepting any of the alternatives. Within the framework of the first alternative, time evolution at the level of "software" is determined by dynamics of "hardware". However, a comprehensive description of "hardware" proves to be too complicated and therefore it is reasonable to model the "software" dynamics directly. On the contrary, if one admits the second variant, dynamics of "software" is affected by the mind and in turn has an influence on the "hard-dynamics".

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Appendix A

Some Conceptions Concerning the Mind and Behavior

A very simple explanation of activity of human beings and animals was given by the conception of the reflex arc introduced by Descartes (1639) in full analogy with mechanical and hydraulic automata: an influence (stimulus) produces a response. However, such a simple scheme can only be adequate for simplest forms of behavior called the *unconditioned reflexes*. Notice, nevertheless, that even in these cases, in order an automatic reaction will be started, an organism should possess an ability of perception, recognition of objects of the environment.

A more complex type of behavior is the *conditioned reflexes*. Among distinguishing features of conditioned reflexes, one can mention the following: (i) conditioned reflexes are acquired reactions, but not inborn, and consequently (ii) they are inconstant, adaptive and possess such properties as (iii) signaling, anticipation [Mackintosh, 1983; McFarland, 1985]. For example, secretion of saliva in a dog organism in response to a ring used as a conditioned stimulus is intended not for digesting the ring but, instead, the saliva prepares conditions to digest a food expected to appear in the near future. The conditioned reflex is considered therefore as a mechanism that enables the being to anticipate future events in order to be better adapted to the environment.

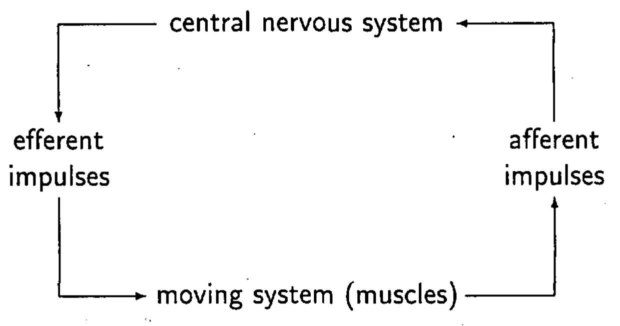
In neurophysiology the conception of the reflex arc was recognized due to the known works of Pavlov and Sherrington [Pavlov, 1927; Sherrington, 1906]. Attempts of Watson, Skinner and others to develop psychology only in the terms of observable notions gave birth to the so-called behaviorism based mainly on the stimulus-response scheme (see, e.g., [Skinner, 1943]). However, such a simple paradigm of unidirectional flow of information turns out to be limited in its ability to produce complex behavior of systems as well as to simulate IP exhibited by animals and man. This became quite obvious due to development of cybernetics in which the concepts of feedback and prediction of the future are of great importance (see for review, e.g., [George, 1977]). So, Wiener and his collaborators in their first paper on cybernetics [Rosenblueth, Wiener, Bigelow, 1943] have proposed a classification of behavior which includes such types as active, purposeful, teleological (with feedback), predictive (extrapolating), etc. (Feedback mechanisms were mentioned even before by Ashby [1940]).

Meanwhile, notions close to feedback and anticipation of the future were formed in physiological studies independently of and even before research into IP in artificial systems. So, Anokhin and Strezh [1933] investigated conditioned reflexes of the dog with bread as reinforcement, and they revealed that if the bread was suddenly substituted by some meat, the dog refused the latter. In view of this and other experiments, Anokhin has concluded that the following processes occur simultaneously in response to a conditioned stimulus: (*i*) efferent impulses are generated toward effectors (muscles, etc.) and (*ii*) an advancing afferentation appears, i.e. an afferent system that anticipates afferent parameters of the future result of the action [Anokhin, 1935, 1949, 1968, 1979]. Further, as the action is completed, these expected parameters are compared with information on the real results of the action. This apparatus for comparison actual and forecasted properties has been called the acceptor of the action results.

Anokhin has also introduced and studied the concept of sanctioning or returning afferentation, i.e. signals from effectors toward the central nervous system (see [Anokhin,1935] and his subsequent papers). Obviously, this is nothing but the feedback notion considered in the context of neurophysiology. The notions of the acceptor of the action results and the returning afferentation became keystones of the Anokhin's theory of the functional system.

The concept of feedback has, in fact, been proposed in physiology by Bernshtein as well (see [Bernshtein, 1947, 1966]). He studied physiology of movements and has suggested that the reflex arc should be substituted by the reflex circle which can be depicted in the picture on the following page.

Bernshtein has also concluded that a movement program is determined by an image of the action result which should be achieved due to the action. He stressed that the image of the needed future plays a great role in organization of activity.



Under influence of ideas of cybernetics the scheme TOTE (test–operate–test–exit) has been proposed and developed [Miller, Galanter, Pribram, 1960; Pribram, 1971] which includes anticipation of future events. Sokolov [1959,1960,1963] has introduced the notion of the neuronal model of a stimulus.

In psychology, the problem of anticipation of the future is considered, in fact, during all the whole last century. This is mainly connected with the concept of set. (A review of early studies in this area can be found in [Gibson, 1941; Asmolov, 1977]; reprints of some papers are collected in [Dennis, 1948]). Brunswik [1939] has introduced into psychology the concept of probabilistic expectation of future events and treated the learning as the forming of probabilistic connections between possible types of activity. On this basis, an assumption appears about probability of an event before it takes place. The notion of the probabilistic forecasting has also been suggested and studied in [Feigenberg, 1963; Feigenberg, Ivannikov, 1978].

A great contribution to investigation into the problem under consideration has been done by Bruner and his collaborators beginning with the so-called "New Look" trend in psychology and up to his theory of perceptual readiness [Bruner, 1957]. According to the latter, perception is represented as a categorization (or decision making) as follows. During the learning process, perceived objects are mapped into categories of features, and, as a result, a representative model of the world is formed. Then, as an object is perceived, features are extracted from the sensory data. If the features enable one to distinguish the object from others, pattern recognition is completed. However, features can often correspond to different categories. In such an occasion, one has to take into account readiness of categories. The readiness of a category is determined both by the probability of appearance of the event in the past and by the state of the subject (needs, motives, drives). The readiest category wins and thereby a preliminary recognition is fulfilled. At the next stage the hypothesis is tested, i.e. relevant sensory information is compared with the features associated with the category and correcting commands return to the receptors, and transform sensory inputs.

Some interesting ideas can be found in philosophy. One of such conceptions asserts that information processing performed by the human brain is characterized by that it interprets the world [Wittgenstein, 1953; Marr, 1982]. Consequently, pattern recognition is such a description of a pattern that can represent what the object is [Marr, 1982].

Hermeneutics originally proposed in philology by Dilthey and Heidegger states that the pre-understanding (Vorverständnis) of a whole text is a necessary prerequisite for the understanding of each single sentence (see, e.g., [Gadamer, 1976; Poggeler, 1972]). On the other hand, a text as a whole is a set of sentences. However, this is not a logical circle but, instead, the so-called hermeneutic spiral. The difference is that the pre-understanding can be changed due to interpretation of elements. Accordingly, recognition is treated by Stegmüller as a process directed to the understanding of the whole by means of an iterative feedback to the pre-understanding (see, e.g., [Poggeler, 1972]). These ideas were applied to the study of information processing performed by nonlinear dynamical systems [Tsuda, 1984; Tsuda et al, 1987]. Namely, pattern recognition was treated as a spontaneous interpretation of input signals in terms of self-organized sets of pieces of information which correspond to elementary objects.

Concerning the assumption accepted in the present paper that anticipation occurs as early as perception, notice that this hypothesis was discussed in [MacKey, 1956; Nicolis, 1986; Bruner, 1957; Sokolov, 1963; Feigenberg, Ivannikov, 1978; Pribram, 1971; Sokolov, Vatkyavichus, 1989]. Our approach is most close to the last two books.

Appendix B

Some Data on the Meaning of Pho-

nemes, Words and Nonverbal Signs

During all the history people attempted to grasp what the meaning is in principle and how words acquire their meanings in particular. So, the great Greek philosopher Plato (427-347 B.C.) stated that we were free in the choice of the name of a thing, but our freedom was restricted by properties of the thing as well as by properties of the language. It is even more ancient book "Shan Hai Ching" ("Book of Mountains and Seas", China, 8-th century B.C. - A.D. 1-st century) that one can find the idea that things shout calling their names.

A number of experimental studies were carried out in *psychosemantics* and *phonosemantics* to find basic semantic factors (SF's) as regards phonemes, words, visual images, etc. [Osgood, 1952, 1962, 1966; Osgood, Suci, Tannenbaum, 1957; Schlosberg, 1954; Bentler, LaVoie, 1972; Petrenko, 1988; Zhuravlev, 1991]. To this end, the factor analysis was applied (see, e.g., [Lawley, Maxwell, 1971; Gottsdanker, 1982; Ledermann, Lloyd, 1984]) which consists of the following steps (we consider the case of phonemes for concreteness):

(1) For every selected SF, a scale is determined by indicating its poles and fixing a certain number of grades between them. Each pole is described by one or several words.

(2) Phonemes are presented; tested people are asked to score each phoneme on the scale. The criterion is the impression made by the phoneme.

(3) The above steps are performed for all the selected SF's. Then the set of SF's are divided into groups so that each group comprises close SF's.

(4) Among all SF's of a group, a leading SF is selected around which the other SF's of the group are located. This selected SF is a primary semantic factor (PSF).

Thus, every SF is treated as a scale in some semantic space (SS) and a PSF is considered as a dimension of the SS that comprises a group of scales close to each other in their meanings.

The three main PSF's were found:

(1) *appraisal*, or assessment, estimate, evaluation, judgment, attitude;

(2) *strength*, or potency, force, power, vigor;

(3) *activity*, or mobility, liveliness.

In some studies, other PSF's were, in addition, revealed such as:

(4) *order*, or ordering, regularity ;

(5) *reality*;

(6) *usual*, or customary, ordinary;

(7) *complexity*;

(8) *comfort*.

The above PSP's correspond to certain groups of SF's, e.g.,

(1) *appraisal*: good—bad; bright, light—dark; kind—wicked, evil, cruel; pretty, beautiful, handsome—ugly, hideous; safe, secure—dangerous; pleasant—unpleasant; simple—complex; etc.;

(2) *strength*: strong—weak; big, large—little, small; heavy—light; manly, masculine—womanly, feminine; powerful—puny; loud—low, soft; brave—cowardly; cold—hot; etc.;

(3) *activity*: active—passive; quick, fast—slow; mobile, lively—sluggish, leisurely; merry, joyful—sad; exited—debilitated; tense—relaxed; etc.

The influence of sounds on the human organism is used in *medical treatment*. So, Chinese therapy is based on the so-called theory of five primary elements so that each of them is associated with certain organs of the body and uttering special sounds affects the state of these organs [Huang Ti, 1949; Chia, 1985; Zhang, Sun, 1985]. Namely, (1) the primary element *"Tree"* is associated with liver, gall bladder, tendons, eyes, and these organs are influenced as the sound *guo* is repeated; analogously (2) the element *"Fire"* is connected with heart, small intestine, vessels, tongue and the sound *zheng*; (3) *"Soil"*—spleen & pancreas, stomach, muscles, mouth—*gong*; (4) *"Metall"*—lung, large intestine, skin, nose—*shang*; (5) *"Water"*—kidney, urinary bladder, bones, ears—*yu*. The sounds *duo, dong, xi, fo, fu, ha* are believed to produce specific effects as well. It is worth noting that not all schools of Chinese qigong recognize this kind of therapy because it is difficult to teach patients to utter the sounds correctly, whereas incorrect pronouncing may produce an undesirable effect.

In European therapy, repeating special sounds was found to produce a healing influence on such organs as gullet, larynx, chest, lung, heart, liver, stomach, thyroid gland, brain and be useful for treating hypertension, sclerosis, respiratory diseases, digestive tract problems, neurosis [Dineika, 1981, 1987].

An important component of mystical practices is the *mantra*, i.e. a phrase, word, syllable or sound which is repeated aloud or mentally and is believed to possess a special spiritual power. The most known system of such a kind is apparently *Yoga* which is broadly divided into Karma Yogä, Bhakti Yoga, Raja Yoga and Gyana Yoga [Vivekananda, 1953; Vishnudevananda, 1959; Petrov, 1983]. In turn, Raja Yoga is broken down into Mantra Yoga, Kundalini Yoga and Hatha Yoga. There are a number of mantras in Yoga: (1) the most known mantra of Yoga (and Hinduism) is *OM* (or *AUM*, or *A-OU-M*); (2) the mantra *OM TAT SAT*; (3) personal mantras given by the teacher (guru); (4) mantras connected with chakras. Every *chakra*, i.e. the astral center or plexus, the storage place of *prana* (vital energy), is symbolized by lotus. Petals of such a lotus and *yantra* in its central part are associated with special mantras (e.g., for Adjna chakra, the mantras *ham* and *ksham* correspond to the petals, while the mantra *ong* is connected with the yantra). Repeating appropriate mantras in an altered state of consciousness produces certain influences on chakras and thereby on the emotional and physiological state of the organism.

The main mantra of first stages of Buddhism is *OM MANI PADME HUM*. There are a number of incantations in various kinds of shamanism. It is also asserted that some kind of mantras are really used in esoteric Christianity [Bezant, 1930].

References

[1] ABBOTT, L.F. 1990. A network of oscilators. J. Phys. A 23:3835–3859.

[2] ABELES, M. 1982. Role of cortical neuron: integrator or coincidence detector? Israel J. Med. Sci. 18:83–92.

[3] ACH, N. 1905. Über die Willenstätigkeit und das Denken. Göttingen.

[4] ADRIAN, E.D. 1928. J. Physiol. 88:127.

[5] AMIT, D.J. 1989. Modelling Brain Functions. Cambridge Univ. Press. Cambridge.

[6] AMIT, D.J. 1994. Persistent delay activity in cortex: a Galilean phase in neurobiology? Network 5:429–436.

[7] AMIT, D.J., H. GUTFREUND & H. SOMPOLINSKY. 1985. Spin-glass models of neural networks. Phys. Rev. Lett. 32:1007–1018.

[8] ANOKHIN, P.K. 1935. Problems of Centre and Periphery in Physiology of Nervous Activity. Gor'ky. *In* Russian.

[9] ANOKHIN, P.K. 1949. Problems of Higher Nervous Activity. AMN SSSR Press. Moscow. *In* Russian.

[10] ANOKHIN, P.K. 1968. Biology and Neurophysiology of Conditioned Reflex. Meditsina. Moscow. *In* Russian.

[11] ANOKHIN, P.K. 1979. System Mechanisms of High Nervous Activity. Nauka. Moscow. *In* Russian.

[12] ANOKHIN, P. & E. STREZH. 1933. Physiol. Journ. USSR 16:280.

[13] ASHBY, W.R. 1940. Adaptiveness and equilibrium. Jornal of Mental Science 86:478–483.

[14] ASMOLOV, A.G. 1977. *In* I.M. Feigenberg & G.E. Zhuravlev, Eds. Probabilistic Forecasting in Activity of Man. 60–111. Nauka. Moscow. *In* Russian.

[15] BAKHUR, V.T. 1986. This Unique "Self". Znanie. Moscow. *In* Russian.

[16] BECHTEREVA, N.P., YU. L. GOGOLITSIN, YU.D. KROPOTOV & S.V. MEDVEDEV. 1985. Neurophysiological Mechanisms of Thinking. Nauka. Moscow. *In* Russian.

[17] BENTLER, P. M. & A.L. LA VOIE. 1972. A Nonverbal Semantic Differential. J. Verbal Learning and Verbal Behavior 11.

[18] BERNSHTEIN, N.A. 1947. On Constructing Movements. Medgiz. Moscow. *In* Russian.

[19] BERNSHTEIN, N.A. 1966. Essays on Physiology of Movements and Physiology of Activity. Meditsina. Moscow. *In* Russian.

[20] BEZANT, A. 1930. Esoteric Christianity, or Small Mysteries. Vestnik. Moscow. *In* Russian.

[21] BRAHAM, R. 1989. Numerical analysis of neural networks. *In* Proc. IEEE/INNS IJCNN. 1428–1432. June 18–20, 1989. 1428. Washington, DC.

[22] BRAHAM, R. & J.O. HAMBLEN. 1990. The design of a neural network with a biologically motivated architecture. IEEE Trans. Neural Networks 1:251.

[23] BRUNER, J.S. 1957. On perceptual readiness. Psychol. Rev. 64:123-152.

[24] BRUNSWIK, E. 1939. Probability as a determiner of rat behaviour. J. Exp. Psychol. 25.

[25] BÜHLER, K. 1934. Sprachtheorie: die Darstellungsfunktion der Sprache. G. Fischer. Jena.

[26] BURNS, R.B. 1982. Self—Concept Development and Education. Holt. London.

[27] CHIA, M. 1985. Taoist Way to Transform Stress into Vitality. Healing Tao Books. Huntington, NY.

[28] CHOMSKY, N. 1956. Three models for the description of language. IRE Trans. Inform. Theory IT-2:113-124.

[29] CHOMSKY, N. 1959. On certain formal properties of grammars. Inform. Contr. 2:137-167.

[30] CHOMSKY, N. 1963. *In* R.D. Luce, R.R. Bush & E.H. Galanter, Eds. Handbook of Mathematical Psychology. 323. Wiley. New York, 1963.

[31] CHOMSKY, N. 1972. Language and Mind. Harcourt Brace Jovanovich. New York.

[32] CHOMSKY, N. & G.A. MILLER. 1958. Finite state languages. Inform. Contr. 1:91-112.

[33] CHURCHLAND, P.M. 1989. A Neurocomputational Perspective: The Nature of Mind and the Structure of Science. MIT Press. Cambridge, MA.

[34] COWAN, J.D. & D.H. SHARP. 1988. Neural nets. Quart. Rev. Biophys. 21:365-427.

[35] DENNIS, W., Ed. 1948. Readings in the History of Phychology. Appleton-Century-Crofts. New York.

[36] DINEIKA, K.V. 1981. Motion, Breathing, Psychic and Physical Training. Polymya. Minsk. *In* Russian.

[37] DINEIKA, K.V. 1987. Ten Lessons of Psychic and Physical Training. Fizkultura i Sport. Moscow. *In* Russian.

[38] DYLJUDENKO, V.F. & A.M. KROT. 1996. A local topological method of the determining of minimal dimension of the embedding of a chaotic attractor. Proc. Acad. Sci. Belarus. Phys. & Math. Sci. 1:104-110. *In* Russian.

[39] FARMER, J.D. 1990. A Rosetta stone for connectionism. Physica D 42:153-187.

[40] FEIGENBERG, I.M. 1963. Probabilistic forecasting in the brain activity. Sov. J. Problems of Phychology 2:34-44. *In* Russian.

[41] FEIGENBERG, I.M. & V.A. IVANNIKOV. 1978. Probabilistic Forecasting and Pretuning to Movements. Nauka. Moscow. *In* Russian.

[42] FEIGENBERG, I.M. 1986. To See—To Foresee—To Act: Psychological Essays. Znanie. Moscow. *In* Russian.

[43] FITZHUGH, R. 1961. Impulses and physiological states in theoretical models of nerve membrane. Biophys. J. 1:445-466.

[44] FREEMAN, W.J. 1987. Biol. Cybern. 56:139.

[45] FREEMAN, W.J. 1992. Tutorial of Neurobiology: From Single Neurons to Brain Chaos. Int. J. Bifurcation and Chaos 2:451-482.

[46] FROLOV, A.A. & I.P. MURAV'EV. 1987. Neuronal Models of Associative Memory. Nauka. Moscow. *In* Russian.

[47] FROLOV, A.A. & I.P. MURAV'EV. 1988. Information Characteristics of Neural Networks. Nauka. Moscow. *In* Russian.

[48] GADAMER, H.G. 1976. Philosophical Hermeneutics. Univ. of California Press.

[49] GEORGE, F.H. 1977. The Foundations of Cybernetics. Gordon and Breach. London.

[50] GIBSON, J. J. 1941. A critical review of the concept of set in contemporary experimental psychology. Psychol. Bull. 38.

[51] GLAUBER, R.J. 1963. J. Math. Phys. 4:294.

[52] GOTTSDANKER, R. 1982. Experimenting in Psychology. Prentice-Hall. Englewood Cliffs, NJ.

[53] GROSSBERG, S. 1988. Nonlinear neural networks: principles, mechanisms, and architectures. Neural Networks 1:17-61.

[54] HADAMARD, J. 1945. 1954. The Psychology of Invention in the Mathematical Field. Princeton Univ. Press. Princeton. Dover Books. New York.

[55] HAKEN, H. 1983. Synergetics. Springer. Berlin.

[56] HAKEN, H. 1988. Information and Self-Organization: A Macroscopic Approach to Complex Systems. Springer. Berlin.

[57] HAKEN, H. 1991. Synergetic Computers and Cognition: A Top-Down Approach to Neural Nets. Springer. Berlin.

[58] HERTZ, J.A., A. KROGH & R. PALMER. 1991. Introduction to the Theory of Neural Computation. Addison-Wesley. Redwood City.

[59] HINDMARSH, J.L. & R.M. ROSE. 1982. A model of the nerve impulse using two first-order differential equations. Nature 296:162–164.

[60] HINDMARSH, J.L. & R.M. ROSE. 1984. A model of neuronal bursting using three coupled first order differential equations. Proc. R. Soc. London B 221:87–102.

[61] HODGKIN, A.L. & A.F. HUXLEY. 1952. A quantitative description of membrane current and its application to conduction and excitation in nerve. J.Physiol. 117:500–544.

[62] HOPFIELD, J.J. 1982. Neural network and physical systems with emergent collective computational abilities. Proc. Natl. Acad. Sci. USA 79:2554–2558.

[63] HOPFIELD, J.J. 1984. Neurons with graded response have collective computational properties like those of two-state neurons. Proc. Natl. Acad. Sci. USA 81:3088–3092.

[64] HUANG TI NEI CHING SU WEN. 1949. The Yellow Emperor's Classic of Internal Medicine. Welliams & Wilkins. Baltimore.

[65] KAPELKO, V.V. & A.D. LINKEVICH. 1996. Chaos and associative generation of information by networks of neuronal oscilators. Phys. Rev. E 54:2802–2806.

[66] KARTYNNICK, A.V. & A.D.LINKEVICH. 1994. Retrieval of memorized patterns by nonsymmetric neural networks: local Lyapunov functions and local contracting maps methods. Optical Memory and Neural Networks 3:329–342.

[67] KARTYNNICK, A.V. & A.D. LINKEVICH. 1995. Global attractors, attracting regions and regions of visiting of dynamical systems. Preprint Belsplav. Minsk.

[68] KEPLER, T., E. MARDER & L.F. ABBOTT. 1990. The effect of electrical coupling on the frequency of model neuronal oscillators. Science 248:83–85.

[69] KRATIN, Y. G. 1982. Neurophysiology and the Theory of Reflection. Nauka. Leningrad. *In* Russian.

[70] KÜLPE, O. 1893. Grundriss der Psychologie. Leipzig.

[71] LAWLEY, D.N. & A.E. MAXWELL. 1971. Factor Analysis as a Statistical Method. Butterworths.

[72] LEDERMANN, W. & E. LLOYD, Eds. 1984. Handbook of Applicable Mathematics. Vol. VI: Statistics. Part B. Wiley. New York.

[73] LEFEBVRE, V.A. 1982. Algebra of Consience. Reidel. Dordrecht.

[74] LEFEBVRE, V.A. 1990a. The Fundamental Structures of Human Reflection. Peter Lang. New York.

[75] LEFEBVRE, V.A. 1990b. From psychophysics to modeling of the soul. Voprosy Filosofii 7:25–30. *In* Russian.

[76] LINKEVICH, A.D. 1993a. Learning neural networks with the aid of projection techniques. *In* V.I. Kuvshinov & D.W. Serow, Eds. Proc. Second Seminar "Nonlinear Phenomena in Complex Systems". February 15–17, 1993. Polatsk. PIYaF. 373–382. Saint-Petersburg.

[77] LINKEVICH, A.D. 1993b. A sequential learning rule for analogous neural networks. Optical Memory and Neural Networks 2:111–116.

[78] LINKEVICH, A.D. 1993c. Neural networks: nonlinear collective dynamics. Proc. Workshop "Mind, Brain and Neurocomputers". 7. November 16–18, 1993. Minsk. G. Krylov, Ed. Advances in Synergetics 1:7–29. Belarusian State Univ. Press. Minsk. 1994.

[79] LINKEVICH, A.D. 1994. Pattern recognition, anticipation and nonlinear dynamics of neurosystems. Proc.Third Seminar "Nonlinear Phenomena in Complex Systems". February 14–16, 1994. Polatsk. *In* V. Kuvshinov & G. Krylov, Eds. Advances in Synergetics 2:251–257. Institute of Physics. Minsk. 1995.

[80] LINKEVICH, A.D. 1996a. Perception, generation of hypotheses, and language. Proc. Forth Workshop "Mind, Brain and Neurocomputers". October 31–November 1, 1996. Minsk. In press.

[81] LINKEVICH, A.D. 1996b. Some properties of piecewise-linear neuron-like elements. Proc. Forth Workshop "Mind, Brain and Neurocomputers". October 31–November 1, 1996. Minsk. In press.

[82] LINKEVICH, A.D. 1996c. Analytic solution of a neuron model exhibiting chaotic behavior. Proc. Fifth Seminar "Nonlinear Phenomena in Complex Systems". Febuary 12–15, 1996. Minsk. In press.

[83] LINKEVICH, A.D. 1997. Language, Mind and Nonlinear Dynamics of Neural Networks. Proc. Sixth Seminar "Nonlinear Phenomena in Complex Systems". February 10–13, 1997. Minsk. In press.

[84] LITTLE, W.A. 1974. The existance of persistent states in the brain. Math. Biosci. 19:101–120.

[85] MACKAY, D.M. 1956. The epistemological problem for automata. *In* C.E. Shannon & J. McCarthy, Eds. Automata Studies. 235–251. Princeton Univ. Press. Princeton.

[86] MACKINTOSH, N.J. 1983. Conditioning and Associative Learning. Clarendon. Oxford.

[87] MARR, D. 1982. Vision. Freeman. New York.

[88] MCFARLAND, D. 1985. Animal Behaviour. Pitman. London.

[89] MCKELVI, S. J. 1973. The meaningfulness and meaning of schematic faces. Perception and Psychophysics 14:343–348.

[90] MICHEL, A.N., J. SI & G. YEN. 1991. Analysis and synthesis of a class of discrete-time neural networks described on hypercubes. IEEE Trans. Neural Networks 2:32–55.

[91] MILLER, G. A., E. GALANTER & K.H. PRIBRAM. 1960. Plans and the Structure of Behavior. Holt. New York.

[92] MILLER, M.I., B. ROYSAM, K.R. SMITH & J.A. O'SULLIVAN. 1991. Representing and computing regular languages on massively parallel networks. IEEE Trans. Neural Networks 2: 56–71.

[93] NAGUMO, J.S., S. ARIMOTO & S. YOSHISAWA. 1962. An active pulse transmission line simulating nerve axon. Proc. IRE 50:2061–2070.

[94] NALIMOV, V.V. 1989. Spontaneity of Consciousness: A Probabilistic Theory of Meanings and Semantic Architectonic of Personality. Prometey. Moscow. *In* Russian.

[95] NICOLIS, G. & I. PRIGOGINE. 1977. Self-Organization in Non-Equilibrium Systems. Wiley. New York.

[96] NICOLIS, J.S. 1986. Dynamics of Hierarchical Systems. Springer. Berlin.

[97] OGDEN, C.K. & I.A. RICHARDS. 1938. 1949. The Meaning of Meaning. Harcourt Brace. New York. Kegan Paul.

[98] OSGOOD, C.E. 1952. A Behavioristic analysis of perception and language as cognitive phenomena. *In* J. S. Bruner et al, Eds. Contemporary Approach to Cognition. Harvard Univ. Press. Harvard.

[99] OSGOOD, C.E. 1962. Studies on the generality of affective meaning systems. Amer. Psychol. 1:1.

[100] OSGOOD, C.E. 1966. Dimensionality of the semantic space for communication via facial expressions. Scand. J. Psychology 7:1. Stockholm.

[101] OSGOOD, C.E., G.J. SUCI & P.H. TANNENBAUM 1957. The Measurement of Meaning. Urbana.

[102] PAVLOV, I.P. 1927. Conditioned Reflexes. Oxford Univ. Press. London.

[103] PENFIELD, W. 1975. The Mystery of the Mind. Princeton Univ. Press. Princeton.

[104] PERETTO, P. 1989. The Modelling of Neural Networks. Editions de Physique. Les Ulis.

[105] PETRENKO, V.F. 1988. Psychosemantics of Consciousness. Moscow State University Press. Moscow. *In* Russian.

[106] PETROV, N. 1983. Self-Suggestion in Ancient Times and Today. Meditsina i Fizkultura. Sophia. *In* Bulgarian.

[107] PINEDA, F.J. 1987. Generalization of back-propagation to recurrent neural networks. Phys. Rev. Lett. 59:2229–2232.

[108] POGGELER, H.O. 1972. Hermeneutische Philosophie. Nymphenburger Verlag. Munchen.

[109] PRIBRAM, K.H. 1971. Languages of the Brain. Prentice-Hall. Englewood Cliffs, NJ.

[110] ROSE, R.M. & J.L. HINDMARSH. 1985. Proc. R. Soc. London B 225:161.

[111] ROSENBLUETH, A., N. WIENER & J. BIGELOW. 1943. Behavior, purpose and teleology. Philosophy of Science 10:18–24.

[112] RUMELHART, D.E. & J.L. MCCLELLAND, Eds. 1986. Parallel Distributed Processing: Explorations in the Microstructure of Cognition. MIT Press. Cambridge, MA.

[113] RUMELHART, D.E., G.E. HINTON & R.J. WILLIAMS. 1986. Learning representations by back-propagating errors. Nature 323:533–536.

[114] SCHLOSBERG, H. 1954. Three dimensions of emotions. Psychol. Review 61:2:81–88.

[115] SECHENOV, I.M. 1961. Reflexes of the Brain. Izd. AN SSSR. Mosco. *In* Russian.

[116] SELZ, O. 1913. Über die Gesetze des geordneten Denkverlaufs. W. Spemann. Stuttgart.

[117] SELZ, O. 1922. Zur Psychologie des produktiven Denkens und des Irrtums. F. Cohen. Bonn.

[118] SELZ, O. 1924. Die Gesetze der produktiven und reproduktiven Geistestätigkeit. F. Cohen. Bonn.

[119] SHADLEN, M.N. & W.T.NEWSOME. 1994. Noise, neural codes and cortical organization. Current Opinion in Neurobiology 4:569-579.

[120] SHERRINGTON, C.S. 1906. 1947. The Integrative Action of the Nervous System. Yale Univ. Press. New Haven & Oxford Univ. Press. London. Cambridge Univ. Press, Cambridge.

[121] SIMONOV, P.V. 1975. Higher Nervous Activity of Man: Motivational and Emotional Aspects. Nauka. Moscow. *In* Russian.

[122] SIMONOV, P.V. 1981. The Emotional Brain. Nauka. Moscow. *In* Russian.

[123] SKINNER, B.F. 1943. The Behavior of Organisms. Appleton-Century-Crofts. New York.

[124] SLOBODCHIKOV, V.I. & E.I. ISAEV. 1995. Psychology of Man: Introduction into Psychology of Subjectivity. Shkola-Press. Moscow. *In* Russian.

[125] SMOLENSKY, P. 1988. On the proper treatment of connectionism. Behavioral and Brain Science 11:1–74.

[126] SOFTKY, W.R. & C. KOCH. 1993. The highly irregular firing of cortical cells is inconsistent with temporal integration of random EPSPs. J. Neurosci. 13:334-350.

[127] SOKOLOV, E.N. 1959. Reports of Acad. Pedagog. Sci. Russia. No 4.

[128] SOKOLOV, E.N. 1960. Neuronal models and the opienting reflex. *In* M.A.B. Brazier, Ed. The Central Nervous System and Behaviour. 187–276. Josiah Macy Jr. Foundation. New York.

[129] SOKOLOV, E.N. 1963. Perception and the Conditioned Reflex. Macmillan. New York.

[130] SOKOLOV, E.N. & G.G. VATKYAVICHUS. 1989. The Neurointelligence: from Neurons —towards Neurocomputer. Nauka. Moscow. *In* Russian.

[131] SHADLEN, M.N. & W.T.NEWSOME. 1994. Current Opinion in Neurobiol. 4:569

[132] SOFTKY, W.R. & C. KOCH. 1993. J. Neurosci. 13:334.

[133] TEILHARD DE CHARDIN, P. 1955. The Phenomenon of Man. Oeuvres. T. 1. Paris. *In* French.

[134] TEMAM, R. 1988. Infinite Dimensional Systems in Mechanics and Physics. Springer. New York.

[135] TOULOUSE, G. 1989. Perspectives on neural network models and their relevance to neurobiology. J. Phys. A 22:1959–1968.

[136] TSUDA, I. 1984. A hermeneutic process of the brain. Progr. Theor. Phys. 79:241–259.

[137] TSUDA, I., E. KOERNER & H. SHIMUZU. 1987. Memory dynamics in asynchronous neural networks. Progr. Theor. Phys. 78:51–71.

[138] USHER, M., M. STEMMLER, C. KOCH & Z. OLAMI. 1994. Network amplification of local fluctuations causes high spike rate variability, fractal firing patterns and oscillatory local field potentials. Neural Comput. 6:795–836.

[139] VEDENOV, A.A. 1988. Modeling Elements of Thinking. Nauka. Moscow. *In* Russian.

[140] VISHNUDEVANANDA, S. 1959. The Complete Illustrated Book of Yoga. Pocket Books. New York.

[141] VIVEKANANDA, S. 1953. The Yoga and Other Works. Rama Krishna & Vivekananda Center. New York.

[142] WERTHEIMER, M. 1945. 1959. Productive Thinking. Harper. New York.

[143] WILSON, H. R. & J.D. COWAN. 1972. Excitatory and inhibitory interaction in localized populations of model neurons. Biophys. J. 12:1–24.

[144] WILSON, H. R. & J.D. COWAN. 1973. A mathemetical theory of the functional dynamics of cortical and thalamic nervous tissue. Kybernetik 13:55–80.

[145] WILSON, W.A. & H. WACHTEL. 1974. Negative resistance characteristic essential for the maintenance of slow oscillations in bursting neurons. Science 186:931–934.

[146] WITTGENSTEIN, L. 1953. 1967. Philosophical Investigations. Basil Blackwell.

[147] MINGWU, ZHANG & SUN XINGYUAN. 1985. Chinese Qigong Therapy. Shandong Science and Technology Press. Jinan.

[148] ZHURAVLEV, A.P. 1991. Sound and Meaning. Prosveshchenie. Moscow. *In* Russian.

A Basic Idea of Consciousness

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Consciousness is something concerned with our knowing things of the bodily senses and mental powers. So, with five senses of our body, we can be aware of things, and with our mind, we can be aware of things too. But only the five senses cannot do with consciousness. This is obvious indeed, because we cannot make "consciousness" with only five senses, implemented by electric sensors. With only five senses, we cannot feel and think anything. We need something extra, which is consciousness, mental power, mind.

Thus, the point in consciousness is "mind". Mind is the ability to take information from five senses, and to digest it, and to react in order to survive and to protect an individual. In this paper, the following hypothetical structure of "mind" is used. "Mind" is divided into two parts: one is the "lower mind" and another is the "higher mind". With lower mind, the mind realizes "protection". With the higher mind, most of the mind is "protection and self-recognition of reasons". So, using these hypotheses, I have tried to propose simple examples for the two kinds of mind, using neural networks.

1 Consciousness in General

Till the middle of this century it was believed that it is the age of quantum mechanics. However, at the end of the 20th century it is said that it is the age of the brain and the mind. A great number of works have been done in this direction [1, 2, 3, 4, 5, 11, 12, 13, 14, 15]. Now many people believe that the human mind is created merely by the brain mechanisms.

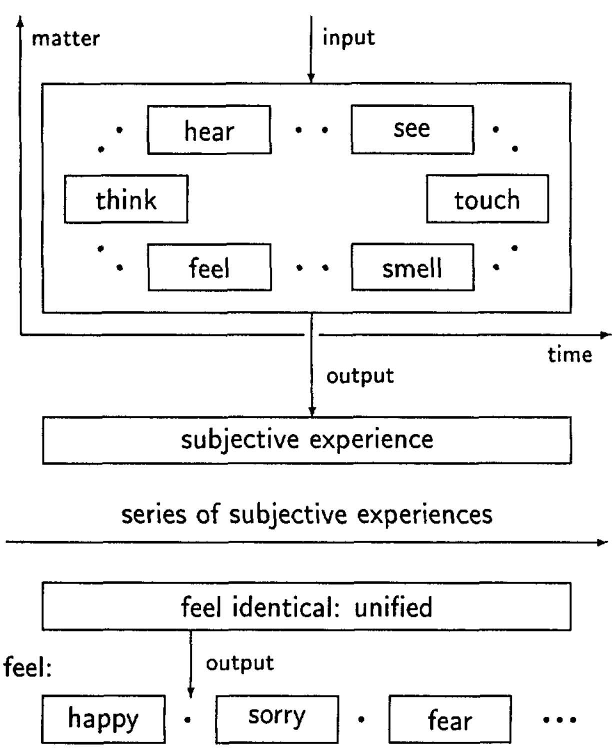
In the beginning of this development, the brain was conceived mainly as a black box. But by the invention of PET, it became possible to study brain mechanisms and the function of the brain, although the study might appear to be at the very beginning of scientific possibilities. Evidently, from now on, it will be possible to find out more precisely how the brain is functioning and how the mind is created through the brain activities. On this way, it will become possible to clear the relationship between brain and mind. So, one may expect that applications of consciousness research in different scientific fields will expand more and more.

2 Theories of Consciousness

In this section, two conjectures and theories on consciousness will be introduced, defined, and discussed.

When we are in an awake state, we think and feel several things. That is to say, we have a direct subjective experience. This is generally called "consciousness". So, consciousness means to have (know) the experience of seeing, hearing, touching, smelling, tasting, thinking, feeling, etc. And the present state of consciousness is a continuation from the previous consciousness states. It is also very important for us to be able to recognize that both sorts of consciousness—the present and the previous one—are informing at the same time within our mind mechanism. In other words, we must feel them identical at the same moment. So, a series of subjective experiences must be unified in some way. From this kind of unification, the feeling of the unique consciousness emerges. In this way of reasoning we come to the conclusion that consciousness is a system presented by the following conjecture, sketched also by a diagram.

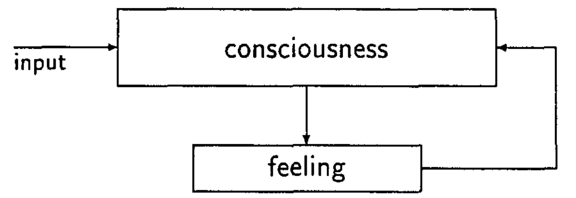
Conjecture 1 [A System of Consciousness] *The mechanism (system) of consciousness has the structure presented by the diagram*



□

The contents of experiences within consciousness are not simple, because they consist of many items we experience, will experience and/or have experienced. Even in this situation, contents must be unified in order to get a unique personality (mind). This means that although all of the experience contents constitute the consciousnesses at the same moment, one of the contents must be always clear while the rest of them is vague. This is quite important, because without this bind state, there would exist several minds (a multi-mind) at the same time. And if we can get the situation that one of the contents is clear, this will represent a kind of concentration (attraction). And this concentration field (area) will be focused by means of feeling, in another words, it will be controlled by the output of a feeling.

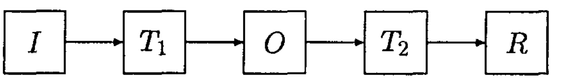
Conjecture 2 [A Unique Personality (Mind)] *Unique personality (mind) will exist when there is a concentration being controlled by an output feeling (consciousness influenced by feeling), according to the diagram*



□

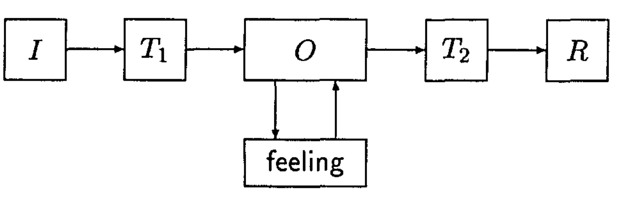
From the above two conjectures, we can say that consciousness (mind) is the ability to take information from five senses, to digest it, and to react in order to survive and to protect an individual. And by considering above facts, and also by seeing our human nature, we can say that mind is divided into two areas. The one is "lower mind" and the another is "higher mind". With the lower mind, most of the mind is "protection". With the higher mind, most of the mind is "protection and self-recognition of reasons (feeling)". So, from these results and conjectures, we deduce two theories.

Theory 1 [Lower Mind Theory] *Lower mind has a structure of the form*



where I represents Input from environment, T_1 is Transformation 1, O is Output into mind, T_2 means Transformation 2, and R represents Reaction. □

Theory 2 [Higher Mind Theory] *Higher mind has a structure of the form*



where I represents Input from environment, T_1 is Transformation 1, O is Output into mind, T_2 means Transformation 2, and R represents Reaction. □

Next, a structure of consciousness can be discussed.

From above conjectures and theories, we come to the structure of consciousness in Fig. 1.

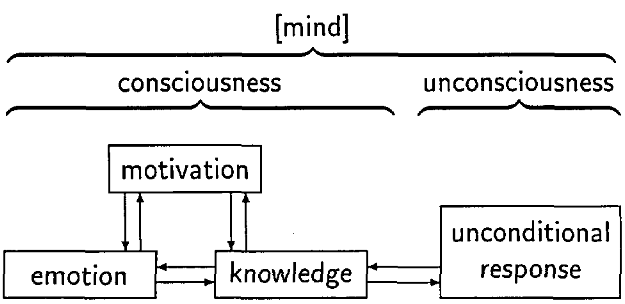


Figure 1: *A rough structure of consciousness*

3 An Example of Consciousness

Here, an example of consciousness is given.

[Example]

There is a man who wants to go to a destination for some reasons. But on his way to the destination, there is a dog who is very dangerous. And he does not like a dog at all. His behavior to a dog is generally as follows:

- If there is not a dog on his way, he wants to go fast to the destination quite happily.
- If he hears a dog barking, he feels danger. So he slows down his speed.
- If he smells a dog, he does not want to go further. He might want to go back.

This example is solved with the "Mind" which has been studied above, that is to say, with both the "lower mind" (unconsciousness) and with the "higher (consciousness) mind" as sketched in Fig. 2. This is a brief view of how neural networks are used and connected. In Fig. 2, circles connected by lines show groups of neural networks.

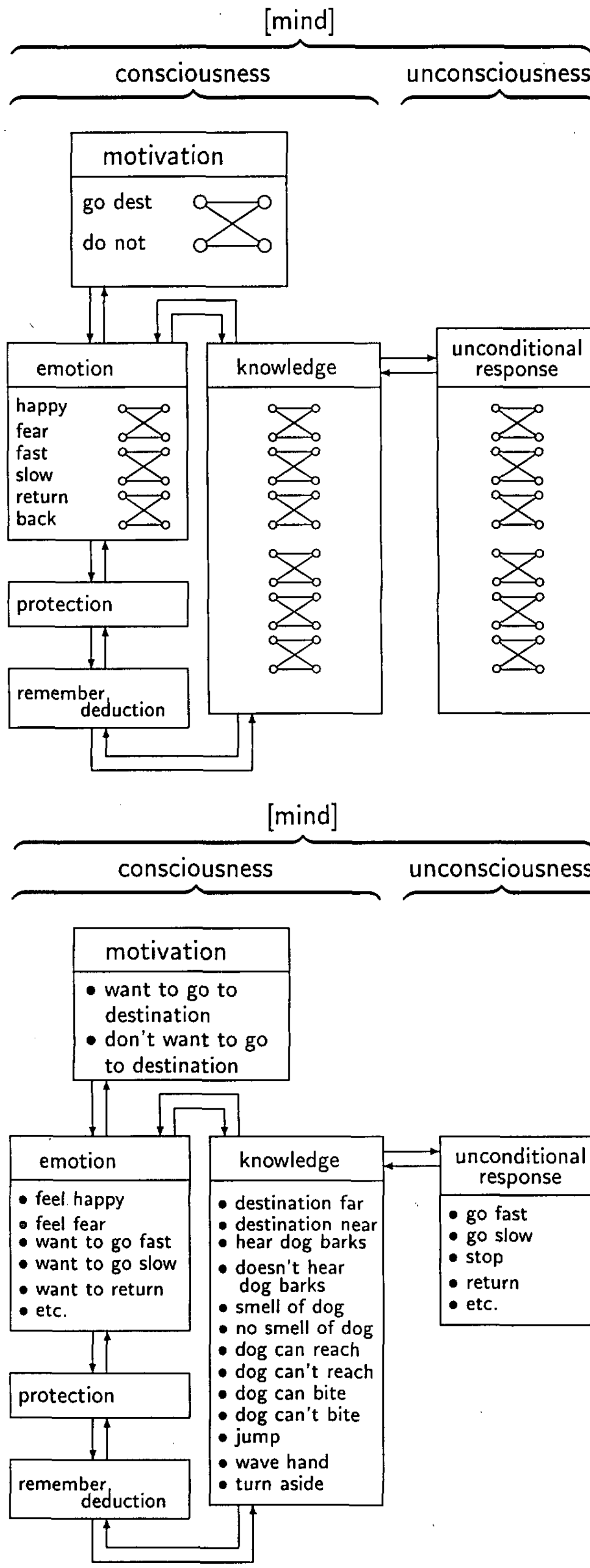


Figure 2: *An example of consciousness structure*

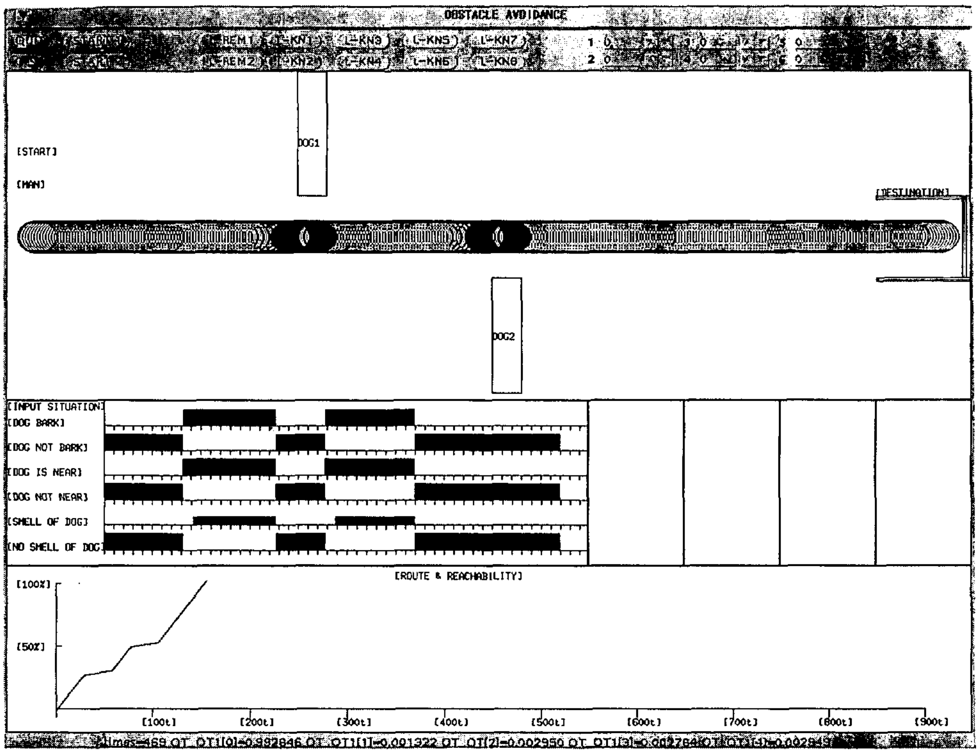


Figure 3: *Example 1: Using the "Lower Mind" and the "Higher Mind".*

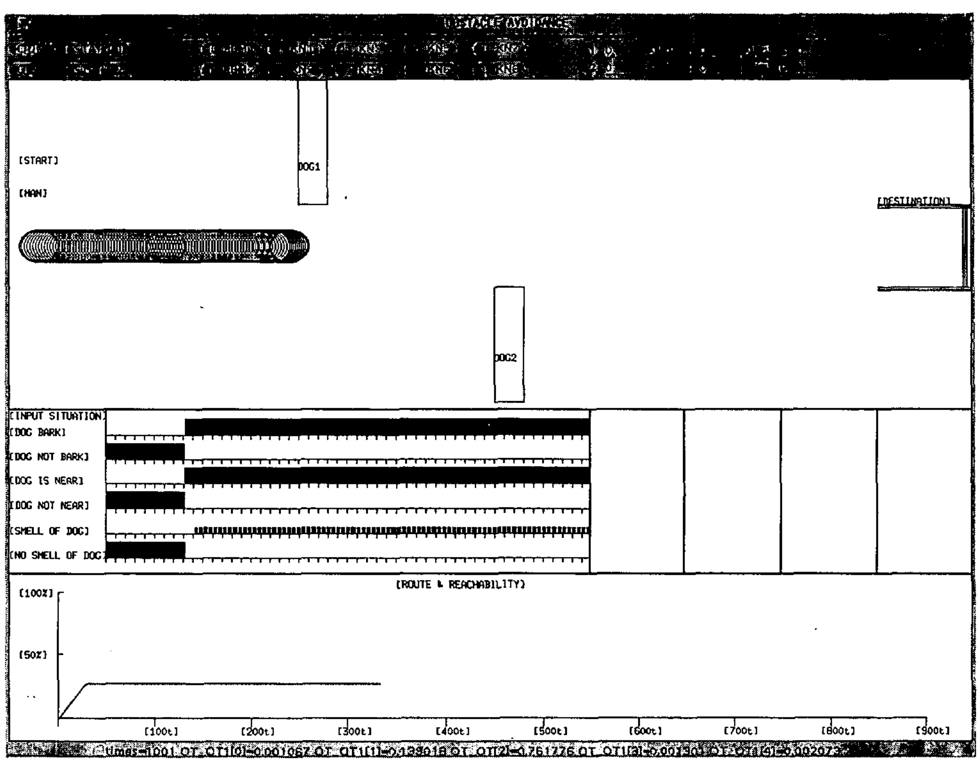


Figure 4: *Example 2: Using the "Lower Mind".*

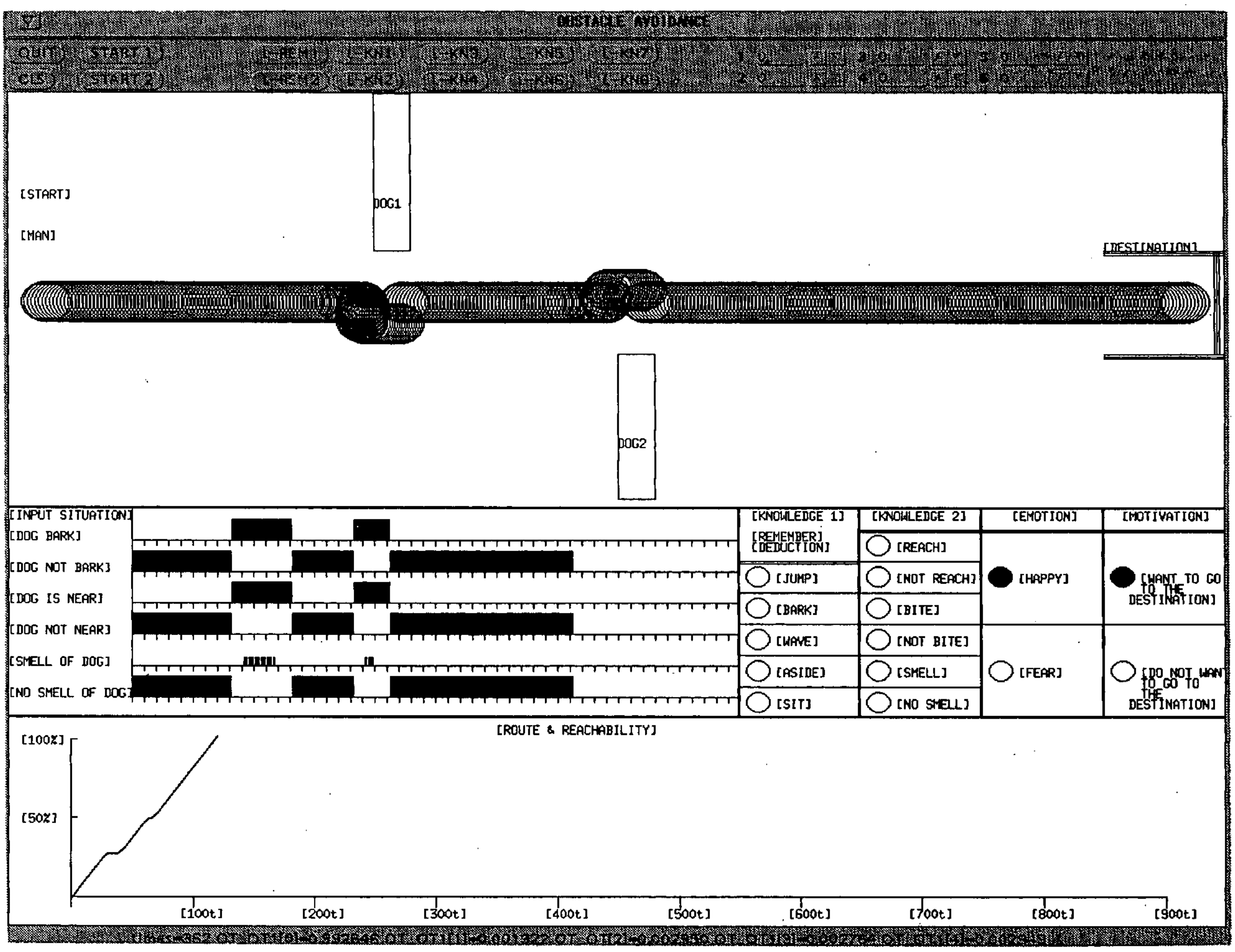


Figure 5: *Example 3: Using the "Higher Mind".*

For each element of "knowledge", "emotion" and "motivation", neural networks of back propagation have been used [6, 7, 8, 9, 10].

Now, let us look into the output examples in Figs. 3–5. Series of circles show which route the man has taken to reach the destination. Series of darker circles show that he went slower because of the dogs. The graphs at the bottom of examples show the ratios of distance reached to time passed.

Examples 1 and 2 show how the man behaves if there is a dog near to him or if there is a smell of dog.

In Example 1 the "Lower Mind" is used, and the result is shown in Fig. 4. With "Lower Mind", he goes smoothly if there are no troubles for him. But if he goes quite near to a dog, he has a chaotic behavior, which means that he cannot move at all.

In Example 2 the "Higher Mind" is used, and the result is shown in Fig. 5. With the "Higher Mind", he can ignore any kind of trouble.

4 Conclusion

In cases presented, "consciousness" has been studied in a basic form, and two conjectures and theories have been introduced. At the end, some evident of results have been obtained. As one can ascertain

1. basic structure and mechanisms of "Mind" and "Consciousness" have been investigated;
2. from the examples shown it can be stated that consciousness is an important factor for getting things done properly in a complex way; and
3. from the behavior observed, we can only guess that it uses a kind of consciousness. This seems to be true.

But still essential problems remain:

1. What is consciousness?
2. How can we know that something possesses "consciousness"?
3. What would be the best communication method with computer which has a consciousness?
4. Can consciousness be imitated?

References

[1] BOOLOS, G. 1992. Lecture note on "Turing, Gödel, Russell". MIT.

[2] FUNAHASHI, K. 1989. On the capabilities of neural networks. MBE-88-52. Denshi-johotsushin. Tokyo.

[3] FUNAHASHI, K. 1989. On the approximate realization of continuous mappings by neural networks. Neural Networks **2:** 183–192.

[4] FUNAHASHI, K. 1990. On the approximate realization of identity mappings by three layer neural networks. **J73-A:** 1: 139–145. Denshi-johoshi. Tokyo.

[5] RUSSELL, B. 1960. Introduction to Mathematical Philosophy.

[6] SUGIYAMA, S. 1994. Semantic and logic theories in neuron networks. IEEE Systems, Man, and Cybernetics **3:** 3: 2449–2452.

[7] SUGIYAMA, S. 1994. Semantic and logic theories in neural networks. International Symposium on Automotive Technology and Automotion. 261–267.

[8] SUGIYAMA, S. 1995. A neural network application to semantic and logic recognition. IEEE Systems, Man, and Cybernetics **4:** 5: 3168–3173.

[9] SUTTON, M. 1992. Neural Networks for Control. MIT Press. Cambridge, MA.

[10] VENURI, V. 1988. Neural Networks. Computer Society Press. New York.

[11] KUBOTA, K. 1995. Brain. Blue Backs Press. Tokyo.

[12] OKI, K. 1994. Explain mind by brain. Blue Backs Press. Tokyo.

[13] BLOOM, E.F. 1985. Brain, Mind, and Behavior. Educational Broadcasting Co. Tokyo.

[14] TOKIZANE, T. 1991. About Brain. Iwanami. Tokyo.

[15] MIGAMI, S. 1991. How Much Do We Know Brain? Kohdansha. Tokyo.

What is Mind? —Quantum Field Theory of Evanescent Photons in Brain as Quantum Theory of Consciousness

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Quantum field theory of evanescent photons is proposed as one and only reliable quantum theory of fundamental macroscopic dynamics realized in the brain. External physical stimuli flowing into the brain are shown to generate macroscopic condensates of evanescent photons which can be interpreted as memory storage of the information carried by the incoming stimuli. Each macroscopic condensate manifests two different types of quantum dynamics; creation-annihilation dynamics of a finite number of evanescent photons requiring microscopic amount of energy, and that of an infinite number of them requiring macroscopic amount of energy. The former is a fundamental process of memory retrieval by which the macroscopic condensate of evanescent photons (memory storage) itself is kept unchanged. It can be induced by even a very small physical stimulus flowing into the brain. The latter is a macroscopic phase transition process in which the macroscopic condensate is deformed into another one, thus resulting in the development of memory storage. This can be induced only by large physical stimuli, and superposition of the information carried by such an external stimulus and the information previously stored in the macroscopic condensate is maintained in the new macroscopic condensate. Consciousness (and unconscious if necessary) can be understood as arising from those creation-annihilation dynamics of evanescent photons, thus mind lives in memory and by memory.

1 Introduction

We live in memory and by memory, and our spiritual life is at bottom simply the effort of our memory to persist, to transform itself into hope ... into our future.

from "Tragic Sense of Life" by Miguel de Unamuno

It has been so far well misunderstood that the incorporation of quantum theory into the functional analysis of brain would provide consciousness study with a blend new scientific understanding of what consciousness is. Here, "quantum theory" means "popular quantum mechanics" just as it appeared in the misunderstanding literature. This "popular quantum mechanics" stands for "introductory quantum mechanics with too many emphases put on the so-called mysterious aspects of quantum mechanics"; e.g. measurement problem unsatisfactorily-solved by the introduction of the essential role of the observer's "consciousness," non-locality of quantum mechanics sounding analogous to "non-locality" of the binding problem in brain science, and superconducting phenomena arising from the Bose-Einstein condensation (shown to exist only at low temperature circumstances turning any life forms down).

It is definitely true that as long as quantum theory remains "popular quantum mechanics" it never provides us with a proper scientific understanding of the deep question "What is consciousness?" but with a fatal misunderstanding. However, in modern physics, quantum theory is not at all "popular quantum mechanics" but "quantum field theory" that plays the most important role of the first principle in physics from which reliable theories are derived covering all the physical phenomena from the creation of our universe and generation of elementary particles to the daily-used infrared signal exchange for TV sets. Then the situation drastically changes: Quantum theory provides us with a proper scientific way to understand what consciousness is, if it stands for "quantum field theory."

The aim of biophysics is certainly to solve the following two last hard questions facing us mankind from the fundamental point of view of physics; "What is life?" and "What is mind?" Unfortunately, this aim so far has not yet been accomplished. Before achieving definite physical pictures of life and mind, it may be needed to radically enlarge the conventional theoretical framework of physics used in biophysics. As long as biophysics is trapped in the phenomenological framework of statistical physics, only superficial descriptions of life phenomena could be obtained, and there would be no chance to get a deeper understanding of the essential aspect of life phenomena such as consciousness.

A deeper understanding of natural phenomena cannot be obtained neither by the results of observations and experiments nor by the phenomenological description of those results, but only after having an adequate grasp of the theories derived from the first principles of physics that seek to explain the nature of the phenomena we study.

In this paper we present a brief exposition of quantum field theory of Nambu-Goldstone bosons (NG bosons, hereafter) as one and only reliable quantum theory of fundamental macroscopic dynamics realized in the brain with which a deeper understanding of consciousness can be obtained. This revolutionary theory was originated by Umezawa (Ricciardi & Umezawa 1967, Stuart et. al. 1978, 1979) in a very elegant and general framework of spontaneous symmetry breaking (SSB, hereafter) formalism, and since then developed into a quantum field theoretical framework of brain functioning called "Quantum Brain Dynamics" (QBD, hereafter) (Jibu & Yasue 1992, 1993a, 1993b, 1994, Jibu et. al. 1994, Hagan et. al. 1994, Jibu & Yasue 1995) and that of general biological cell functioning called "Quantum Biodynamics" (Del Giudice et. al. 1982, 1985, 1986 1988, 1989, Preparata 1995, Jibu et. al. 1997). There, Umezawa proposed a general theory of quanta of long-range coherent waves in and among brain cells, and showed an outstanding mechanism of memory storage and retrieval in terms of NG bosons characteristic to SSB formalism.

Existence of a long-range coherence in general biological cells was also suggested theoretically by Fröhlich (Fröhlich 1968) without recourse to the general framework of SSB. It is still believed in biophysics that Fröhlich first introduced the concept of long-range coherence in the investigation of biological systems mainly due to the long-standing debate upon credibility of the so-called biophoton emission supposed to have something to do common with the coherent electric dipole wave predicted to exist in biological cells by Fröhlich. Actually it was Umezawa who did it in course of developing a quantum field theoretical formulation of memory mechanism in the brain.

2 Memory

Memory itself has been usually dismissed from our consideration when talking about the hard question "What is mind ?" A consequence is that we are under an illusion that an "object" called mind would exist by itself in the natural world. Those who wish to pursue the physical picture of mind should pay attention to the alarm raised by

Miguel de Unamuno quoted in the very beginning. Mind is no more than an "object" that can "exist" for the first time when and only when memory exists and is maintained. Perhaps, a "physical picture of mind" may be something like an insubstantial mirage wandering about over a boundless desert of memory. In this sense it might not be surprising that Umezawa and his colleagues started the theoretical investigation of the physical picture of mind in 1960's with developing a quantum field theoretical framework of memory mechanism in terms of macroscopic long-range coherence phenomena in and among the brain cells.

The clear and profound understanding of not only the essential aspect of but also the real meaning of the existence of matter in our universe was the lifework of Umezawa completed in 1993 (Umezawa 1993, 1995). Making a very active use of the framework of SSB, he derived firstly in the whole history of quantum theory the very existence of macroscopic objects from the theoretical framework of quantum field theory so far believed to deal with only microscopic objects. There, macroscopic matter was shown to manifest a spatio-temporal behavior as a mass subject to the dynamical laws of classical mechanics and classical electromagnetism. Furthermore, it was also revealed that NG bosons (and NG fermions called "Goldstinos," if necessary), generated as quanta of internal degrees of freedom of macroscopic matter for restoring the Lorentz and translational symmetries broken by the very existence of macroscopic matter in question, become "elementary particles" as microscopic constituents of the macroscopic matter well described by quantum mechanics. Macroscopic matter can be understood now as a condensate (i.e., condensed collective state) of NG bosons extended to a macroscopic scale.

Umezawa's lifework aimed also at the clear and deep understanding of life phenomena in which macroscopic living matter can be investigated by means of the same framework of SSB in quantum field theory as macroscopic (non-living) matter. As was mentioned in Introduction, it has yielded good harvests of QBD and quantum biodynamics. The former investigates the fundamental processes realized in and among the brain cells confined as macroscopic matter in the cranium, and the latter develops a general framework to study the typical quantum electrodynamical phenomena in general biological cells. Those two theories are essentially the same, but the brain tissue as macroscopic matter confined in cranium together with water has a characteristic feature that intrinsic modes of electromagnetic field can be easily established independent of the external modes of electromagnetic field outside the cranium. Therefore, in QBD, the brain tissue as macroscopic living matter must be regarded as the totality of macroscopic condensates of NG bosons of not only matter field but also electromagnetic field (Jibu et. al. 1996).

3 Fundamental Processes of Brain Functioning

In the theoretical framework of QBD, the brain tissue is regarded as the totality of macroscopic condensates of NG bosons of matter fields of electrons and nucleons together with those of electromagnetic field in the cranium. Actually, over 70 percent of the macroscopic condensates can be found in the form of water, and under 30 percent in the form of biomolecules (i.e., biological constituent molecules) such as lipids and proteins. For the purpose of describing fundamental processes of brain functioning with emphases put on such a hierarchical structure of macroscopic condensates, it is convenient to focus on the electric dipole field derived from matter fields of electrons and nucleons as the first approximation, that is, the electric dipole field approximation of the macroscopic condensates. This electric dipole field describes the spatio-temporal change of all the electric dipole moments inherent in water molecules and other biomolecules. The theoretical situation is quite similar to the case of ferromagnetic matter in which the magnetic dipole field is derived from matter fields of electrons and nucleons as the first approximation of the macroscopic condensates constituting macroscopic ferromagnetic matter.

For describing the fundamental processes realized in ferromagnetic matter as macroscopic condensates, collective dynamics (collective mode) of the magnetic dipole field called "magnon" must be analyzed within the framework of quantum field theory. Similarly, it is needed to focus on collective dynamics of the electric dipole field for investigating the fundamental processes of brain functioning realized in the brain tissue. In this case the system of macroscopic condensates constituting the membranes and cytoskeltons of the brain cells (i.e., neurons and glias) not only plays the role of boundary condition to but also suffers from collective dynamics of the electric dipole field of the remaining system of macroscopic condensates; the water electric dipole field. Consequently, the electric dipole field considered mainly in QBD becomes that of the water molecular field in the vicinity of cell membranes or cytoskeltons, and it will be called the water electric dipole field hereafter.

The water electric dipole field in the perimembranous region immediately adjacent to the cell membrane can be divided into two parts; inside and outside of a brain cell. The water electric dipole field in the inner perimembranous region links to that in the vicinity of cytoskeltons, and form an electric dipole field confined in and characteristic to a brain cell. Therefore, this electric dipole field is regarded to manifest fundamental physical processes maintaining the biological functioning of each brain cell. The water electric dipole field in the outer perimembranous region is mutually linked covering the surfaces of all the brain cells, thus forming intercellular water filling up the gaps between all the neighboring cells. This electric dipole field spreading between and covering over all the brain cells is regarded to play the important role in realizing the nonlocal fundamental physical processes of the brain functioning; a key concepts for solving the binding problem.

Memory itself and the appearance of mind including consciousness realized in the continual transformation of memory do not suffer from change or distortion due to the death of individual brain cells. Taking this fact into account, it may be concluded that the physical picture of mind can be found not in the intracellular water electric dipole field but the intercellular water electric dipole field. Of course, we may be allowed to moderate the definition of mind and to think about "mind" of individual cell. In this case "mind" can be attributed to the monocellular organ such as an amoeba, and our mind may be no more than a sophisticated "society" of "minds" of all the brain cells; sounds adequate for accepting Minsky's sociology of mind (Minsky 1985).

From the point of view of QBD, "memory" and "mind" of each brain cell are realized by collective dynamics of the intracellular water electric dipole field, and memory and mind (consciousness plus unconscious) of the totality of brain cells are realized by that of the intercellular water electric dipole field. Before proceeding to the exposition of non-local fundamental processes given by the intercellular water electric dipole field, a quick survey of the "local" fundamental processes of the water electric dipole field inside the individual brain cell will be given in the next section.

4 Quantum Biodynamics of Individual Cell

It was in 1967 when the paper by Ricciardi and Umezawa was published in which the fundamental physical processes of the brain functioning was revealed to be characteristic to the SSB phenomena of certain quantum fields in the individual cell. It was just in the time of intensive development of the fundamental application of the SSB mechanism in quantum field theory to elementary particle and high-energy physics. The concept of SSB was first introduced in elementary particle physics by Nambu, Jona-Lasinio and Goldstone in 1961, and since then it has been playing the central role in the unified gauge field theory of elementary particles. It succeeded in explaining why some of the actual elementary particles (i.e., energy quanta of quantum fields) violates certain symmetry property though the physical laws governing the internal degrees of freedom of quantum fields manifest complete symmetry. This is a specific situation in quantum field theory in which the Lagrangian or the Hamiltonian of the quantum field in question is kept invariant under a certain continuous transformation, but the ground state (called vacuum state in quantum field theory) is not. A general theorem called NG theorem in quantum field theory asserts that massless (i.e., mass equal to zero) quanta obeying the Bose-Einstein statistics emerge as new dynamical agents restoring the broken symmetry if the ground state happens to be of SSB type (Umezawa 1993). They are called NG bosons, and actually understood as quanta of long-range coherence wave field realized by the existence of the ground state violating the original dynamical symmetry of the quantum field.

In a special case in which the original dynamical symmetry is given by the gauge transformation of the gauge field such as the electromagnetic field, the long-range coherence wave field is transformed into a longitudinal mode of the gauge field and NG bosons lie concealed behind gauge bosons (such as photons), and consequently those gauge bosons become massive (i.e., mass equal to non-zero). This mechanism of making massless gauge bosons massive was first proposed by Higgs and called the Higgs mechanism. Furthermore, the SSB mechanism has been applied to the translational symmetry and Lorentz symmetry in Minkowski space-time, and supersymmetry between Bose-Einstein statistics and Fermi-Dirac statistics, thus obtaining Umezawa's new world view: Elementary particles supposed to constitute macroscopic matter are nothing but NG bosons and NG fermions (Goldstinos) emerging to restore the translational and Lorentz symmetry and supersymmetry broken by the existence of macroscopic matter in our universe (Umezawa 1993, 1995, Jibu & Yasue 1995).

A stable macroscopic condensate of water is a ground state of the water electric dipole field, and the ground state manifests an infinite degeneracy just as the ground state of the magnetic dipole field of the ferromagnetic matter does. This infinite degeneracy comes from the symmetry property inherent in quantum dynamics of the water electric dipole field: Dynamics of the water electric dipole field interacting with electromagnetic field remains invariant even if the whole system is transformed by any spatial rotation. There is no specific direction in space for this system of water electric dipole field and electromagnetic field. However, in the ground state all the electric dipole moment vectors of the water electric dipole field are aligned in one and the same direction in a spatial region of macroscopic spatial dimension, and so there are as many different choice of the ground state as that of the spatial direction of those aligned electric dipole moment vectors.

Notice that the ground state of water electric dipole field is no longer invariant under the spatial rotation, and so it is of SSB type. Indeed, a ground state in which all the electric dipole moment vectors of the water electric dipole field are aligned in one and the same direction is transformed into another ground state with the direction of alignment changed by the spatial rotation. Such a ground state of SSB type manifests a macroscopic order because all the electric dipole moment vectors of the water electric dipole field are aligned in one and the same direction in a spatial region of macroscopic spatial dimension. In this sense the ground state of SSB type is said to be a macroscopic ordered state. The spatial dimension of the region of a macroscopic ordered state (called "coherence length") of water electric dipole field in the vicinity of cytoskeltons and cell membranes is estimated to be $20 \sim 50\mu m$, thus covering the spatial extent of each single cell (Del Giudice et. al. 1989).

According to the intensive quantum field theoretical study of quantum biodynamics (Del Giudice et. al. 1982, 1985, 1986, 1988, 1989, Preparata 1995), the macroscopic ordered state of water electric dipole field manifests an "electric" Meissner effect and eliminates the imposed external electric field outside the macroscopic region of ground state. However, the imposed external electric field with intensity higher than the certain threshold value cannot be eliminated but is likely pinched into fine filaments settled into the macroscopic ordered state. Then protein assembling molecules accumulates into filamented and tubular forms of proteins along with the gradient of the pinched filaments of electromagnetic field, resulting in the formation of protein filaments and microtubules in cytoplasm of each individual cell. Thus quantum biodynamics can describe the formation process of cytoskeltons in biological cells.

As for "memory" and "mind" of an individual (brain) cell, the macroscopic ordered state of water electric dipole field in the vicinity of cytoskeltons, especially microtubules, was shown to play the important role in realizing quantum optical networks in cytoplasm (Jibu & Yasue 1994, Jibu et. al. 1994, Hagan et. al. 1994). Investigating the collective dynamics of the water electric dipole field, especially the coherent interaction between the electric dipole field and electromagnetic field, in the vicinity of a microtubule in the individual brain cell, Jibu and others predicted that each microtubule manifests a quantum optical activity as emitting pulse mode photons arising from the mechanism of Dicke's superradiance. Frequency range of the superradiance can be estimated to be inversely proportional to the energy difference between the lowest energy eigenvalue and the first or second excited energy eigenvalue of the spinning degree of freedom of a water molecule, thus lying between far-infrared and near-ultraviolet. They also revealed that those pulse mode photons can propagate along the microtubule without attenuation thanks to the effect of "self-induced transparency," one of the non-linear quantum optical effect characteristic to the coherent interaction between the electric dipole field and electromagnetic field (Jibu & Yasue 1994, Jibu et. al. 1994). Furthermore, both of those quantum optical coherence phenomena have characteristic time scale one order shorter than the relaxation time of thermal fluctuations at body temperature, and so they are free from thermal noise induced by the thermal environment.

Superradiance and self-induced transparency thus provide each individual cell with idealistic quantum optical networks in which pulse mode photons from near-ultraviolet to far-infrared frequency region propagate along the cytoskeletal microtubules. The information processing realized by such quantum optical networks must be the only physically acceptable mechanism to materialize both "memory" and "mind" of a single cell.

5 Memory and Consciousness in Quantum Brain Dynamics

Ricciardi and Umezawa proposed first a blend new theoretical framework of fundamental physical processes in the individual brain cell in terms of a general quantum field extended in each brain cell subject to the spontaneous symmetry breaking (SSB) mechanism (Ricciardi & Umezawa 1967). A few years later Stuart suggested that such a quantum field extends not only in but also among all the brain cells, and it forms a global quantum field theoretical system covering the whole brain tissue. This idea was developed into a quantum field theoretical model of non-local memory storage and retrieval with the help of the introduction of the explicit form of Hamiltonian describing the underlying dynamics of quantum fields by Takahashi, and finally the prototype of quantum brain dynamics (QBD) were obtained (Stuart et. al. 1978, 1979):

There, quantum field theory of two interacting fields in the brain is proposed as one and only reliable quantum theory of fundamental macroscopic dynamics realized in the brain. One quantum field is called "corticon field" as its energy quantum is called "corticon," and the another is called "exchange Bose field" or "stuarton field" after the name of its energy quantum "exchange boson" or "stuarton." The ground states of those two interacting fields are of SSB type and manifest macroscopic ordered states which can be seen as macroscopic condensates of Nambu-Goldstone (NG) bosons emerging from the broken symmetry. External physical stimuli flowing into the brain are shown to generate macroscopic condensates of NG bosons which can be interpreted as memory storage of the information carried by the incoming stimuli. Each macroscopic condensate manifests two different types of quantum dynamics; creation-annihilation dynamics of a finite number of NG bosons requiring microscopic amount of energy, and that of an infinite number of them requiring macroscopic amount of energy. The former is a fundamental process of memory retrieval by which the macroscopic condensate of NG bosons (memory storage) itself is kept unchanged. It can be induced by even a very small physical stimulus flowing into the brain. The latter is a macroscopic phase transition process in which the macroscopic condensate is deformed into another one, thus resulting in the development of memory storage. This can be induced only by large physical stimuli, and superposition of the information carried by such an external stimulus and the information previously stored in the macroscopic condensate is maintained in the new macroscopic condensate. Consciousness (and unconscious if necessary) can be understood as arising from those creation-annihilation dynamics of NG bosons, thus mind lives in memory and by memory.

This specific model called "corticon model" in QBD succeeded in clarifying many fundamental properties of memory; memory is stable because it is stored in the ground state, memory is of non-local nature in the brain as pointed out by Pribram (Pribram 1971, 1991) because it is realized by macroscopically extended regions of ordered states in the brain tissue, and so on (Stuart et.

al. 1978, 1979). Despite of those advantages, this "corticon model" seemed to have two shortcomings: First, capacity of memory storage is quite large as the number of the degenerate ground states (theoretically infinite but actually a finite number of the order comparable to the number of NG bosons taking part in the macroscopic condensates of the ground state), but it is still not large enough for explaining the huge capacity of our actual memory capacity. (Of course, the situation is much better than in the conventional theories of neural network models.) Second, the physical reality of the system of interacting "corticon" and "stuarton" fields are not specified.

As for the former, Vitiello (Vitiello 1995) incorporated a general framework of thermo field dynamics (TFD) discovered by Takahashi and Umezawa (Takahashi & Umezawa 1975) into QBD and revealed that the capacity of memory storage becomes actually infinite if the system of "corticon" and "stuarton" fields is an open system interacting dissipatively with the external system because the ground state is no longer a pure state but a mixed state of all the degenerate ground states. The latter was solved by Jibu and Yasue (Jibu & Yasue 1992, 1993a, 1993b, 1994, 1995) who made up the physical picture of QBD in which the "corticon field" is substantiated as the water electric dipole field extending in and among the brain cells and the "exchange Bose field" as the electromagnetic field in the cranium.

6 Real Quantum Brain Dynamics and Evanescent Photons

Jibu and Yasue (Jibu & Yasue 1992, 1993a 1993b, 1994, 1995) revealed that the intracellular and intercellular water electric dipole field plays the role of "corticon field" and the electromagnetic field interacting with this water electric dipole field plays the role of "exchange Bose field." A special attention was paid to the intercellular water electric dipole field in the whole gap region among each neighboring brain cells, that is, the outer perimembranous region (Jibu et. al. 1996). Starting from the usual Hamiltonian to describe the interaction between the electric dipole field and electromagnetic field in quantum field theory, they derived the reduced Hamiltonian of the same form as that of the magnon model of ferromagnetic matter in which macroscopic regions of ordered states of water electric dipole field emerges as infinitely degenerate ground states of SSB type. In the magnon model of ferromagnetism, each macroscopic region of ordered (ground) states of the magnetic dipole field is called a magnetic domain, and so that of the water electric dipole field may be called a "water electric domain." Existence of such an ordered ground state of the interacting quantum system of electric dipole field and electromagnetic field has been fully investigated by Enz within the realm of standard non-perturbative renormalization technique (Enz 1997).

Just as in the case of macroscopic ordered states of intracellular water electric dipole field, the coherence length of water electric domains in the outer perimembranous region is found to be in the range $20 \sim 50\mu m$. Those water electric domains in the outer perimembranous region linking to each other in the whole gaps among all the brain cells are elements of the storage of our short-term memory. Of course, the formation of those water electric domains (memory storage) is subject to the boundary conditions given to the system of water electric dipole field and electromagnetic field by the external system of macroscopic neuronal stimuli, and so they are memory storage of the external stimuli. In QBD the memory retrieval is achieved by the generation of NG bosons triggered by even a small external stimuli, and so it is in Jibu and Yasue's physical picture of QBD in which NG bosons are nothing but "electric dipole phonons" or "polaritons." Therefore, water electric domains of macroscopic ordered states can be seen as macroscopic condensates of those electric dipole phonons. Notice that electric dipole phonons are energy quanta of the long-range coherence wave of the electric dipole field, and they behave as "charged quanta of sound" with characteristic energy (frequency) inherent in each macroscopic condensate. Due to the intensive study of Del Giudice et al. (Del Giudice et. al. 1982, 1985, 1986, 1988, 1989, Preparata 1995), the characteristic frequency of a typical macroscopic condensate of the "charged quanta of sound" of water is shown to be in the radiofrequency region (1-100 MHz), and this shows a good agreement with a part of the resonantly sensitive frequency region verified by experiments (Ho et. al. 1994)

If mind lives in memory and by memory as pointed out by Miguel de Unamuno, the physical picture of mind would be no more than the quantum field theoretical creation-annihilation dynamics of electric dipole phonons realized in the outer perimembranous regions of all the brain cells. In other words, we obtain the physical picture of consciousness in which the orchestration of charged quanta of sound in the perimembranous region is ever going on changing the forms of resonating instruments (memory storage) by the external stimuli.

As the Hamiltonian derived by Jibu and Yasue has the same form not only as Takahashi's Hamiltonian in the original formal framework of QBD but also as Dicke's Hamiltonian for superradiance phenomena, it is quite likely that certain non-linear quantum optical effect may be dominant in the fundamental physical processes taking place in the macroscopic ordered states of water electric dipole field in the outer perimembranous region covering the whole brain tissue (Jibu et. al. 1996). Especially, electric dipole phonons (NG bosons) are transformed into the longitudinal mode of electromagnetic field (gauge field) by the Higgs mechanism in quantum field theory, and consequently photons (i.e., energy quanta of electromagnetic field) become to bear mass $M \approx 13.6eV$ in the macroscopic region of ordered state of water electric dipole field. Such a massive photon cannot propagate freely in space because its momentum becomes purely imaginary and manifests exponential spatial damping. In other word, this massive photon is not a quantum of propagating mode, but that of non-propagating mode of electromagnetic field whose existence is assured only by tunneling effects in quantum field theory. It is called an "evanescent photon" or "tunneling photon" in this sense.

Now, it is found that the electric dipole phonons (NG bosons) hide themselves under massive evanescent photons, and so the macroscopic condensates of electric dipole phonons playing the role of memory storage in QBD can be thought of as macroscopic condensates of massive evanescent photons. If we approximate the macroscopic condensates of massive evanescent photons by Bose-Einstein condensates of the ideal Bose gas with mass $M \approx 13.6eV$, then a standard calculation in quantum field theory results in the rough estimation of the critical temperature (under which the Bose-Einstein condensates is maintained) $T \approx 300$. This means that the macroscopic condensate of massive evanescent photons is one and only Bose-Einstein condensates maintained even at body temperature (Jibu et. al. 1996).

As for the transformation process of the short-term memory storage to the long-term memory storage, we can once again utilize the electric Meissner effect in the macroscopic condensates of massive evanescent photons: The pinched filaments of electric field in the macroscopic condensates of massive evanescent photons were shown to be coated selectively by specific molecules and ions (Del Giudice et. al. 1982, 1985, 1986 1988, 1989, Preparata 1995), and the more they are coated, the more the macroscopic condensates of massive evanescent photons (memory storage in QBD) are made stable. Thus the molecular coating due to the electric Meissner effect provides us with a possible mechanism of transformation from the short-term memory stored in the macroscopic condensates of massive evanescent photons to the long-term memory stored in the same macroscopic condensates but with coated filaments of biomolecules. Actually it has been reported that the distribution pattern of such a molecular coating has been observed in the cerebellum of rats after substantial learning (Nakazawa et. al. 1995).

7 Conclusion

We would like to conclude the present paper by showing a few remarks.

As was emphasized by Crick (Crick 1994) we do not know the physical origin of brain waves (EEG), though we have used and relied on brain waves for long time as one and only scientific indicator of consciousness. Indeed Umezawa's aim to start the original research of QBD was to obtain deeper understandings from the fundamental point of view of physics of not only the mechanism of memory but also that of brain waves (Stuart et. al. 1978, 1979). Some of the collective dynamics of the macroscopic condensates of massive evanescent photons in the perimembranous regions of the brain cells manifests slowly changing modes of the electromagnetic field in macroscopic scale in the cranium, and it may be supposed that those specific modes measured in terms of the electric potential at the scalp is the brain wave (Jibu & Yasue 1995). As the macroscopic condensates of massive evanescent photons are the physical substrates for memory storage in QBD, their collective dynamics is the physical substrate for mind (consciousness plus unconscious), and so those slowly changing modes are certainly a part of the activity of mind. Namely, it can be concluded that the brain wave (EEG) is really a reliable scientific measure of the activity of mind from the physical point of view of QBD.

It would be better, of course, to detect the whole collective dynamics of the macroscopic condensates of evanescent photons by means of certain non-demolition measurement devices. Many practical investigations have to be made intensively before we obtain a "near-future" medical instrument to observe the collective dynamics of the macroscopic condensates of evanescent photons in the brain tissue and print out the "CT picture of mind." We are preparing a series of experiments to observe directly the macroscopic condensates of evanescent photons.

From the general point of view of quantum biodynamics the existence of macroscopic condensates of evanescent photons not only in the perimembranous region but also in the vicinity of all the structural biomolecules in cytoplasm (e.g. protein filaments, microtubules, and DNAs) may play the role of indicator of life/death of a cell, and it would be challenging to consider it something much more than a mere physical indicator, that is, a physical definition of life.

Appendix: A Mathematical Sketch of Quantum Brain Dynamics

We aimed at making the present paper accessible from wider audience who are not familiar with any mathematical formulation of quantum physics. However, it may be helpful for those who once studied quantum physics if a mathematical sketch of the framework of quantum brain dynamics (QBD) is given explicitly in Appendix.

A Quantum Electrodynamics of Ordered Water

Like any other quantum electric dipole field, the water electric dipole field can be represented by a two-component spinor field

$$\psi(\boldsymbol{x},t) = \begin{pmatrix} \psi^+(\boldsymbol{x},t) \\ \psi^-(\boldsymbol{x},t) \end{pmatrix}$$

where $\psi^+(\boldsymbol{x},t)$ and $\psi^-(\boldsymbol{x},t)$ are spinor components. The electric dipole moment of the water electric dipole field is then given by

$$\tilde{\psi}(\boldsymbol{x},t)\frac{\hbar}{2}\sigma\psi(\boldsymbol{x},t) ,$$

where

$$\tilde{\psi}(\boldsymbol{x},t) = \left(\psi^+(\boldsymbol{x},t)^* \ \psi^-(\boldsymbol{x},t)^*\right)$$

is the adjoint spinor field,

$$\sigma = (\sigma_1, \sigma_2, \sigma_3)$$

is a vector with three components equal to Pauli spin matrices, and $\hbar$ denotes the Planck constant divided by 2π.

The water electric dipole field manifests localization of electric dipole moment in a sense that $\psi(\boldsymbol{x},t) \neq 0$ only in each position $\boldsymbol{x} = \boldsymbol{x}_m$ of the m-th manifestation of localization. Such a localization of the water electric dipole field has been regarded as a molecule of water, that is, an H_2O molecule, though a naive picture of water as a mere group of H_2O molecules more than Avogadro's number fails to well describe quantum dynamics of water. The water electric dipole field with M localizations can be described by M quantum dynamical variables

$$\tau^m(t) = \tilde{\psi}(\boldsymbol{x}_m,t)\sigma\psi(\boldsymbol{x}_m,t) , \ m = 1,2,3,\cdots,M .$$

These quantum dynamical variables $\tau^m(t)$'s are not Pauli spin matrices but still subject to the same commutation relations as those satisfied by Pauli spin matrices:

$$\left[\tau_1^m(t), \tau_2^j(t)\right] = 2i\tau_3^m(t)\delta_{mj} ,$$

$$\left[\tau_2^m(t), \tau_3^j(t)\right] = 2i\tau_1^m(t)\delta_{mj} ,$$

$$\left[\tau_3^m(t), \tau_1^j(t)\right] = 2i\tau_2^m(t)\delta_{mj} ,$$

where $[A, B] \equiv AB - BA$, $\tau^m(t) = (\tau_1^m(t), \tau_2^m(t), \tau_3^m(t))$, $i^2 = -1$ and δ_{mj} is Kronecker's delta symbol meaning

$$\delta_{mj} = \begin{cases} 1 & \text{if } m = j \\ 0 & \text{if } m \neq j \end{cases}$$

Let us consider the electromagnetic field confined in a spatial region of volume V containing water. The quantum dynamics of the electromagnetic field is usually described in terms of a vector field called vector potential of the electromagnetic field. The electric and magnetic fields can be derived from the vector potential. Let

$$\boldsymbol{A}(\boldsymbol{x}, t) = (A_1(\boldsymbol{x}, t), A_2(\boldsymbol{x}, t), A_3(\boldsymbol{x}, t))$$

be the vector potential of the electromagnetic field. According to the canonical quantization procedure in quantum field theory, we introduce an eigenmode expansion of the vector potential,

$$\boldsymbol{A}(\boldsymbol{x}, t) = \sum_{\lambda} a_\lambda(t)\boldsymbol{u}_\lambda(\boldsymbol{x}) .$$

Here, $\{\boldsymbol{u}_\lambda(\boldsymbol{x})\}_{\lambda=1}^{\infty}$ denotes a complete normalized orthogonal system of vector-valued functions defined on the spatial region V subject to the eigenvalue equation

$$(\Delta + \frac{\omega_\lambda^2}{c^2})\boldsymbol{u}_\lambda(\boldsymbol{x}) = 0$$

together with a subsidiary condition

$$div\, \boldsymbol{u}_\lambda(\boldsymbol{x}) = 0$$

and appropriate boundary conditions. Here, ω_λ is a positive constant standing for the eigenvalue of the eigenmode of electromagnetic field represented by the eigenfunction $\boldsymbol{u}_\lambda(\boldsymbol{x})$, and c denotes the speed of light. We assume for simplicity that the vector potential is linearly polarized, obtaining $\boldsymbol{u}_\lambda(\boldsymbol{x}) = \boldsymbol{e}u_\lambda(\boldsymbol{x})$, where $\boldsymbol{e}$ is a constant vector of unit length pointing in the direction of linear polarization.

In quantum field theory, $a_\lambda(t)$ and its complex conjugate $a_\lambda^*(t)$ are identified with the annihilation and creation operators up to the multiplicative factor, and it is convenient to introduce the canonical operators $P_\lambda(t)$ and $Q_\lambda(t)$ satisfying the following relations:

$$a_\lambda(t) = \frac{1}{\sqrt{2\hbar}}\left\{\sqrt{\omega_\lambda}Q_\lambda(t) + \frac{i}{\sqrt{\omega_\lambda}}P_\lambda(t)\right\}$$

$$a_\lambda^*(t) = \frac{1}{\sqrt{2\hbar}}\left\{\sqrt{\omega_\lambda}Q_\lambda(t) - \frac{i}{\sqrt{\omega_\lambda}}P_\lambda(t)\right\}$$

As long as those dynamical variables $P_\lambda(t)$ and $Q_\lambda(t)$ are regarded as canonical operators, quantum field theory assumes the canonical commutation relations:

$$\begin{aligned} P_\lambda(t)Q_\nu(t) - Q_\nu(t)P_\lambda(t) &\equiv [P_\lambda(t), Q_\nu(t)] \\ &= -i\hbar\delta_{\lambda\nu} \qquad (1) \\ P_\lambda(t)P_\nu(t) - P_\nu(t)P_\lambda(t) &\equiv [P_\lambda(t), P_\nu(t)] \\ &= 0 \qquad (2) \\ Q_\lambda(t)Q_\nu(t) - Q_\nu(t)Q_\lambda(t) &\equiv [Q_\lambda(t), Q_\nu(t)] \\ &= 0 \qquad (3) \end{aligned}$$

Starting from the canonical operators subject to the canonical commutation relations, quantum dynamics of the electromagnetic field can be well described by the Hamiltonian operator; that is, the total energy of the electromagnetic field expressed in terms of the canonical operators,

$$H_{EM} = \frac{1}{2}\sum_{\lambda=1}^{\infty}\{P_\lambda(t)^2 + \omega_\lambda^2 Q_\lambda(t)^2\} . \qquad (4)$$

This Hamiltonian operator describes the quantum dynamics of only the electromagnetic field. Therefore, quantum brain dynamics, that is, the quantum dynamics of the water electric dipole field and electromagnetic field interacting with each other in and among the brain cells, will be completed after obtaining the Hamiltonian operators describing the quantum dynamics of the water electric dipole field and its interaction with the electromagnetic field.

As for the water electric dipole field, the Hamiltonian operator can be approximated to be

$$H_W = \varepsilon\sum_{m=1}^{M}\tau_3^m(t) \qquad (5)$$

as long as higher energy excitations are irrelevant to macroscopic objects in ordered phases. Here, $\varepsilon \approx 200cm^{-1}$ is a positive constant standing for the minimum amount of excitation energy of each localization of the water electric dipole field. The interaction between the water electric dipole field and the electromagnetic field can be described by the Hamiltonian

$$\begin{aligned} H_I &= -f \sum_{m=1}^{M} \sum_{\lambda=1}^{\infty} \{a_\lambda^*(t)\tau_-^m(t) + \tau_+^m(t)a_\lambda(t)\} \\ &= -f \sum_{m=1}^{M} \sum_{\lambda=1}^{\infty} \sqrt{\frac{2}{\hbar}} \Big\{ \sqrt{\omega_\lambda}\tau_1^m(t)Q_\lambda(t) - \\ &\qquad \frac{1}{\sqrt{\omega_\lambda}}\tau_2^m(t)P_\lambda(t) \Big\}, \qquad (6) \end{aligned}$$

where

$$\tau_\pm^j \equiv \tau_1^j \pm i\tau_2^j$$

are ladder operators in energy spin space of water electric dipole field, and f denotes the coupling constant between the water electric dipole field and the electromagnetic field which is nothing but the electric dipole moment of water. Then the total Hamiltonian operator describing quantum brain dynamics is given by the sum,

$$H_{QBD} = H_{EM} + H_W + H_I , \qquad (7)$$

denoting the total energy of the system of water electric dipole field and electromagnetic field interacting with each other.

It is an immediate consequence that this total Hamiltonian, governing the quantum dynamics of the electromagnetic field and the water electric dipole field interacting with each other, remains invariant under the transformation of canonical variables given by

$$\begin{aligned} Q'_\lambda(t) &= Q_\lambda(t)\cos\theta - \frac{1}{\omega_\lambda}P_\lambda(t)\sin\theta \\ P'_\lambda(t) &= \omega_\lambda Q_\lambda(t)\sin\theta + P_\lambda(t)\cos\theta \\ \tau_1^j{}'(t) &= \tau_1^j(t)\cos\theta + \tau_2^j(t)\sin\theta \qquad (8) \\ \tau_2^j{}'(t) &= -\tau_1^j(t)\sin\theta + \tau_2^j(t)\cos\theta \\ \tau_3^j{}'(t) &= \tau_3^j(t) \end{aligned}$$

for a continuous parameter θ. This transformation corresponds to a continuous rotation around the third axis in energy spin space and can be regarded as belonging to the continuous group $SO(2)$ of rotations in two dimensions. In quantum brain dynamics as the system of water electric dipole field and electromagnetic field, it is shown that the system manifests a dynamical symmetry property represented by a compact Lie group of rotation. It is this dynamical symmetry property that makes the system of water electric dipole field and electromagnetic field rich in macroscopic structure of order.

Let us look for a time-independent solution to the Heisenberg equations for the canonical variables in order to investigate the dynamically ordered state of the system of the electromagnetic field and the water electric dipole field in the region V. The Heisenberg equations are given by

$$\begin{aligned} \frac{dQ_\lambda(t)}{dt} &= \frac{1}{i\hbar}[Q_\lambda(t), H] \\ \frac{dP_\lambda(t)}{dt} &= \frac{1}{i\hbar}[P_\lambda(t), H] \\ \frac{d\tau_1^j(t)}{dt} &= \frac{1}{i\hbar}[\tau_1^j(t), H] \qquad (9) \\ \frac{d\tau_2^j(t)}{dt} &= \frac{1}{i\hbar}[\tau_2^j(t), H] \\ \frac{d\tau_3^j(t)}{dt} &= \frac{1}{i\hbar}[\tau_3^j(t), H] \end{aligned}$$

and the time-independent solution is obtained as follows up to quantum fluctuations:

$$\begin{aligned} P_\lambda(t) &\equiv 0 \\ Q_\lambda(t) &\equiv Q_\lambda^0 \\ \tau_1^j(t) &\equiv v \qquad (10) \\ \tau_2^j(t) &\equiv 0 \\ \tau_3^j(t) &\equiv w \end{aligned}$$

Here, Q_λ^0 is a constant taking different values for each different eigenmode λ, and v and w are also constants. Each spin variable $\tau^j = (\tau_1^j, \tau_2^j, \tau_3^j)$ describing the j-th localization of the water electric dipole field is found to be aligned in one and the same direction given by a constant vector $(v, 0, w)$. Such a long-range alignment of spin variables is nothing but a manifestation of a dynamical order of the system of quantized electromagnetic field and water electric dipole field. Namely, there exists a long-range order so that the spin variable is systematized globally in the region V to realize a uniform configuration.

It is interesting to note that this time-independent solution, representing a dynamically ordered state of the system of quantized electromagnetic field and water electric dipole field in the region V, is no longer invariant under the continuous transformation of canonical variables (8). The direction of alignment is transformed into another direction under such a continuous rotation around the third axis. Thus, a strange situation is realized in which the total Hamiltonian, governing the quantum dynamics of canonical variables, is invariant under a certain compact continuous transformation, whereas it admits a stable time-independent solution which is not invariant under the same transformation. In quantum field theory, such a situation is known as spontaneous symmetry breaking, and several interesting quantum phenomena are known to emerge (Umezawa 1993). Namely, the Nambu-Goldstone theorem in quantum field theory asserts that in such a situation of spontaneous symmetry breaking cooperative excitations of the symmetry attributes appear as long-range correlation waves and behave as bosons (i.e., quanta obeying the Bose-Einstein statistics) whose minimum energy is zero (Umezawa 1993). They are Nambu-Goldstone bosons. Since the Nambu-Goldstone boson manifests a continuous energy spectrum above zero, it is also called a gapless mode or massless boson because there exists no energy gap in the spectrum.

In the actual case of the system of the quantized electromagnetic field and the water electric dipole field, the spin variables related to the electric dipole moment of the water electric dipole field are aligned uniformly in a dynamically ordered state of spontaneous symmetry breaking type. Nambu-Goldstone bosons created with near vanishing energy requirement are nothing but quanta of long-range correlation waves of aligned electric dipoles. Such Nambu-Goldstone bosons can be created by even very weak perturbations and propagate over distances up to the coherence length of about $50\mu m$. It is found in quantum brain dynamics that the Nambu-Goldstone theorem in quantum field theory assures the existence of specific macroscopic objects in the brain realized by ordered states of quantized electromagnetic field and water electric dipole field interacting strongly with each other. If the emphasis is put on matter, such a macroscopic object may be understood as an ordered water in the brain. If the emphasis is put on light, on the other hand, such a macroscopic object can be seen as being made of virtual photons (i.e., evanescent photons) enveloping the water electric dipole field. In terms of Nambu-Goldstone bosons, furthermore, we can see such a macroscopic object as a macroscopic condensate of Nambu-Goldstone bosons.

B Fast Phenomena: Superradiance

We are mainly interested in the ordered collective behavior of quantum dynamics of electromagnetic field and water electric dipole field in the region V. Let us introduce therefore collective dynamical variables $S^{\pm}_{\lambda}(t)$ and $S(t)$ for water electric dipole field by

$$S^{\pm}_{\lambda}(t) \equiv \sum_{j=1}^{M} \tau^{j}_{\pm}(t) u_{\lambda}(\boldsymbol{x}_j)$$

and

$$S(t) \equiv \sum_{j=1}^{M} \tau^{j}_{3}(t) \,.$$

Then, the total Hamiltonian (7) becomes

$$H = H_{EM} + \varepsilon S(t) - f \sum_{\lambda=1}^{\infty} \left\{ a^{*}_{\lambda}(t) S^{-}_{\lambda}(t) + S^{+}_{\lambda}(t) a_{\lambda}(t) \right\} . \tag{11}$$

It seems worthwhile to notice here that this total Hamiltonian for the system of M localizations of water electric dipole field and electromagnetic field in the region V is essentially of the same form as Dicke's Hamiltonian for the laser system (Dicke 1954). Therefore, it might be expected that water in the region V should manifest a laser-like coherent optical activity. Inspection of the form of the total Hamiltonian (11) reveals that it manifests a dynamical symmetry property not evident in the ground state so that the resulting quantum dynamics is known to involve certain long-range order creating phenomena due to spontaneous symmetry breaking (Ricciardi & Umezawa 1967, Stuart et al. 1978, 1979). The spatial dimension of this long-range order, that is, the coherence length l_c is estimated to be inversely proportional to the energy difference ε, or $l_c \approx 50\mu m$. Among the long-range order creating phenomena we may find a specific one in which the collective dynamics of the water electric dipole field in the spatial region of linear dimension up to $50\mu m$ can give rise to cooperative emission of coherent photons given energy by certain systems external to the quantum system of electromagnetic field and water electric dipole field.

Let us consider the system of structured biomolecules in brain cells that can provide the quantum system of electromagnetic field and water electric dipole field with energy. About 20 $\sim$ 30 percent of the brain is made of a variety of structured biomolecules, especially proteins forming the cytoskeletal structure and lipids forming the membrane structure. There exist typical protein molecules which manifest relatively large electric dipole moments due to their own intrinsic electron states. The more geometrically structured such protein molecules are, the larger the total electric dipole moment becomes. Therefore, it seems reasonable to take into account only the highly structured protein molecules in the cytoskeletal structure of brain cells as the external system of the quantum system of electromagnetic field and water electric dipole field in the brain. Microtubules are such ones which manifest a common highly geometrical structure of hollow cylinder about $25nm$ in diameter whose wall is a polymerized array of protein subunits called tubulins having a dynamical degree of freedom of electric dipole. The length of a microtubule may range from tens of nanometers to micrometers.

For simplicity, we consider the microtubule as a hollow cylinder with radius $r_{MT} \approx 12nm$ and length $l_{MT} \approx 10^2 \sim 10^3 nm$. The spatial region V of the quantum system of electromagnetic field and water electric dipole field is either the hollow core of the microtubule or exterior region adjacent to the wall of the microtubule.

Let us investigate the collective dynamics of electromagnetic field and water electric dipole field in the region V starting from the total Hamiltonian (11). We assume for simplicity that only one eigenmode with a specific eigenvalue, say ω_{λ_0}, resonates with the energy difference ε between the two principal energy eigenstates. Namely we have

$$\varepsilon = \hbar\omega_{\lambda_0} , \qquad (12)$$

and all the other eigenmodes are neglected. In the conventional laser theory, this is known as a single mode laser.

Since we have only one eigenmode with eigenvalue ω_{λ_0}, we may omit all the eigenvector indices of the dynamical variables. Then, the total Hamiltonian (11) becomes

$$H = \hbar\omega(a^*a + \frac{1}{2}) + \varepsilon S - f(a^*S^- + S^+a) . \qquad (13)$$

The corresponding Heisenberg equations of motion for the three collective dynamical variables, S and $S^{\pm}$, for water electric dipole field and the two variables, a^* and a, for electromagnetic field are given by:

$$\begin{aligned}
\frac{dS}{dt} &= -i\frac{f}{\hbar}(a^*S^- - S^+a) &(14)\\
\frac{dS^+}{dt} &= i\frac{2f}{\hbar}Sa^* + i\frac{\varepsilon}{\hbar}S^+ &(15)\\
\frac{dS^-}{dt} &= -i\frac{2f}{\hbar}Sa - i\frac{\varepsilon}{\hbar}S^- &(16)\\
\frac{da^*}{dt} &= -i\frac{2\pi\varepsilon f}{\hbar V}S^+ &(17)\\
\frac{da}{dt} &= i\frac{2\pi\varepsilon f}{\hbar V}S^- . &(18)
\end{aligned}$$

Let us investigate the most interesting case in which the eigenmode with eigenvalue ω represents a pulse mode of electromagnetic field. Because of the short length of the microtubule cylinder, the pulse mode propagating along the microtubule cylinder stays in the region V only for a short transit time $t_{MT} \approx l_{MT}/c$. As this transit time of the pulse mode is much shorter than the characteristic time of thermal interaction due to disordered environment of the body temperature T, the collective dynamics of the system of electromagnetic field and water electric dipole field is free from thermal dissipation and fluctuation, and can be considered as a closed system well-described by the above Heisenberg equations of motion. Furthermore, the time derivative of the dynamical variables a^* and a of the quantized electromagnetic field can be approximated by a^*/t_{MT} and a/t_{MT} in the case of a pulse mode propagating along the longitudinal axis of the microtubule cylinder. Then, Eqs. (17) and (18) yield

$$\begin{aligned}
a^* &= -i\frac{2\pi\varepsilon f l_{MT}}{\hbar V}S^+ &(19)\\
a &= i\frac{2\pi\varepsilon f l_{MT}}{\hbar V}S^- . &(20)
\end{aligned}$$

This means that a pulse mode of the quantized electromagnetic field in the region V follows the collective dynamics of water electric dipole field. In other words, once a collective mode with long-range order is created in quantum dynamics of water electric dipole field due to the spontaneous symmetry breaking, coherent emission of pulse modes of the quantized electromagnetic field follows. This phenomenon is called superradiance.

The important question is whether such a collective mode can be realized in the quantum dynamics of water electric dipole field starting from any incoherent and disordered initial and boundary conditions. Notice that such an incoherent and disordered initial and boundary conditions of water electric dipole field is due to the interaction between water electric dipole field and thermally disordered states of electric dipoles of tubulins. The onset of this collective mode can be seen by rewriting the three Heisenberg equations (14)-(16) for the collective variables of water electric dipole field by substituting Eqs. (19) and (20), obtaining

$$\frac{dS^{\pm}}{dt} = \beta S S^{\pm} \pm i\varepsilon S^{\pm} \qquad (21)$$

$$\frac{dS}{dt} = -\beta S^{+} S^{-} , \qquad (22)$$

where β is a positive constant given by

$$\beta = \frac{4\pi\varepsilon f^2 l_{MT}}{\hbar^2 V} .$$

These are coupled nonlinear differential equations for non-commuting operators S and $S^{\pm}$, and have semi-classical solutions specifying a collective mode realized in the quantum dynamics of water electric dipole field starting from any incoherent and disordered initial and boundary conditions. Then, coherent emission of pulse modes of the quantized electromagnetic field follows, and the phenomenon of superradiance is shown to take place in the spatial region V inside or in the vicinity of the microtubule.

The intensity of coherent photon emission due to the superradiance can be given in this semi-classical approximation by

$$I = \frac{\hbar^2}{(4t_R f)^2} sech^2(\frac{t-t_0}{2t_R}) ,$$

where

$$t_R = \frac{c\hbar^2 V}{4\pi f^2 \varepsilon M l_{MT}}$$

and $t_0 = t_R \ln 2M$ denote life time and delay of the superradiance, respectively.

We have found that the quantum collective dynamics of water electric dipole field and electromagnetic field inside or in the vicinity of the microtubule cylinder manifests the long-range cooperative phenomenon of superradiance in which collective excitation of water electric dipole field can be induced by incoherent and disordered perturbations due to the macroscopic thermal dynamics of protein molecules forming the wall of the microtubule cylinder. This fact ensures that each microtubule in the cytoskeletal structure of brain cells, that is, neurons, astrocytes and glia cells, may play an important role in the optical information processing regime of brain functioning as a superradiant device which converts the macroscopic disordered dynamics of protein molecules into the long-range ordered dynamics of water electric dipole field and electromagnetic field involving a pulse mode emission of coherent photons. In other words, each microtubule is a coherent optical encoder in a dense microscopic optical computing network in the cytoplasm of each brain cell.

We have shown the possibility of a completely new mechanism of fundamental brain functioning in terms of coherent photon emission by superradiance in and around microtubules. Unlike a laser, superradiance is a specific quantum theoretical ordering process with a characteristic time much shorter than that of thermal interaction. Therefore, microtubules may be thought of as ideal optical encoders providing a physical interface between the following two systems: The conventional macroscopic system of classical, disordered and incoherent neural dynamics in terms of transmembrane ionic diffusions as well as thermally perturbed molecular vibrations. And the yet unknown microscopic optical computing network system of ordered and coherent quantum dynamics free from thermal fluctuation (noise) and dissipation (loss).

C Slow Phenomena: Water Laser and Thermal Fluctuation

We have focused on the collective dynamics of the quantum system of electromagnetic field and water electric dipole field in the vicinity of a microtubule whose characteristic time is much shorter than that of thermal fluctuation and dissipation due to the interaction with thermally disordered dynamics of electric dipoles of protein molecules. We consider now the case in which the collective dynamics has characteristic time comparable to that of thermally disordered dynamics and suffers from thermal fluctuation and dissipation. It will be shown that the laser-like emission of coherent photons can be realized even in such a case with thermal noise and loss provided that the electric dipoles of protein molecules of the microtubule manifest a certain collective dynamics sufficient to "pump up" the water electric dipole field. Recall the Heisenberg equations of motion for the three collective dynamical variables, S and $S^{\pm}$, for water electric dipole field and the two variables, a^* and a, for the quantized electromagnetic field (14) - (18). Taking the thermal interaction with the disordered external systems at body temperature T, the Heisenberg equations of motion must be replaced by either the Heisenberg-Langevin equation or the Schrödinger-Langevin equation (Yasue 1976, 1977, 1978a, 1978b, 1979). In the present analysis we use the Heisenberg-Langevin equations:

$$\begin{aligned} \frac{dS}{dt} &= -\gamma(S - S_\infty) - i\frac{f}{\hbar}(a^*S^- - S^+a) + \eta \\ \frac{dS^+}{dt} &= i\frac{2f}{\hbar}Sa^* - \gamma_0 S^+ + i\frac{\varepsilon}{\hbar}S^+ + \eta^+ \\ \frac{dS^-}{dt} &= -i\frac{2f}{\hbar}Sa - \gamma_0 S^- - i\frac{\varepsilon}{\hbar}S^- + \eta^- \\ \frac{da^*}{dt} &= -\gamma_{EM}a^* - i\frac{2\pi\varepsilon f}{\hbar V}S^+ + \eta_{EM}^* \\ \frac{da}{dt} &= -\gamma_{EM}a + i\frac{2\pi\varepsilon f}{\hbar V}S^- + \eta_{EM} \end{aligned} \quad (23)$$

Here, γ and γ_0 are damping coefficients for the water electric dipole field, γ_{EM} is a damping coefficient for the electromagnetic field, η and $\eta^{\pm}$ are thermal fluctuations for the water electric dipole field, η_{EM}^* and η_{EM} are thermal fluctuations for the electromagnetic field, and S_∞ is a parameter designating the rate of pumping due to the interaction with a certain collective dynamics of the electric dipoles of protein molecules of the microtubule.

In this case, the collective dynamical variables of water electric dipole field can be deleted in the adiabatic approximation, and the Heisenberg-Langevin equations (23) can be reduced approximately to the Heisenberg-Langevin equations for the quantized electromagnetic field, that is

$$\frac{da^*}{dt} = \alpha a^* - \beta a a^* a^* + \xi^* \quad (24)$$

$$\frac{da}{dt} = \alpha a - \beta a^* a a + \xi \; . \quad (25)$$

Here, α and β are constants given by

$$\begin{aligned} \alpha &= -\gamma_{EM} + \frac{4\pi\varepsilon f^2 S_\infty}{\hbar^2 V \gamma_0} \\ \beta &= \frac{16\pi\varepsilon f^4 S_\infty}{\hbar^4 V {\gamma_0}^2 \gamma} \end{aligned}$$

and ξ^* and ξ are effective thermal fluctuations for the quantized electromagnetic field.

The Heisenberg-Langevin equations (24) and (25) governing the collective dynamics of the quantized electromagnetic field in the region V can be reduced to the Langevin equation if Glauber's coherent state representation is adopted (Klauder & Sudarshan 1968):

$$\frac{dZ}{dt} = \alpha Z - \beta \overline{Z} Z^2 + B \; . \quad (26)$$

Here, $Z = Z(t)$ is a Markov process in the complex plane denoting the complex eigenvalue of the electromagnetic field operator a, $B = B(t)$ is a complex Gaussian white noise representing the thermal fluctuation of the quantized electromagnetic field and $\overline{z}$ denotes the complex conjugate of a complex number z. The mean and variance of the complex Gaussian white noise are given by

$$\langle B(t) \rangle = 0$$

and

$$\langle \overline{B(t)} B(s) \rangle = 2D\delta(t-s)$$

respectively, where $\langle \quad \rangle$ indicates the expectation value, $\delta(t)$ is the Dirac delta function and D is a diffusion constant given by

$$D = \frac{M\pi^2\varepsilon^2 f^2 \gamma_0}{2\gamma_{EM}^2 \hbar^2 V^2} + \frac{2\pi\gamma_{EM}\varepsilon}{V}\left(\frac{1}{e^{\varepsilon/k_B T} - 1} + \frac{1}{2}\right)$$

with k_B the Boltzmann constant.

The Langevin equation (26) is equivalent to the Fokker-Planck equation

$$\frac{\partial}{\partial t} f = -\frac{\partial}{\partial z}[(\alpha z - \beta \overline{z} z^2) f] + D\frac{\partial^2}{\partial z \partial \overline{z}} f \quad (27)$$

for the probability distribution function $f = f(z, \overline{z}, t)$ of the complex Markov process $Z(t)$. The stationary solution of the Fokker-Planck equation (27) can be obtained immediately;

$$f = C\exp[\frac{2\alpha\overline{z}z - \beta(\overline{z}z)^2}{2D}], \qquad (28)$$

where C is a normalization constant such that

$$\iint f(z, \overline{z}, t) dz d\overline{z} = 1 \qquad (29)$$

holds.

This stationary solution (28) of the Fokker-Planck equation (27) is nothing but the unique equilibrium probability distribution function of the Markov process $Z(t)$. By the explicit form given by Eq. (28), it is immediately clear that the characteristics of the equilibrium probability distribution of the Markov process $Z(t)$, denoting the dynamics of the quantized electromagnetic field in the region V, depend sensitively on the rate of pumping S_∞ provided by the disordered dynamics of electric dipoles of the microtubule proteins. Namely for smaller values of S_∞ such that $\alpha < 0$, the most probable value for the intensity of the electromagnetic field $I = \sqrt{\overline{Z}Z}$ vanishes, while it becomes nonvanishing for larger values of S_∞ such that $\alpha > 0$, obtaining

$$I = \sqrt{\frac{\alpha}{\beta}} .$$

We have found that the collective dynamics of the quantum system of electromagnetic field and water electric dipole field in the region V manifests a long-range cooperative phenomenon of photon emission even if the thermal fluctuation and dissipation are taken into account. Excitation of the quantized electromagnetic field, that is, emission of photons in the region V is induced by the interaction with the thermally disordered dynamics of electric dipoles of tubulins if the pumping rate S_∞ exceeds a threshold value,

$$S_\infty > \frac{\hbar^2 V \gamma_0 \gamma_{EM}}{4\pi\varepsilon f^2} .$$

Macroscopic Condensates of Evanescent Photons

We have revealed that the quantum system of electromagnetic field and water electric dipole field manifests long-range ordered dynamics due to the spontaneous symmetry breaking in quantum field theory even though it suffers from interaction with thermally disordered dynamics of the external systems of biomolecules. For the time scale much shorter than the characteristic time of thermal fluctuation at body temperature, manifestation of such a collective mode as long-range ordered dynamics was found to result in nonlinear quantum optical phenomena such as superradiance, realized in macroscopic regions adjacent to the highly structured biomolecules as cytoskeletal microtubules. For the longer time scale, the collective mode was shown to be realized as the water laser emitting coherent photons. In both cases, the most important role was played by the collective mode of the quantum system of electromagnetic field and water electric dipole field interacting strongly with each other.

As was clarified systematically by Umezawa (Umezawa 1993), collective modes of long-range ordered dynamics are nothing but macroscopic objects of quantum origin. Crystals, magnetic media and superconducting media are familiar examples of such macroscopic objects, but it seems difficult to get a correct image of the "macroscopic object" realized by a collective mode of the quantum system of electromagnetic field and water electric dipole field. Of course, the collective mode in question was shown to induce coherent photon emission phenomena. However, it must be emphasized that those photons are not ordinary ones but specific ones which cannot go away from the spatial region occupied by the "macroscopic object." In other words, those photons are associated not to the usual advancing plane wave mode but to the evanescent wave mode of the quantized electromagnetic field wrapping the localizations of water electric dipole field, and they can exist only in conjunction with water. We call such photons "evanescent photons" in water.

Since the evanescent photons in water are not associated to the advancing plane wave, we cannot see them from the outside as light. Therefore, we need to put the finest optical fiber or metallic fiber into the region of "macroscopic object" made of evanescent photons in water, so that energy quanta of the trapped evanescent wave mode are scattered into the advancing plane wave mode and finally detected as light. As the evanescent wave mode of the quantized electromagnetic field is maintained by the ordered dynamics of water electric dipole field strongly coupled to it, the evanescent photons accompany the coupled wave of water electric dipole field and can be seen as charged quanta. Namely, unlike the usual concept of photons, the evanescent photons in water have effective electric charge e^* and effective mass m^*, and behave as Bose quanta with the transmission speed smaller than the speed of light c.

It may be of certain help for giving a correct image of the "macroscopic object" of a collective mode of the quantum system of electromagnetic field and water electric dipole field if we call it "evanescent photon water." Namely, evanescent photon water is a typical macroscopic object in brain cells which can be regarded as a macroscopic condensate of evanescent photons with certain effective charge and mass. The physical situation is similar to that of superconducting media in which a macroscopic (Bose-Einstein) condensate of pseudo-particles called Cooper pairs with certain effective charge and mass is realized. The macroscopic condensate of Cooper pairs is realized only at lower temperature close to absolute zero, and so superconductive phenomena of Cooper pairs can hardly be realized in macroscopic objects at body temperature. This fact had been referred to as a common negative claim against the possibility of superconductive phenomena in living matter. However, because the macroscopic condensate of evanescent photons has been shown to be realized even at body temperature in the vicinity of structured biomolecules as cytoskeletal microtubules, we can expect the possibility of superconductive phenomena of evanescent photons in living matter, especially in the brain. Simply put, as the evanescent photon has mass nonvanishing but much smaller than that of the Cooper pair of electrons, the macroscopic condensate of evanescent photons has the critical temperature higher than the body temperature, and we still have superconducting phenomena in evanescent photon water in the brain at body temperature (Jibu et al. 1996). Therefore, it seems highly plausible that it is not the microscopic quantum mechanical system of electrons in biomolecules but the macroscopic quantum ordered dynamical system of evanescent photons in water which plays the essential role in realizing the biological order in living matter.

As the evanescent photon in evanescent wave mode can be described as a pseudo-particle with small but nonvanishing effective charge e^* and mass m^* subject to the usual Schrödinger equation, the macroscopic condensate of evanescent photons in the region V of the quantum ordered dynamics of electromagnetic field and water electric dipole field may be well described by the macroscopic Schrödinger equation for the macroscopic wavefunction, just as it was so in the case of macroscopic condensates of Cooper pairs (Feynman et al. 1968). Namely, macroscopic ordered dynamics of the most important "macroscopic object" in the brain —evanescent photon water—is governed by the macroscopic wavefunction $\Psi = \Psi(\boldsymbol{x}, t)$ subject to the macroscopic Schrödinger equation

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m^*}\Delta\Psi + e^*U\Psi\ , \qquad (30)$$

where $U = U(\boldsymbol{x}, t)$ denotes the mean electric potential given by the external systems. It is interesting to notice here that this macroscopic Schrödinger equation applies not only to evanescent photon water in the vicinity of cytoskeletal microtubules but also to evanescent photon water immediately adjacent to dendritic membranes of brain cells.

As the dendritic membrane of the brain cell is composed of two oppositely oriented phospholipid molecules, not only does the outer layer but also the inner layer contact with evanescent photon water manifesting macroscopic Bose-Einstein condensation of evanescent photons. Consequently, we can expect that, within the patch (or compartment) of cell membranes that falls within the coherence length of the ordered dynamics of water electric dipole field and electromagnetic field, a couple of outer and inner perimembranous regions separated by a thin layer of cell membrane form a Josephson junction, that is, a sandwich-structured junction of two regions of macroscopic condensation weakly coupled with each other through the membrane by means of quantum tunneling mechanism. The Josephson junction is a well-investigated superconducting device which is shown to maintain specific superconducting phenomena called Josephson effects (Feynman et al. 1968). The appearance of Josephson effects in general biological cells had been suggested theoretically and several positive experimental results were reported (Del Giudice et al. 1989, Preparata 1995). However, emphasis was put mainly on the extraordinary sensitivity of the superconducting current across the Josephson junction (i.e., Josephson current) to the imposed magnetic field. Such a (magnetic) Josephson effect can be an important clue as not only an indirect evidence of the existence of the high-temperature macroscopic condensate of evanescent photons (i.e., evanescent photon water) but also a possible mechanism explaining the high sensitivity of the brain to the weak magnetic field.

Besides the magnetic Josephson effect we have another one typical for the Josephson junction; that is, an electric Josephson effect (Feynman et al. 1968). The latter will play an important role in realizing the non-linear network of high-temperature superconducting currents among the brain cells:

Let us focus on a domain of the dendritic membrane smaller than the coherence length l_c in which the sandwich-structured Josephson junction is realized in terms of the macroscopic condensates of evanescent photons in the perimembranous regions outside and inside the membrane. The electric potential difference $U = U(t)$ between the outer and inner surfaces of the membrane can be thought of as the voltage across the Josephson junction. Then, the standard quantum field theoretical treatment of the electric Josephson effect yields that the Josephson current induced by the voltage $U(t)$ is given by

$$J(t) = J_0 \sin\left(\theta_0 + \frac{q}{\hbar}\int_0^t U(s)ds\right) , \qquad (31)$$

where J_0, θ_0 and q are certain constants (Yasue 1978a). The circuit equation for the Josephson junction is therefore given by

$$C_0 \frac{dU(t)}{dt} = -J(t) , \qquad (32)$$

where C_0 stands for the capacitance parameter of the membrane. Introducing a new variable

$$W(t) \equiv \theta_0 + \frac{q}{\hbar}\int_0^t U(s)ds ,$$

we can rewrite Eq. (32) as follows:

$$\frac{d^2W(t)}{dt^2} = -\frac{J_0 q}{C_0 \hbar} \sin W(t) . \qquad (33)$$

This is a non-linear differential equation of the same form as the classical equation of motion for the physical pendulum, and has an oscillatory solution $W = W(t)$ represented implicitly by the elliptic function. Correspondingly, the membrane electric potential difference $U(t)$ manifests a self-excited oscillation

$$U(t) = \frac{\hbar}{q}\frac{dW(t)}{dt} \qquad (34)$$

characteristic to the Josephson junction. This is called the Josephson oscillation and a small oscillating current across the Josephson junction is called the Josephson oscillating current.

Considering a cell membrane as a horizontal plane patched by many Josephson junctions smaller than the coherence length across which the Josephson oscillating currents perpendicular to the plane are maintained. Then, collective modes of the totality of those Josephson oscillating currents emerge as "plasmon" modes which can propagate horizontally as solitons along the plane of cell membrane without damping. This remarkable fact can be seen from the propagation equation for the plasmon mode obtained by rewriting Eq. (33) in terms of spatial variables:

$$\frac{\partial^2 W(\boldsymbol{x},t)}{\partial t^2} - v^2 \frac{\partial^2 W(\boldsymbol{x},t)}{\partial x^2} = -\frac{J_0 q}{C_0 \hbar} \sin W(\boldsymbol{x}, t) \qquad (35)$$

Here, v stands for the characteristic speed of the plasmon mode, and x denotes one of the spatial directions along the membrane. This equation is known to be the Sine-Gordon equation, and admits soliton solutions which propagate along the spatial direction without damping.

Finally, we have found that the dendritic membrane of the brain cell sandwiched by macroscopic condensates of evanescent photons (i.e., evanescent photon water) may manifest a very peculiar physical feature as a non-linear electric device: Plasmon modes propagating as solitons horizontally along the membrane have a long transmission range and can be excited easily by smaller energy gain. Furthermore, the plasmon mode is strongly coupled with electromagnetic field, and it emits and absorbs low energy photons in sub-millimeter range of wavelength. On the other hand, Josephson currents flowing across the membrane perpendicularly generate charge density waves in and among the brain cells.

As there are extremely many Josephson junctions in the totality of dendritic membranes of the brain cells, we can think of a huge non-linear network of high-temperature superconducting currents across the Josephson junctions among the brain cells. Dynamics of this huge network could be seen by investigating all the Josephson oscillations coupled with each other. Although the detailed investigation seems difficult in practice, we can expect that a considerable number of synchronized Josephson oscillations would result in realizing the macroscopic electric potential oscillations measured by microelectrode recordings of sensory activated dendritic fields or by recordings made from scalp. In other words, the totality of synchronized Josephson oscillations in the dendritic membranes can be supposed to generate at least a portion of the scalp-recorded electroencephalogram (EEG). The fact that the Josephson oscillation is extraordinarily sensitive to the magnetic field imposed on the Josephson junction might explain the experimental finding that the human brain can be influenced by small variations of the Earth's magnetic field.

Expecting the further theoretical investigation of various physical aspects of evanescent photon water not only in brain cells but also in general biological cells to be respectable, we conclude our exposition by Umezawa's words (Umezawa 1993):

> Through this structure (of macroscopic ordered states in quantum field theory), the entire body as a whole may form a system of intensive correlations.

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References

[1] CRICK, F. 1994. The Astonishing Hypothesis: The Scientific Search for the Soul. Charles Scribner's. New York.

[2] DEL GIUDICE, E., S. DOGLIA & M. MILANI. 1982. A collective dynamics in metabolically active cells. Phys. Lett. 90A:104–106.

[3] DEL GIUDICE, E., S. DOGLIA, M. MILANI & G. VITIELLO. 1985. A quantum field theoretical approach to the collective behaviour of biological systems. Nucl. Phys. B251:375–400.

[4] DEL GIUDICE, E., S. DOGLIA, M. MILANI & G. VITIELLO. 1986. Electromagnetic field and spontaneous symmetry breaking in biological matter. Nucl. Phys. B275:185–199.

[5] DEL GIUDICE, E., G. PREPARATA & G. VITIELLO. 1988. Water as a free electric dipole laser. Phys. Rev. Lett. 61:1085–1088.

[6] DEL GIUDICE, E., S. DOGLIA, M. MILANI, C.W. SMITH & G. VITIELLO. 1989. Magnetic flux quantization and Josephson behaviour in living systems. Phys. Scripta 40:786–791.

[7] DICKE, R.H. 1954. Coherence in spontaneous radiation processes. Phys. Rev. 93:99–110.

[8] ENZ, C.P. 1997. On Preparata's theory of a superradiant phase transition. Helv. Phys. Acta 70:141–153.

[9] FEYNMAN, R.P., R.B. LEIGHTON & M. SANDS. 1965. The Feynman Lectures on Physics: Quantum Mechanics. Addison Wesley.

[10] FRÖHLICH, H. 1968. Long-range coherence and energy storage in biological systems. Intern. J. Quantum Chem. 2:641–649.

[11] HAGAN, S., M. JIBU & K. YASUE. 1994. Consciousness and anesthesia: An hypothesis involving biophoton emission in the microtubular cytoskeleton of the brain. *In* K.H. Pribram, Ed. Origins: Brain and Self Organization. 153–171. Lawrence Erlbaum. New Jersey.

[12] HO, M.-W., F.-A. POPP & U. WARNKE. 1994. Bioelectrodynamics and Biocommunication. World Scientific. Singapore.

[13] JIBU, M. & K. YASUE. 1992. A physical picture of Umezawa's quantum brain dynamics. *In* R. Trappl, Ed. Cybernetics and Systems Research '92. 797–804. World Sci. Singapore.

[14] JIBU, M. & K. YASUE. 1993a. Intracellular quantum signal transfer in umezawa's quantum brain dynamics. Cybernetics and Sys. 24:1–7.

[15] JIBU, M. & K. YASUE. 1993b. The basics of quantum brain dynamics. *In* K.H. Pribram, Ed. Rethinking Neural Networks: Quantum Fields and

Biological Data. 121–145. Lawrence Erlbaum. New Jersey.

[16] JIBU, M. & K. YASUE. 1994. Is brain a biological photonic computer with subneuronal quantum optical networks? *In* R. Trappl, Ed. Cybernetics and Systems Research '94. 763–770. World Scientific. Singapore.

[17] JIBU, M. & K. YASUE. 1995. Quantum Brain Dynamics. An Introduction. John Benjamins. Amsterdam.

[18] JIBU, M., S. HAGAN, S.R. HAMEROFF, K.H. PRIBRAM & K. YASUE. 1994. Quantum optical coherence in cytoskeletal microtubules: Implications for brain function. BioSystems 32:195–209.

[19] JIBU, M., S. HAGAN & K. YASUE. 1995. Subcellular quantum optical coherence: Implications for consciousness. *In* S.R. Hameroff, A.W. Kaszniak & A.C. Scott, Eds. Toward a Science of Consciousness: The First Tucson Discussions and Debates. 493–505. MIT Press.

[20] JIBU, M., K.H. PRIBRAM & K. YASUE. 1996. From conscious experience to memory storage and retrieval: The role of quantum brain dynamics and boson condensation of evanescent photons. Intern. J. Mod. Phys. 10:1735–1754.

[21] JIBU, M., K. YASUE & S. HAGAN. 1997. Evanescent (tunneling) photon and cellular "vision". BioSystems. In press.

[22] KLAUDER, J.R. & E.C.G. SUDARSHAN. 1968. Fundamentals of Quantum Optics. Benjamin. New York.

[23] MINSKY, M. 1987. The Society of Mind. Simon and Schuster. New York.

[24] NAKAZAWA, K., S. MIKAWA, T. HASHIKAWA & M. ITO. 1995. Transient and persistent phosphorylation of AMPA-type glutamate receptor subunits in cerebellar Purkinje cells. Neuron 15:697–709.

[25] PREPARATA, G. 1995. QED Coherence in Matter. World Scientific. Singapore.

[26] PRIBRAM, K.H. 1971. Languages of the Brain. Englewood Cliffs, NJ.

[27] PRIBRAM, K.H. 1991. Brain and Perception. Lawrence Erlbaum. New Jersey.

[28] RICCIARDI, L.M. & H. UMEZAWA. 1967. Brain and physics of many-body problems. Kybernetik 4:44–48.

[29] STUART, C.I.J.M., Y. TAKAHASHI & H. UMEZAWA. 1978. On the stability and non-local properties of memory. J. Theor. Biol. 71:605–618.

[30] STUART, C.I.J.M., Y. TAKAHASHI & H. UMEZAWA. 1979. Mixed-system brain dynamics: Neural memory as a macroscopic ordered state. Found. Phys. 9:301–327.

[31] TAKAHASHI, Y. & H. UMEZAWA. 1975. Thermo field dynamics. Collective Phenomena 2:55–80.

[32] UMEZAWA, H. 1993. Advanced Field Theory: Micro, Macro, and Thermal Physics. American Institute of Physics. New York.

[33] UMEZAWA, H. 1993. Development in concepts in quantum field theory in half century. Math. Japonica 41:109–124.

[34] VITIELLO, G. 1995. Dissipation and memory capacity in the quantum brain model. Intern. J. Mod. Phys. B 9:973–989.

[35] YASUE, K. 1976. Quantization of dissipative dynamical systems. Phys. Lett. 64B:239–241.

[36] YASUE, K. 1977. A note on the derivation of the Schrödinger-Langevin equation. J. Stat. Phys. 16:113–116.

[37] YASUE, K. 1978a. Quantum mechanics of nonconservative systems. Ann. Phys. 114:479–496. NY.

[38] YASUE, K. 1978b. Stochastic quantization of wave fields and its application to dissipatively interacting fields. J. Math. Phys. 19:1892–1897.

[39] YASUE, K. 1979. Stochastic quantization: A review. Internat. J. Theor. Phys. 18:861–913.

System-Processual Backgrounds of Consciousness

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

1 Introduction

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

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

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

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

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

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

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

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

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

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

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

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

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

3 Why Include Quantum Systems?

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

The main reasons for the quantum hypothesis are the following:

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

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

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

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

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

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

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

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

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

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

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

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

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

- *quantum coherent superpositions* (quantum computing [21, 45]) and *conscious events*

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

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

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

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

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

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

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

4 Multi-Level Coherence in Brain

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

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

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

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

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

5 Explicit versus Implicit Collective States: Patterns versus Attractors

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

7 Questions Concerning the Fractal-like Nature of Brain

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

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

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

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

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

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

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

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

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

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

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

8 Conclusions

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

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

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

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

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

sciousness question [33, 1, 79].

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

is analogous to the quantum density matrix or statistical operator

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

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

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

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

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

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

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

is similar to the quantum equation

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

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

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References

[1] Toward a Science of Consciousness. 1996. Tucson II—Consciousness Research Abstracts. JCS/Imprint Acad.

[2] Collected papers presented at the colloquium "Memory: Recording Experience in Cells and Circuits". 1996. Proc. Natl. Acad. Sci. USA **93**:13435–13551.

[3] Alberts, B. *et al.* 1983. Molecular Biology of the Cell. Garland. New York.

[4] Amit, D. 1989. Modeling Brain Functions (The world of attractor neural nets). Cambridge Univ. Press. Cambridge.

[5] Amoroso, R. 1995. The extracellular containment of natural intelligence. Informatica **19**:585–590.

[6] AMOROSO, R. & B.E. MARTIN. 1995. Modeling the Heisenberg matrix: Quantum coherence and thought at the holoscape manifold and deeper complementarity. *In* K. Pribram, Ed. Scale in Conscious Experience: Is the Brain too Important to Be Left to Biologists to Study? Lawrence Erlbaum. Mahwah, NJ.

[7] BAIRD, B. 1990. Bifurcation and category learning in network models of oscillating cortex. Physica D **42**:365–384.

[8] BEAR, M.F. 1997. How do memories leave their mark? Nature **385**:481–482.

[9] BERG, R.H., S. HVILSTED & P.S. RAMANUJAM. 1996. Peptide oligomers for holographic data storage. Nature Lett. **383**:505–508.

[10] BERTLMANN, R.A. 1990. Bell's Theorem and the nature of reality. Foundat. Physics **20**:1191–1208.

[11] BJORKEN, J.D. & S.D. DRELL. 1965. Relativistic Quantum Fields. Chapter 6, Propagator Theory. McGraw-Hill. New York.

[12] BOHM, D. & B. HILEY. 1993. The Undivided Universe. An ontological interpretation of quantum theory. Routledge. London.

[13] BOHM, D. 1980. Wholeness and Implicate Order. Routledge and Paul Kegan. London.

[14] BRAY, D. 1995. Protein molecules as computational elements in living cells. Nature **376**:307–312.

[15] BRENTANO, F. 1973. Psychology from an Empirical Standpoint. Routledge and Kegan Paul. London.

[16] BURNOD, Y. 1990. An Adaptive Neural Network: the Cerebral Cortex. Prentice Hall. London.

[17] CHRISLEY, R.L. 1995. Quantum Learning. *In* P. Pylkkänen & P. Pylkkö, Eds. New Directions in Cognitive Science. 77–89. Finnish AI Soc., Helsink.

[18] DAUGMAN, J.G. 1985. Uncertainty relation for resolution in space, spatial frequency, and orientation optimized by 2-D visual cortical filters. J. Optical Soc. Amer. A **2**:1160.

[19] DAVIES, P.C.W. & J.R. BROWN, Eds. 1986. The Ghost in the Atom. Cambridge Univ. Press. Cambridge.

[20] DEUTSCH, D. 1991. Quantum mechanics near closed time-like lines. Physical Rev. D **44**:3197–3217.

[21] DEUTSCH, D. 1992. Quantum Computation. Physics World. June 1992. 57–61.

[22] DEWDNEY, C., P.R. HOLLAND, A. KYPRIANIDIS & J.P. VIGIER. 1988. Spin and non-locality in quantum mechanics. Nature **336**:536–544.

[23] DOMANY, E., J.L. VAN HEMMEN & K. SCHULTEN, Eds. Models of Neural Networks. Springer. Berlin.

[24] FRESCURA, F.A.M. & B.J. HILEY. 1980. The implicate order, algebras and spinor. Foundat. Physics **10**:7–31.

[25] GOSWAMI, A. 1990. Consciousness in Quantum Physics and the Mind-Body Problem. J. Mind & Behavior **11**:1:75.

[26] GOULD, L.I. 1995. Reflections on the relevance of nonlocality to cognitive science and the philosophy of mind. *In* P. Pylkkänen & P. Pylkkö, Eds. New Directions in Cognitive Science. 104–114. Finnish AI Soc., Helsinki.

[27] HAGELIN, J.S. 1987. Is consciousness a unified field? A field theorists's perspective. Modern Sci. & Vedic Sci. **1**:29–87.

[28] HAKEN, H. 1991. Synergetic Computers and Cognition. A Top-Down Approach to Neural Net). Springer. Berlin.

[29] HAKEN, H. 1996. Principles of Brain Functioning. Springer. Berlin.

[30] HAMEROFF, S.R. 1994. Quantum coherence in microtubules: a neural basis for emergent consciousness? J. Consciousness Studies **1**:91–118.

[31] HAMEROFF, S.R. & R. PENROSE. 1996. Conscious events as orchestrated space-time selections. J. Consciousness Studies **3**:36–53.

[32] HAMEROFF, S.R. & R. PENROSE. 1995. 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? 243–275. Lawrence Erlbaum Assoc. Mahwah, NJ.

[33] HAMEROFF, S.R., A.W. KASZNIAK & A.C. SCOTT, Eds. 1996. Towards a Science of Consciousness. Tucson I. MIT Press, Cambridge, MA.

[34] HILEY, B.J. & F.D. PEAT, Eds. 1987. Quantum Implications. Routledge. London.

[35] HO, M.W. 1996. The biology of free will. J. Consciousness Studies **3**:231–244.

[36] HOPFIELD, J.J. 1982. Neural networks and physical systems with emergent collective computational abilities. Proc. Nat. Acad. Sci. USA 79:2554–2558.

[37] JIBU, M. & K. YASUE. 1995. Quantum Brain Dynamics and Consciousness. John Benjamins. Amsterdam/Philadelphia.

[38] KAFATOS, M. & R. NADEAU, R. 1990. The Conscious Universe. Springer. New York.

[39] KAK, S.C. 1995. On quantum neural computing. Inform. Sci. **83**:143–160.

[40] KAK, S.C. 1995. Quantum neural computing. Advances in Imaging and Electron Physics **94**:259–313.

[41] KAK, S.C. 1997. Does quantum information have relevance in neuroscience? *In* Proc. Intl. Conf. on Info. Sci. 141–144. NC.

[42] KAK, S.C. 1996. The three languages of the brain: quantum, reorganizational, and associative. *In* K.H. Pribram & J. King, Eds. Learning as Self-Organization. Lawrence Erlbaum Assoc. Mahwah, NJ.

[43] KOCH, CH. 1997. Computation and the single neuron. Nature **385**:207–210.

[44] LIBET, B. 1993. The neural time factor in conscious and unconscious events. *In* Experimental and Theoretical Studies of Consciousness. P. 123. John Wiley & Sons. Chicheseter.

[45] LLOYD, S. 1995. Quantum-mechanical computers. Scien. Amer. (Oct. 1995) 44–50.

[46] LLOYD, S. 1996. Universal quantum simulators. Science **273**:1073–1078.

[47] LOCKWOOD, M. 1989. Mind, Brain and the Quantum. Blackwell. Oxford.

[48] MANNION, C.L.T. & J.G. TAYLOR. 1992. Information Processing by Oscillating Neurons. *In* J.G. Taylor & C.L.T. Mannion, Eds. Coupled Oscillating Neurons. Springer. London.

[49] MCCLELLAND, J.L., D.E. RUMELHART & PDP research group. 1986. Parallel distributed processing. Explorations in the Microstructure of Cognition. Vol. 1: Foundations. Vol. 2: Psychological and Biological Models. MIT Press. Cambridge, MA.

[50] MARCER, P.J. 1995. Getting quantum theory off the rocks: Nature as we consciously perceive it, is quantum reality. Proceed. 14^{th} Int. Congress on Cybernetics. 435–440. Namur, Belgium.

[51] MARCER, P.J. 1995. A quantum-mechanical model of evolution and consciousness. Proceed. 14^{th} Int. Congress on Cybernetics. 429–434. Namur, Belgium.

[52] MARCER, P.J. & W. SCHEMPP. 1997. The brain as a conscious system. To be publ. in J. General Systems.

[53] OHYA, M. 1989. Some aspects of quantum information theory and their applications to irreversible processes. Reports Math. Physics **27**:19–46.

[54] PAVŠIČ, M. 1991. On the interpretation of the relativistic quantum mechanics with invariant evolution parameter. Foundat. Physics **21**:1005–1019. *See also* 1994. Foundat. Physics **24**:1495–1518 *and* 1981. Lett. Nuovo Cimento **30**:111–115.

[55] PENROSE, P. 1994. Shadows of the Mind. A Search for the Missing Science of Consciousness. Oxford Univ. Press. Oxford.

[56] PERUŠ, M. 1995. Synergetic approach to cognition-modeling with neural networks. *In* K. Sachs-Hombach, Ed. Bilder im Geiste. 183–194. Rodopi. Amsterdam/Atlanta.

[57] PERUŠ, M. 1995. All in One, One in All. Brain and Mind in Analysis and Synthesis. DZS. Ljubljana (in Slovene, Engl. transl. in progress).

[58] PERUŠ, M. 1995. Analogies of neural and quantum processing. Consequences for cognitive science. *In* P. Pylkkänen & P. Pylkkö, Eds. New Directions in Cognitive Science. 115–123. Finnish AI Soc. Helsinki.

[59] PERUŠ, M. 1997. Multi-level synergetic computation in brain. Advances in Synergetics **9**: (in press).

[60] PERUŠ, M. 1997. System-processual backgrounds of mystical and meditational experience. World Futures: J. General Evol. (in press).

[61] PRIBRAM, K. 1991. Brain and Perception. Lawrence Erlbaum Assoc. Hillsdale.

[62] PRIBRAM, K., Ed. 1993. Rethinking Neural Networks. Quantum Fields and Biological Data. Lawrence Erlbaum Assoc. Hillsdale.

[63] PRIBRAM, K. 1997. What is mind that the brain may order it? Proceed. Symp. Appld Math. **52**:301–329.

[64] RAKOVIĆ, D. & DJ. KORUGA, Eds. 1995. Consciousness. ECPD. Belgrade.

[65] SAMSONOVICH, A., A. SCOTT & S. HAMEROFF, S. 1992. Acousto-conformational transitions in cytoskeletal microtubules: Implications for intra-cellular information processing. Nanobiol. **1**:457–468.

[66] SATARIĆ, M.V., R.B. ŽAKULA & J.A. TUSZYNSKI. 1992. A model of the energy transfer mechanism in microtubules involving a single soliton. Nanobiol. **1**:445–456.

[67] SCHEMPP, W. 1993. Bohr's Indeterminacy Principle in Quantum Holography, Self-adaptive Neural Network Architectures, Cortical Self-Organization, Molecular Computers, Magnetic Resonance Imaging and Solitonic Nanotechnology. Nanobiol. **2**:109.

[68] SCHEMPP, W. 1994. Analog VLSI network models, cortical linking neural network models, and quantum holographic neural technology. 213–260. *In* J.S. Byrnes et al., Eds. Wavelets and Their Applications. Kluwer. Amsterdam.

[69] SCHEMPP, W.: 1995. Phase coherent wavelets, Fourier transform magnetic resonance imaging, and synchronized time-domain neural networks. Proceed. Steklov Inst. Math. **3**:323–351.

[70] SHIPOV, G.I. 1995. A Theory of Physical Vacuum. Sections 2.4 and 2.5, especially. Book-manuscript. Moscow (to be publ.).

[71] SILVERMAN, M.P. 1993. More than one mystery: Quantum interference with correlated charged particles in magnetic fields. Amer. J. Physics **61**:514–523.

[72] SQUIRES, E.J. 1993. Quantum theory and the relation between the conscious mind and the physical world. Synthese **97**:109.

[73] STAPP, H.P. 1991. Quantum Propensities and the Brain-Mind Connection. Foundat. Physics **21**:12:1451.

[74] STERN, A. 1992. Matrix Logic and Mind. North-Holland/Elsevier, Amsterdam.

[75] STERN, A. 1994. The Quantum Brain. North-Holland/Elsevier. Amsterdam.

[76] ŠLECHTA, J. 1993. On a Quantum-Statistical Theory of Pair Interaction Between Memory Traces in the Brain. Informatica **17**:109–115 (and other refs. within).

[77] TUSZYNSKI, J.A., H. BOLTERAUER & M.V. SATARIĆ. 1992. Self-organization in biological membranes and the relationship between Fröhlich and Davydov theories. Nanobiol. **1**:177–190.

[78] VITIELLO, G. 1992. Coherence and Electromagnetic Fields in Living Matter. Nanobiol. **1**:221–228.

[79] ŽELEZNIKAR, A.P. 1996. Πόλεμος of Consciousness. Informatica **20**:475–484.

Prospects for Conscious Brain-like Computers: Biophysical Arguments

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The key problem of the future theory of consciousness is how to incorporate altered states of consciousness within a new paradigm, as purely biochemical mechanisms are not accelerated up to several orders of magnitude, in comparison with subjective time sense dilation in altered states of consciousness—in respect to the normal awake state. The electromagnetic (EM) component of ultralowfrequency (ULF) "brainwaves" provides an extraordinary biophysical basis for consciousness-like displays in both normal and altered states of consciousness: it enables perfect fitting with narrowed limits of conscious capacity in normal awake states, very extended limits in altered states of consciousness (due to the relativistic mechanism of dilated "subjective" time base), and most peculiar space-time transpersonal interactions in transitional states of consciousness during the interchange of normal and altered states of consciousness (due to the relativistic generation of wormholes in highly noninertial "subjective" reference frame, fully equivalent to extremely strong gravitational fields according to Einstein's Principle of equivalence); it also enables the dream-like mixing of the normally conscious and unconscious contents in altered states, due to the relativistic Doppler mapping of the EM component of the "objective" ULF brainwave power spectrum on the zero-degenerate-frequency "subjective" one. As the rather complex additional low-dielectric ($\varepsilon_r \approx 1$) weakly ionized gaseous "optical" neural network is necessary in these processes, it seems that biological molecular hardware will essentially determine further development of brain-like computers with artificial consciousness, in the form of neural networks with embedded brainwaves-like ULF ionic electrical activity. In transitional states of consciousness such nonprogrammable brain-like computers could be able to solve even most subtle problems creatively, by multiple re-addressing the problem and taking the most frequent solution as the optimal one. As the whole situation resembles on the quantum theory of measurement, such creative brain-like computers with artificial consciousness might be named quantum computers.

1 Introduction

The prevailing scientific paradigm considers information processing inside the central nervous system as occurring through hierarchically organized and interconnected neural networks. Along with development of experimental techniques enabling physiological investigation of interactions of hierarchically interconnected neighboring levels of biological neural networks, significant contribution in establishing the neural network paradigm was given by theoretical breakthroughs in this field during the past decade [1]. Neural networks, to emulate brain function, have many good properties: parallel functioning, relatively quick realization of complicated tasks, distributed information, weak sensitivity on damages, as well as learning abilities, i.e. adaptation upon changes in environment and improvement based on experience.

During the learning process, apart from the brain's hierarchy of neural networks, a significant role in global distribution and memorizing (over the whole cortex) of hierarchically processed information is played by brainwaves [2]. While something is learned, information is hierarchically processed in primary, secondary, and tertiary brain areas, being afterwards spread by brainwaves over the whole cortex; however, when learning is achieved (so called habituation), the same visual stimulus can only be found in the visual system! Of particular interest in this process is also extended reticular-thalamic activating system (ERTAS) [3], as a hierarchical system of neural networks which compares currently processed information with the one memorized in the cortex, giving priority and amplifying one piece of information to the conscious level; the remaining pieces of information rest nonamplified at unconscious levels. This is basically also the mechanism of "emotional coloring" of some information!

2 Altered States of Consciousness: Special Relativity Unavoidable?

A particularly significant role of brainwaves involves in modeling states of consciousness—and especially altered states of consciousness, characterized by extraordinary acceleration in psychological information processing, which cannot be explained by purely biochemical intersynaptic processes in biological neural networks.

It should be pointed out that purely biochemical mechanisms of the ERTAS are not accelerated up to several orders of magnitude, as the subjective time sense is dilated in altered states of consciousness [4-6] (REM sleep, meditation, hypnosis, psychedelic drug influence, some psychopathological states, and near-death experiences)—in respect to the normal awake state.

The only mechanism that can account for the extremely dilated subjective time base in altered states of consciousness is the physical relativistic one, if only the "subjective" observer can be associated with an EM field of the ultralowfrequency (ULF) brain activity (ongoing (EEG) and evoked potentials (EPs), henceforth brainwaves) which can move through the brain with relativistic velocities, as it was extensively elaborated in our biophysical model of altered states of consciousness for the last ten years [7,8]. However, it is necessary that complete information (both conscious and unconscious) is permanently coded from neural network to brainwaves, presumably as brainwaves' spatiotemporal patterns of the brain ionic structure, resulting from the spatio-temporal changes and activations of the synaptic interconnections in the neural networks of the brain.

To be more specific, the ionic medium supporting propagation of the brainwave ULF ionic currents must be inhomogeneous [8] to ensure that the "subjective" observer (associated with the EM component of reference ULF brainwaves), moving through the part of medium of greater ε_r, could register time-dilated information from faster EM component of brainwaves moving through the neighboring part of medium of lower (cf. Fig. 1). Then, at every moment the "subjective" observer is associated with the EM component of brainwaves in the dielectrically "denser" medium, and the whole system behaves like some "center of consciousness". The informational content of such a "subjective" observer is continuously replaced by a new incoming EM component of brainwaves. So, we have permanently some "stream of consciousness". More precisely, for inflowing information (in the form of ULF brainwave ionic currents, coded in spatiotemporal patterns from the brain neural networks) to be recognized by the structured ionic medium, that medium itself must have a form of some kind of "optical" neural network—thus the "subjective" observer being associated with the EM component of brainwaves in dielectrical "condensations"

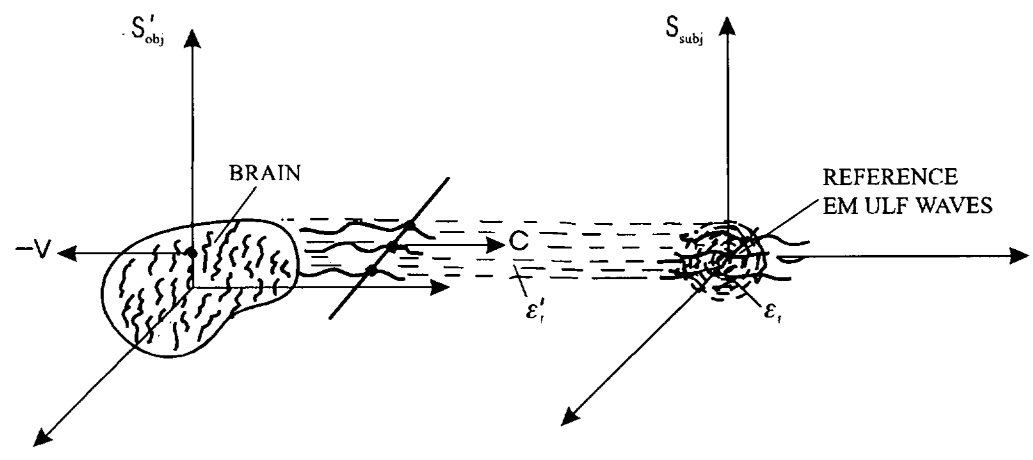

Figure 1: *Figure accompanying the explanation for the necessity of the structured dielectric ($\varepsilon_r \geq \varepsilon'_r$) ionic medium, to ensure that the "subjective" observer ($S_{\rm subj}$), related to EM field moving through the part of medium of greater ε_r, could register time-dilated information from faster EM waves moving through the neighboring part of medium of lower ε'_r [8]. More precisely, for inflowing information (in the form of EM field of ULF brainwave ionic currents, coded in spatiotemporal patterns from the brain neural networks) to be recognized by the structured ionic medium, that medium itself must have a form of some kind of "optical" neural network—thus the "subjective" observer $S_{\rm subj}$ being associated with the EM component of brainwaves in dielectrical "condensations" (of greater ε_r), behaving like "distributed centers of consciousness"!*

(of greater er), behaving like "distributed centers of consciousness"!

It should be also pointed out that it might not be quite accidental that consciousness is related to the EM field of ULF brainwave ionic currents, as the intensity of irradiated ULF EM field is extremely low (intensity I of the field of frequency f, irradiated from a dipole source of linear dimensions d, has a dependence $I \sim f^4 d^2$ [9]), giving rise to consciousness localized around the body.

The model perfectly fits with the narrowed-down limits of conscious capacity in normal awake state (when brainwaves are predominantly located in the brain tissue with relative dielectric permittivity $\varepsilon_r \gg 1$), and very extended limits in altered states of consciousness (characterized by low-dielectric $\varepsilon_r \approx 1$ states, when the relative velocity between the "objective" laboratory reference frame and the "subjective" one is highly relativistic, $v = c_0/\sqrt{\varepsilon_r} \approx c_0$, where c_0 is a velocity of EM waves in vacuum)—due to biophysical relativistic mechanism of dilations of the subjective time base [7,8] (cf. Fig. 2)[1]. This rel-

[1] By attaching the "objective" reference frame to the brain (i.e. laboratory) which moves relatively to the "subjective" reference frame with velocity $v = c_0/\sqrt{\varepsilon_{\rm r}}$ (where c_0 denotes the propagation velocity of the EM field in vacuum, and $\varepsilon_{\rm r}$ the ULF relative dielectric permittivity of the denser ionic structure where brainwaves propagate), the relativistic relation between the time intervals [10], from the viewpoint of the inertial "subjective" observer ($v = c_0/\sqrt{\varepsilon_{\rm r}} =$ const), is

$$\Delta t^{\rm subj} = \frac{\Delta t_0^{\rm obj}}{\sqrt{1-\frac{v^2}{c^2}}} = \left.\frac{\Delta t_0^{\rm obj}}{\sqrt{1-\frac{\varepsilon'_{\rm r}}{\varepsilon_{\rm r}}}}\right|_{\frac{\varepsilon_{\rm r}}{\varepsilon'_{\rm r}}\approx 1} \gg \delta t_0^{\rm obj}$$

where $v = c_0/\sqrt{\varepsilon'_{\rm r}}$ denotes the propagation velocity of the incoming EM field inside the neighboring part of ionic structure with lower dielectric permittivity ($\varepsilon'_{\rm r} < \varepsilon_{\rm r}$, cf. Fig. 1). This could account for the striking dilations of the subjective time base ($\Delta t^{\rm subj}$) in comparison with the objective time measured by the laboratory clock ($\Delta t_0^{\rm obj}$), in altered states of consciousness, if $\frac{\varepsilon_{\rm r}}{\varepsilon'_{\rm r}}$. This condition can be achieved only in a low-dielectric weakly ionized gaseous structured medium (with $\varepsilon_{\rm r} \gtrsim \varepsilon'_{\rm r} \approx 1$), as the brain is a highly nonhomogeneous structure where $\varepsilon_{\rm r}$ could range from $\varepsilon_{\rm r} \geq 2$ (characteristic of biopolymers) across $\varepsilon_{\rm r} \geq 81$ (characteristic of free tissue water) to $\varepsilon_{\rm r} \sim 10^5$ (character-

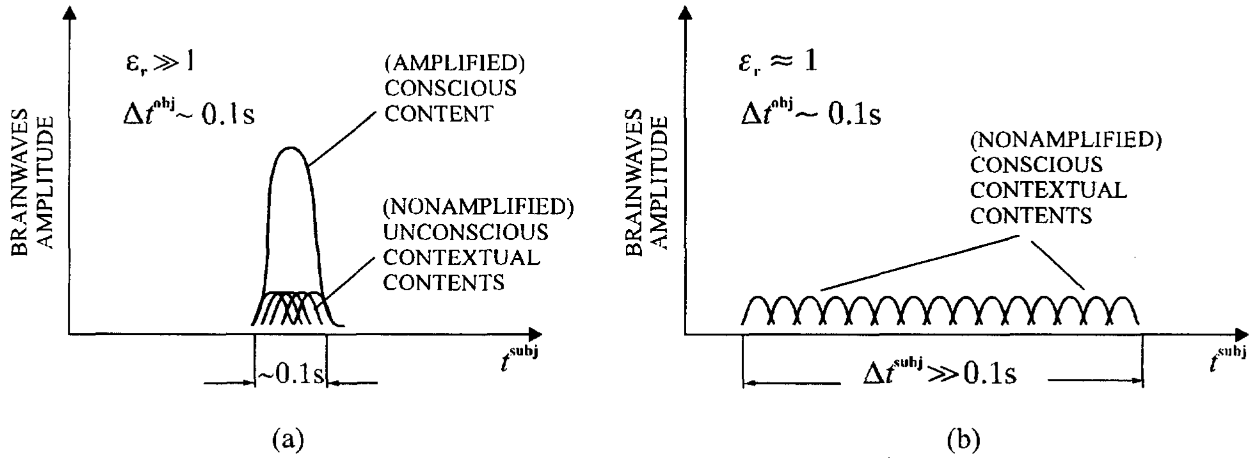

Figure 2: *Schematic display of (a) overlapping process (during $\Delta t^{\mathrm{subj}} \sim 0.1s$) of amplified (by ERTAS) EM component of brainwaves with conscious content and non-amplified EM component of brainwaves with unconscious contextual contents, in normal awake state ($\varepsilon_r \gg 1$), and (b) differentiated contextual contents, in altered states of consciousness ($\varepsilon_r \approx 1$), with extremely dilated "subjective" time base ($\Delta t^{\mathrm{subj}} \gg 0.1$ s)—due to the biophysical relativistic mechanism of the model.*

ativistic mechanism also enables the dream-like mixing of the normally conscious and unconscious contents in altered states, due to the relativistic Doppler mapping of EM component of the "objective" ULF brainwaves power spectrum on the zero-degenerate frequency[2] "subjective" one [7,8] (cf. Fig. 3)[3]. So, in dreams we have "subjective" integration of normally conscious and unconscious contents, this being presumably their major role in the growth of human personality.

The biophysical nature of low-dielectric ($\varepsilon_r \gtrsim \varepsilon_r' \approx 1$) structure has been analyzed in detail elsewhere [8]. It has been shown that this struc-

istic of cell membranes, with striking polarization of the volume ion density within the porous cell wall, strongly depending on metabolic cell processes) [11].

[2]This does not diminish the rate of "subjective" information processing, as this process is not serial but parallel (both in spatiotemporal and frequency domains), being enhanced on "subjective" level by greately enlarged temporal resolution due to extremely dilated "subjective" time base in altered states of consciousness (cf. Fig.2(b)).

[3]The relativistic relation between the frequencies [12] measured in the two reference frames, moving away from one another ($\alpha = \pi$), is

$$f^{\mathrm{subj}} = f_0^{\mathrm{obj}} \left. \frac{\sqrt{1-\frac{v^2}{c^2}}}{1-\frac{v}{c}\cos\alpha} \right|_{\alpha=\pi} = f_0^{\mathrm{obj}} \left. \frac{\sqrt{1-\frac{\varepsilon_r'}{\varepsilon_r}}}{1+\sqrt{\frac{\varepsilon_r'}{\varepsilon_r}}} \right|_{\frac{\varepsilon_r}{\varepsilon_r'}\approx 1} \ll f_0^{\mathrm{obj}}$$

which describes the striking relativistic Doppler shift of the excited "objective" brainwave frequency (f_0^{obj}) down to the vanishing "subjectively" observed brainwave frequency ($f^{\mathrm{subj}} \approx 0$ Hz) in low dielectric ($\varepsilon_r \gtrsim \varepsilon_r' \approx 1$) altered states. This can account for the mixing of conscious and unconscious contents in the altered states of consciousness, as five main frequency bands of both the spontaneous (EEG) and evoked (EP) brainwave activities, $f_{0\gamma}^{\mathrm{obj}}$ (30–50 Hz), $f_{0\beta}^{\mathrm{obj}}$ (13–30 Hz), $f_{0\alpha}^{\mathrm{obj}}$ (8–13 Hz), $f_{0\theta}^{\mathrm{obj}}$ (3,5–8 Hz), and $f_{0\delta}^{\mathrm{obj}}$ (0,5–3,5 Hz), the first three of them predominantly corresponding to normally conscious states [13] and the last two corresponding to normally unconscious states [14], for $\varepsilon_r/\varepsilon_r' \approx 1$ start merging from the viewpoint of the "subjective" reference frame: $f_\gamma^{\mathrm{subj}} \approx f_\beta^{\mathrm{subj}} \approx f_\alpha^{\mathrm{subj}} \approx f_\theta^{\mathrm{subj}} \approx f_\delta^{\mathrm{subj}} \approx 0$ Hz, Fig.3. Although the "objective" brainwave power spectra in such states do not differ significantly from the spectrum of the alert state [15], the essential difference appears in the "subjective" brainwave power spectra; for the sake of comparison, in the alert state the brainwaves are predominantly located in the brain tissue (with $\varepsilon_r \gg 1$), when a differentiated "subjective" spectrum exists: $f_i^{\mathrm{subj}} = f_{0i}^{\mathrm{obj}}\sqrt{1-\varepsilon_{rmr}'/\varepsilon_{rmr}} \Big/ \left(1+\sqrt{\varepsilon_{rmr}'/\varepsilon_{rmr}}\right)$, $i = \gamma, \beta, \alpha, \theta, \delta$, cf. Fig.3. This could be the biophysical mechanism of dreams, which particularly implies their psychological significance: in dreams one has continuous access and more efficient "subjective" integration of normally conscious and unconscious contents, giving rise to integration and growth of human personality (otherwise divided into conscious and unconscious associative "ego" states), which results in alleviation of emotional conflicts!

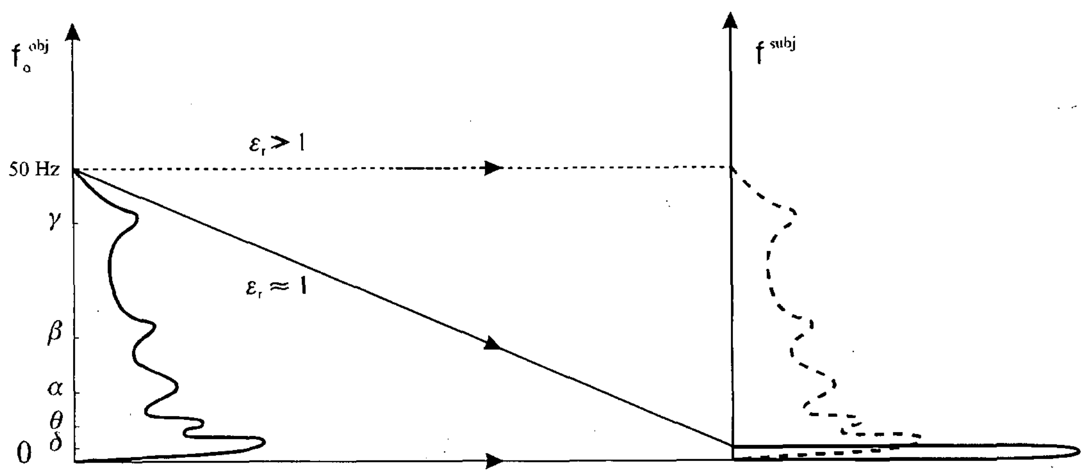

Figure 3: *Display of Doppler mapping of EM component of the "objective" brainwave power spectrum on the "subjective" one, in psychologically altered states ($\varepsilon_r \approx 1$, solid line), and normal awake states ($\varepsilon_r \gg 1$, dashed line).*

ture could be related to partly displaceable (from the body) unhomogeneous ionic acupuncture system which can conduct ULF ionic currents $\sim 10^{-7}$ A. The ionic concentration in the channels of displaced ionic structure has been estimated as $\sim 10^{15}$ cm^{-3}, with a tendency of deterioration during a period of ~1 hour.

3 Transitional States of Consciousness: General Relativity Unavoidable?

It should be noted that some peculiar spatial relativistic effects in altered states of consciousness (when $\varepsilon_r \approx 1$) are predicted by the model [8]: the weakly ionized gaseous neural network, with embedded ULF brainwave currents, enables that even long "objective" distances can be "subjectively" optically recognized contracted; and, such displaced ionic "optical" neural network can perceive an environment panoramically, as reported by reanimated patients.

Even more peculiar *spatio-temporal transpersonal interactions* are predicted in transitional (nonstationary) states of interchange of normal and altered states of consciousness (when brainwaves traverse from high-dielectric ($\varepsilon_r \gg 1$) to low-dielectric ($\varepsilon_r \approx 1$) state or *vice versa*, the relative velocity $v = c_0/\sqrt{\varepsilon_r}$ of "subjective" reference frame being subjected to abrupt change in short transitional period $t \sim 0,1$s, with "subjective frame" acceleration $\sim c_0/t \sim 10^9 \text{m/s}^2$) . Deeper understanding of physical mechanisms of these processes obviously sinks into the General theory of relativity, applied to highly noninertial reference frames (like in enormously strong gravitational fields of "wormholes", where similar phenomena are expected [16]). From the point of view of General theory of relativity, physical processes in accelerated reference frame outside gravitational field and in that one inside gravitational field with equivalent (gravitational) acceleration—are identical (so-called *Principle of equivalence*, being one of the fundamentals of Einstein's theory of gravitation). Theoretical analyses show that in enormously strong gravitational fields so-called wormholes (or Einstein-Rosen space-time bridges) are created, whose entrance and exit could be in very distant space-time points. As in transitional states of consciousness the "subjective" reference frame, related to EM field of brainwaves, is subjected to quick change of velocity, with equivalent acceleration comparable with that one in enormously strong gravitational field of wormholes, according to the Principle of equivalence one could expect, in such brief states, the creation of Einstein-Rosen bridge and tunneling of "subjective observer", i.e. consciousness, in previously "mentally addressed" exit in space-time[4]—reminiscences on passing through some tunnel being really reported by many patients reanimated from clinical death [6]! It should be pointed out that apart from the EM field, the displaced part of ionic acupuncture system (in the form of ionic neural network, having the "optical" sensory function), must also be tunneled in such (acausal) interactions of consciousness with distant events in space-time[5]!

Finally, if the EM field of ULF ionic currents represents sophisticated internal display (related to consciousness) of neural network information processing, it seems that consciousness is not privilege of humans—but can be also a characteristic of higher animals. Even more, if microtubular cytoskeletal structures have neural network-like electrical activities on subcellular level [19], it seems that consciousness can be descended down to the cellular and even subcellular level. Naturally, the conscious content displayed in such EM internal displays depends on the complexity of corresponding neural network information processing at different levels, from subcellular to brain ones. Furthermore, as the EM field is only one out of four manifestations (electromagnetic, gravitational, weak and strong nuclear forces) of the unified physical field [20], it can be tentatively generalized that the unified field itself may be internal conscious display for various physical processes at different structural levels, from macroscopic cosmic to microscopic subnuclear ones. As a consequence, one could conjecture that Nature itself has consciousness at different structural levels, both animate and inanimate, as it is widely claimed in esoteric traditional knowledge[6] [21].

Although such nonlocal pantheistic idea of consciousness is rather bizarre, it can naturally help in resolving the fundamental problem of the wave function reduction in the quantum theory of measurement [22], where in an act of measurement (including finally the very act of conscious observation of the act of measurement) the macroscopic measuring apparatus (including consciousness as a "subjective" observer) makes reduction of the initial wave function into one of the possible eigenfunctions of the system.

4 Quantum Collapse: Consciousness Unavoidable?

The problem of the *wave function reduction* (quantum collapse) in an act of measurement is "orthodoxly" interpreted in quantum theory of measurement as the discontinues change induced by the observation of a quantity with eigenstates $\Psi_1, \Psi_2, \dots$, in which the initial wave function $\Psi = \sum_i a_i \Psi_i$ will be changed to the state Ψ_j with probability $|a_j|^2$. The collapse of the wave function and the assignment of statistical probabilities do not follow from the Schrödinger equation—they are consequences of an external *a priori* metaphysics, which is allowed to intervene at this point and suspend the Schrödinger equation, or rather replace the boundary conditions on its solution by those of the collapsed state function. The problem of quantum theory of measurement has not been consistently re-solved to date, and has been the subject of many serious theoretical efforts, from the very beginning of Quantum mechanics [22].

On the other hand, recent tests of Bell's inequality suggest that Quantum mechanics is *nonlocal theory* [23], as even very distant parts of quantummechanical system (which cannot exchange light signals) can be physically corre-

[4]To support this, one can cite the technique adopted by "extrasenses" when they want to exert some distant influence: they always intensely visualize the person or place, as mental targets! On the other hand, this could be deeply connected with the role of consciousness in quantum theory of measurement, where consciousness with its act of observation affects the final collapse of the initial wave function into one of possible probabilistic eigenstates—which implies that the collapse could be related with generation of local Einstein-Rosen bridge [16], as it is elaborated further on.

[5]This could be a biophysical mechanism of the so-called astral projections of consciousness, those presumably being the basis of most psychic phenomena [17] (providing also explanation for transitional nature and difficult reproducibility of these phenomena); the mentioned "astral projections" are presumably also the basis of religious experiences [18], with mental addressing on spatio-temporally distant abundant ionic archetypic structures from religious traditions, being the target of prayer in transitional states of consciousness.

[6]In that context, all local consciousnesses might be interconnected (through previously described interactions in altered and, especially, in transitional states of consciousness) making the giant cosmic informational network with delocallized consciousness, implying the crucial significance of morals, both on the level of thoughts and feelings!

lated in the act of measurement (like in Einstein-Podolsky-Rosen paradox [22]). As an extreme consequence, this implies that consciousness as a "subjective" observer in such kind of experiment must have nonlocal properties. The property of *nonlocality of consciousness is automatically fulfilled* in our relativistic biophysical model, according to which consciousness is inherently and globally related to the very *electromagnetic field* of the brainwaves ionic current! Having in mind that EM field is only one of the four manifestations of the unified physical field—it might be that the very *unified field* represents nonlocal internal collective conscious display for various physical processes at different structural levels, from microscopic to macroscopic ones.

This bizarre nonlocal pantheistic idea of consciousness can naturally help in resolving the fun- damental difficulties of the wave function reduction. In one of the most recent approaches, Penrose proposes gravitationally induced wave function reduction [24]. Actually, the gravitational field of the state of the observing apparatus Φ, with all possible observable outputs Φ_i, must be also involved in the superposition of quantum eigenstates ($\Psi\Phi = \sum_i a_i \Psi_i \Phi_i$)—which implies different space-time geometries superimposed. However, when the geometries become sufficiently different (on the Planck-Wheeler scale $\sim 10^{-35}$m), thus implying ill-defined standard superposition of the *matter* eigenfunctions in strictly separate spaces—Nature must choose between one of them and actually effects wave function reduction. Moreover, as microparticles are continuously subjected to fantastic accelerations ($\sim v^2/r \sim 10^{23}$m/s^2 for electrons bounded in atoms, and $\sim 10^{29}$ m/s^2 for protons and neutrons bounded in nucleus, ...), which can be met also in extremely strong gravitational fields—according to the Principle of equivalence one should expect [8] continuous opening and closing of local Einstein-Rosen bridges, addresses of their exits being related (probabilistically) to one of the possible eigenstates of corresponding microparticles. This process might yet be the mechanism for some sort of the wave function reduction, implying why so important the *mental addressing* is in transitional states of consciousness, described above (cf. footnote 3)! It also reveals that Quantum mechanics and the General theory of relativity seem to be deeply interconnected on microparticle level, showing that microparticles are continuously vanishing and reemerging (subjected obviously to corresponding conservation laws) in measurement-like interactions, throwing a new light on wave-particle dualism and other quantum mechanical phenomena.

In that framework, the role of consciousness in quantum theory of measurement turns out to be extremely important [8]! For instance, in gravitationally induced wave function reduction, the very mechanism for this process could be continuous opening and closing of local microparticles' Einstein-Rosen bridges, addresses of their exits being related (probabilistically) to one of the possible eigenstates Ψ_i of corresponding microparticles—and everything being related to corresponding probabilistic addressing Φ_i of "collective consciousness".

It should be noted that physical interaction of the displaced gaseous ionic "optical" neural network with possible "objective" system (described by possible wave function Ψ_i) or corresponding possible state of "collective consciousness" (Φ_i), during transitional states of consciousness—opens also a question on the nature of wave functions—which should provide a picture of quantum-level physical *reality* (not only serving as a calculational device, useful merely for calculating probabilities, or as an expression of the experimenter's "state of knowledge" concerning physical system)[7]!

[7]Then by changing initial state of "collective consciousness" (Φ) one can influence probabilities of realization of corresponding states Φ_i, i.e. possible objective states Ψ_i. As the state of "collective consciousness" (Φ) is a composite state constituted of (noninteracting) states of all "individual consciousness" (ψ_k), $\Phi \sim \prod_k \phi_k$, it follows that the change of state ϕ_k of "individual consciousness" can affect the state Φ of "collective consciousness", and therefore the probabilities for realization of possible objective states Ψ_i. This is particularly true if the state Ψ is very sensitive on small changes of initial conditions, which is the case for physical systems described by deterministic chaos [25]. Having in mind that the brain and corresponding state ϕ_k of "individual consciousness" is such kind of system, then the composite state Φ of "collective consciousness" is also described by deterministic chaos—and therefore very sensitive on small changes in initial conditions! Such a conclusion implies extraordinary practical significance of morals and contents of our "individual consciousness", as they directly determine the probability of realization of possible objective states Ψ_i, i.e. the future events, no matter how bizarre this conclusion looks like [8]!

5 Conclusion: Prospects for Brain-like Computers

Our biophysical analysis of the serial conscious psychological mode in normal and altered states of consciousness, implies that consciousness is a subtle display in the form of electromagnetic component of ULF ionic brainwave currents, embedded in ionic structure capable of (even distant) spatio-temporal displacements from the body in transitional states of consciousness. As rather complex ionic structure is necessary in these processes, it seems that biological molecular hardware will essentially determine further development of brain-like computers with artificial consciousness, in the form of neural networks with embedded brainwaves-like ULF ionic electrical activity. Such neural networks could emulate most of altered states of consciousness, which might be technologically multiplied in respect to human ability to control such states, by far surpassing human brain.

Besides having artificial consciousness, in transitional states of consciousness such nonprogrammable brain-like computers could be able to solve creatively even most subtle problems. It would be only necessary to "mentally" re-address the problem, to get the statistics of anticipatively obtained solutions: the most frequent one will be the optimal solution of the problem addressed. As the whole situation of probing the world of virtual possibilities[8] resembles on quantum theory of measurement, such creative brain-like computers with artificial consciousness might be named quantum computers.

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[8] What might be the physical nature of this world is still an open question, but one possibility is that it could be a world described by eigenstates Φ_i of "collective consciousness". This quantum mechanical wievpoint is supported by the computer experiments with random number generators, implying that only nonactualized possible futures can be anticipated (more accurately for a priori greater probabilities of their realization) [26]. What is actually anticipated in transitional states of "individual consciousness" might be the evolved state of "collective consciousness" $\Phi(t)$ in some future moment t (to which "individual consciousness" has access, being the constitutional part of "collective consciousness", cf. footnotes 5 and 6), which is quantummechanically described by deterministic unitary evolution governed by Schrödinger equation (or Dirac equation in relativistic case).

References

[1] HECHT-NIELSEN, R. 1990. Neurocomputing. Addison-Wesley. New York.

[2] JOHN, E.R. 1972. Switchboard versus statistical theories of learning and memory. Science 177:850–864;

JOHN, E.R., T. YANG, A.B. BRILL, R. YOUNG & K. ONO. 1986. Double-labeled metabolic maps of memory, Science 233:1167–1175;

ECKHORN, R., R. BAUER, W. JORDAN, M. BROSCH, W. KRUSE, M. MUNK & H.J. REITBOECK. 1988. Coherent oscillations: A mechanism of feature linking in the visual cortex? Biol. Cybern. 60:121–130;

GRAY, C.M., P. KÖNIG, A.K. ENGEL & W. SINGER. 1989. Oscillatory responses in visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. Nature 338:334–337;

CRICK, F. & C. KOCH. 1990. Towards a neurobiological theory of consciousness. Seminars in the Neurosciences 2:263–275;

CRICK, F. 1994. The Astonishing Hypothesis. The Scientific Search for Soul. Charles Scribner's Sons, New York & Maxwell Macmillan International.

[3] POPER, K.R. & J.C. ECCLES. 1977. The Self and Its Brain. Springer. Berlin. [Chs. E2,8];

BAARS, B.J. 1988. A Cognitive Theory of Consciousness. Cambridge Univ. Press. Cambridge, MA.

[4] TART, C., Ed. 1972. Altered States of Consciousness. Academic, New York.

[5] JASPERS, K. 1953. Allgemeine Psychopathologie. Springer, Berlin.

[6] MOODY, R.A., Jr. 1975. Life after Life. Bantam. New York;

MORSE, M. 1990. Closer to the Light: Learning from the Near-Death Experiences of Children. Ivy Books. New York.

[7] RAKOVIĆ, D. 1987. Biocomputers—the perspectives. Proc. 15th Yug. Conf. Microelectr. MIEL-87. 143–146. In Serbian;

RAKOVIĆ, D., DJ. KORUGA, D. DJAKOVIĆ, Ž. MARTINOVIĆ, V. DESIMIROVIĆ & DJ. MINIĆ. 1989. Ultralowfrequency "optical" biocomputers: Biophysical arguments. *In* F. Hong, Ed. Molecular Electronics: Biosensors and Biocomputers. Plenum. New York. 397–405;

RAKOVIĆ, D., DJ. KORUGA, Ž. MARTINOVIĆ & G. STANOJEVIĆ. 1989. Molecular electronics and neural networks: Significance of ionic structure. Proc. Ann. Int. Conf. IEEE/EMBS 11:1366–1367. *In* Y. Kim & F.A. Spelman, Eds. Part 4/6;

RAKOVIĆ, D. 1990. Neural networks vs. brainwaves: Prospects for cognitive theory of consciousness. Proc. Ann. Int. Conf. IEEE/EMBS 12:1431–1432. *In* P.C. Pedersen & B. Onaral, Eds. Part 3/5;

RAKOVIĆ, D. 1991. A cognitive theory of consciousness: Possible educational framework. Ibid. 2373–2374. Part 5/5;

RAKOVIĆ, D. 1991. Neural networks, brainwaves, and ionic structures: Acupuncture vs. altered states of consciousness. Acup. and Electro-Therap. Res. Int. J. 16:89–99;

RAKOVIĆ, D., DJ. KORUGA, Ž. MARTINOVIĆ & G. STANOJEVIĆ. On biophysical structure of brain-like biocomputers. *In* P.I. Lazarev, Ed. Molecular Electronics: Materials and Methods. 211–217. Kluwer, Dordrecht, The Netherlands;

RAKOVIĆ, D. 1992. Neural networks versus brainwaves: A model for dream-like states of consciousness. Proc. Ann. Int. Conf. IEEE/EMBS 14:2651–2652 (1992). *In* J.P. Morucci, R. Plonsey, J.L. Coatrieux & S. Laxminarayan, Eds. Part 6;

RAKOVIĆ, D. 1992. Neural networks versus brainwaves: Biophysical model for ELF interactions. Ibid. 2750–2751;

RAKOVIĆ, D. 1994. Neural networks, brainwaves, and ionic structures: Biophysical model for states of consciousness. Int. Conf. Toward a Scientific Basis of Consciousness. Tucson. April 12–17, 1994.

[8] RAKOVIĆ, D. 1995. Brainwaves, neural networks, and ionic structures: Biophysical model for altered states of consciousness. *In* D. Rakovič & Dj. Koruga, Eds. Consciousness: Scientific Challenge of the 21st Century. ECPD. Belgrade. 291–316;

RAKOVIĆ, D. 1994, 1995. Fundamentals of Biophysics. Grosknjiga. Belgrade. Chs. 5,6. In Serbian;

RAKOVIĆ. D. 1996. Hierarchical neural networks and brainwaves: Towards theory of consciousness. Proc. ECPD Seminar. 189–198. Lj. Rakić, D. Raković, Dj. Koruga, and A. Marjanović, Eds. In Serbian.

[9] LANDAU, L.D. & E.M. LIFSCHICS. 1973. Field Theory. Nauka. Moscow. Ch. 9. In Russian.

[10] Ref. 9. Ch. 1.

[11] ADEY, W.R. 1981. Tissue interactions with nonionizing electromagnetic fields. Physiol. Rev. 61:435–514, and references therein.

[12] Ref. 9. Ch. 6.

[13] BASAR, E. 1980. EEG Brain Dynamics. Elsevier. Amsterdam. Ch. 2.

[14] Ref. 4. Sect. 3. FOULKES, D. 1964. Theories of dream formation and recent studies of sleep conscious- ness. Psychol. Bull. 62:236–247.

[15] Ref. 4. Sect. 8.

[16] THORNE, K.S. 1994. Black Holes and Time Warps: Einstein's Outrageous Legacy. Picador. London. Ch. 14, and references therein.

[17] JAHN, R.G. 1982. The persistent paradox of psychic phenomena: An engineering perspective. Proc. IEEE 70:136–170.

[18] MARKIDES, K.C. 1990. Fire in the Heart. Healers, Sages and Mystics. Paragon House. New York.

[19] HAMEROFF, S.R. 1987. Ultimate Computing. Biomolecular Consciousness and Nanotechnology. North-Holland. Amsterdam;

KORUGA, DJ. 1990. Molecular networks as a sub-neural factor of neural networks. BioSystems 23:297-303.

[20] SCHWARZ, J.H. 1987. Superstrings. Physics Today. Nov.1987, 33–40, and references therein.

[21] WILBER, K. 1980. The Atman Project. Quest. Wheaton, IL;

VUJIČIN, P. 1995. States of consciousness in esoteric practice. *In* D. Raković & Dj. Koruga, Eds. Consciousness: Scientific Challenge of the 21st Century. ECPD. Belgrade; and references therein.

[22] WHEELER, J.A. & W.H. ZUREK, Eds. 1983. Quantum Theory and Measurement. Princeton Univ. Princeton.

[23] ASPECT, A., J. DALIBARD, & G. ROGER. 1982. Experimental test of Bell's inequalities using time-varying analyzers. Phys. Rev. Lett. 49: 1804–1807. *Also in* P. LAHTI & P. MITTELSTAEDT, Eds. Symposium on the Foundations of Modern Physics. 1985. World Scientific. Singapore.

[24] PENROSE, R. 1994. Shadows of the Mind. A Search for the Missing Science of Consciousness. Oxford Univ. Oxford. Part II, and references therein.

[25] BABLOYANTZ, A. 1988. Chaotic dynamics in brain activity. *In* E. Basar, Ed. Dynamics of Sensory and Cognitive Processing by the Brain. Springer. Berlin. 196–202.

[26] RADIN, D.I. 1988. Effects of a priori probability on PSI perception: Does precognition predict actual or probable futures. J. Parapsych. 52:187-212.

Model of the Neuron Working by Quantum Holography

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The objective is to predict the information processing morphology and dynamics of the human neuron as required by the model of the brain working by quantum holography set out in an earlier paper (Marcer and Schempp, in press), and summarised in section 2.
This model of a conscious system employing brain/mind interaction is in excellent broad agreement with the facts of human cognitive behaviour, neurophysiology and neuropsychology. This paper extends that agreement.

1 Introduction

Quantum holography which describes the processes of generalised holography by means of the standard quantum mechanical formalism compatible with the transactional interpretation (Cramer, 1986) incorporates signal theory into quantum physics (Schempp, 1986) by means of the spatio-temporal quantization procedure of Kirillov. It is an experimentally validated signal processing paradigm for the three dimensional encoding and decoding of information, defined by means of the mathematics of the Heisenberg nilpotent Lie group (Schempp, 1992). This specifies the symmetries for holography to be possible. An example is functional magnetic resonance imaging fMRI which concerns the resonant coupling of classical electro-magnetic fields with the quantum mechanical spin populations of soft tissues, where body and brain scan images are extracted as diffraction patterns (Schempp, 1997). Quantum holography is therefore a candidate information processing paradigm ideally suited to modelling the brain's perceptive and cognitive faculties including those of its sensory apparatus in the three dimensional world in which we live.

2 The Brain as a Conscious System Modelled by Quantum Holography

In holography, phase is the essential quantity of physical significance. That is, the principles concern whether signals in the form of waves are in phase or out of phase so as to reinforce or attenuate each other, and where wave interference patterns constitute holograms encoding the three dimensional shape and properties of objects.

The earlier paper (Marcer and Schempp, in press) was therefore able to conclude that the analogue information processing/phase dynamics controlling human organisms had reached an evolutionary stage where it operates by means of quantum non-local coherence on many scales. Thus in a model based on the emitter/absorber description of quantum mechanics (see Appendix), quantum non-local coherence applies from the whole brain down to what is traditionally the quantum level culminating in a Berry phase (Anandan, 1992)(Resta, 1997). Thus if the human organism is a quantum mechanical partially coherent whole as quantum holography requires, then the organism's geometric or Berry

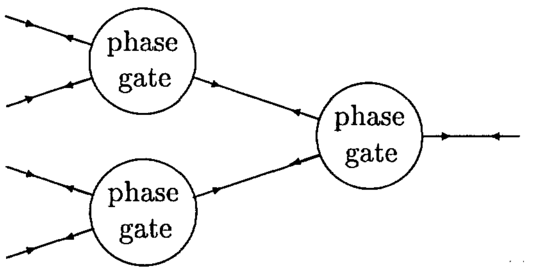

Figure 1: Phase gating *or lossless information processing where* ⟶ *indicates information is combined and* ⟵ *that it is filtered into its components parts. In quantum holography all signals are normalized and so from the viewpoint of the amplitude of the signal appear as a bit or sequence of bits. It is however the phase that conveys the information.*

phase consisting of a complete mental record of the history of the organism from its conception, constitutes the model for the mind. This overcomes the usual arguments that postulating an homunculus implies infinite regression. In the human organism, therefore, mental/mind events and processes, i.e. thought may control neural events and processes and vice versa.

In this control loop, it was shown that neurons acting as phase gates (Fig. 1), fulfil the dual functions of analysis and synthesis, filtering and combining respectively sensory data and thought to produce

a) a frequency oriented paged holographic associative memory in the form of synchronously partitioned dendrite arboresences, and

b) the incremental stream of conscious perception and cognition we all experience, using phase conjugate adaptive resonance.

That is the principal modes of phase conjugate adaptive resonance of the quantum holography taking place determine the stream of consciousness, while the less dominant modes proceed unconsciously so as to filter and taxonomize the data of sensory experience and thought onto the paged memory in accordance with sharp frequency adaptive coupling conditions. These modes expand and contract the neural and dendritic arboresences as sensory experience (i.e. neurally controlled processes) and thought (i.e. mentally controlled processes) dictate.

For this to be possible across the whole neural system, the paper showed, the activity/action potentials of the neurons must (in accordance with the information processing principles of quantum holography) correspond to the group of symmetries

$$X_v : C_G(0,0,z) \longrightarrow \exp(2\pi i v z)$$

which define the centre character X_v frequency $v \neq 0$ of the Heisenberg group G's one dimensional centre C_G of unipotent matrices

$$(0,0,z) \text{ where } (x,y,z) \text{ stands for } \begin{pmatrix} 1 & x & y \\ 0 & 1 & z \\ 0 & 0 & 1 \end{pmatrix}$$

which is the three dimensional representation of $G, i = \sqrt{-1}$, and x, y, z have their usual meaning of spatial measures.

That is, the z axis and the one dimensional centre C_G of G are identified with the axis of the axon of the neuron so that for any phase conjugate resonant frequency $v \neq 0, X_v$ determines up to a unitary isomorphism, a unique infinite dimensional irreducible unitary linear representation of the Schrödinger type U_v of G in the Hilbert space $\mathcal{H} = L^2(R)$ of square-integrable complex-valued densities on the real line R. $\overline{U}_v$, the contragredient representation of U_v, is then the feedback or back propagation representation of G and of the activity of the neuron, and

$$U_v/C_G = X_v \text{ and } \overline{U}_v/C_G = X_{-v}$$

are the centre character representations modulo C_G.

In this way in this model of the brain/mind, neural processes may control mental processes and vice versa, and

a) as shown, the action potentials of the neurons encode phase, the quantity of physical significance in holography, so as to act as phase gates (Fig. 1) to produce the reversible fan in/fan out assembly the holographic associative memory requires. This assembly filters and combines the sensory data and thought which consists of holographic interference patterns P_j, so that

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b) the brain or assembly of neurons may for the purpose of cognition function as a square law detector in relation to the Hilbert space $L^2(R)$. That is, the closest pattern $P_j, j = k$ to the pattern newly input will be incrementally amplified by adaptive resonance while the remaining stored patterns $P_j, j = 1$ to $n, j \neq k$ are simultaneously attenuated, and

c) the model has the advantage of allowing the brain/mind to utilise quantum non-local coherence to achieve the massive parallelism observed. This is quantum parallelism, such that in relation to simultaneous activity in geometrically separated brain segments and to affecting a "change of mind" (i.e. the shutting down of activity in one set of segments and replacing this by that in another set), these can be carried out instantaneously without the use of co-ordinating signals from a central control or switching centre as in a classical machine. That is, the brain/mind is a fully, distributed, synchronously partitioned, massively parallel processor and memory.

3 What is Quantum Holography?

In holography one records not the optically formed image of an object as in photography, but the object (image bearing) wave itself. This is done by mixing the wave with a separate coherent (non-object image bearing) wave or beam. Illumination of this record called a hologram with the corresponding coherent non-object 'anti-wave or beam' reconstructs the original object wave yielding the optical object image. This image is practically indiscernible from the original optically formed object image including three dimensional parallax effects. Of particular interest is phase conjugation (Pepper David, 1985), the condition whereby the object wave is returned in real or virtual form along its path, so the object image and the original object coincide.

In quantum holography, the above two wavelet mixing processes for the encoding and decoding respectively of three dimensional object images, are described mathematically via the usual quantum mechanical formalism. This provides a generic quantum specification of holography so that the optical process described above applies to any form of physical wave, electromagnetic, acoustic, chemical etc, and the condition of phase conjugation results in adaptive resonance. In particular, where wavelet mixing concerns a common source of waves to provide both the object illumination (and thus the object image bearing beam), and the (non-object image bearing) reference beam, quantum holography concerns non-local quantum coherence effects.

Quantum holography, a paradigm for the geometric encoding and decoding of information, can therefore be utilised to provide hypotheses concerning the morphology and dynamics of the brain/mind and the neuron, where its predictions are testable against the facts of cognitive behaviour, neurophysiology, and neuropsychology. The model exploits many of the most remarkable properties of quantum physics which classical physics and computation exclude, so that the brain/mind and the neuron are non-classical machines computing quantum mechanically in non-algorithmic mode by selection and adaption/learning. It will be objected that the brain and the neuron cannot work quantum coherently or by holography because they are far too noisy. In fact, holographic imaging through increasing inhomogeneity, called superresolution imaging (Leith and Chunha, 1989), employing phase conjugation, only serves to sharpen images, and so this widely quoted objection is almost certainly erroneous, especially as noise in actual neural assemblies is known to produce effects like those observed in superresolution, called 'stochastic resonance' (Moss and Pei, 1995). Thus it can be postulated that the behaviour of entropy as an information metric (Zurek, 1989a, 1989b) concerns this phase conjugate domain where quantum holography takes place.

It may also be objected that the brain/mind does not employ phase conjugation. However two simple perceptual experiments serve to show this too is erroneous:

a) Snap one's fingers and ask where the brain/mind creates the acoustic object image of the snap. Listen. It is outside the head coincident with the snap, as a phase conjugate image must be; similarly

b) reach out for a nearby object. Not only do the visual and the tactile object images the brain/mind creates coincide, but this coincidence is also with the object in every geometric particular with reference to the scale of resolution of which the senses are capable.

Phase conjugation must be of vital importance to the processes of image formation of the brain/mind or imagemaker, since the survival of the imagemaker is completely dependent on locating objects in three dimensional space where they actually are, whether it be by vision, sound or touch or even by taste or smell; that is, of sensing the world "the way it actually is".[1] Phase conjugation is also essential to communication between imagemakers. For what an imagemaker cognizes objects to be, depends entirely on the imagemaker's own history of experience. This history is unique, since each imagemaker follows its own unique position or worldline of motion and no two can be exactly the same. However what imagemakers share in common, on their own scale, is the objects of that scale and their positions relative to one another in the Cartesian theatre the objects define.

Thus according to the model, bats see acoustically "the same reality" we see visually but they attach totally different meaning to the objects seen as the result of their different genetic constitution, sensory apparatus, and their individual history of experience. Thus quantum holography provides a clear definition of objectivity and subjectivity since it is objects that implicitly label all aspects of experience in a universal way for all observers on that scale. Objects therefore provide a common labelling for the basis of all communication between such observers with a common genetic heritage and sensory apparatus, and languages are shared arbitrary labellings of objects and their properties such that

each holographic encoding of an icon or object ⇄ (maps to and from) the holographic encoding of the arbitrary label for that icon or object

It can therefore be postulated that the morphology of the human brain contains an instantiation of such mappings. That is, the two brain hemispheres and corpus callosum (which joins them) are where these encodings and the maps (to and from) respectively are realised. Thus the right hemisphere containing the holographic encodings of the real world is the artistic brain, and the left, containing the arbitrary labellings for real world objects and their properties is the logical brain since an essential element of such labellings of objects includes number and sets and their logical relationship or mappings one to the other. Thus quantum holography subject to phase conjugation specifies the mappings necessary to both geometry and logic, and provides the canonical labelling any model of information processing must have if it is formally and correctly to constitute computation. That is, quantum holography is indeed a well structured paradigm of universal information processing based on adaption/learning.

It is worthwhile emphasising that function magnetic resonance imaging (fMRI) (Schempp, 1997), already a most impressive way of realising quantum computation based on the Heisenberg group, is the hottest topic in cognitive neuroscience, for what, experimentally, it reveals (non-invasively) about the living brain, where, for example, complex areas such as the visual cortex, the motor strip and the silent speech area are being mapped. These mappings show a morphology and dynamics in accordance with the temporal coding principle of biological neural networks as discovered by Eckhorn, Singer and collaborators, von der Malsburg and others (Schempp, 1990); that is, timing is everything, as it is in fMRI itself. The application of these new image processing principles to the brain's and the neuron's own working, as postulated here, is therefore a natural progression.

The basis of the theory to be considered is therefore quantum holographic phase conjugate adaptive resonance (Schempp, 1992). This concerns a physically realisable form of image and signal processing based on an emitter/absorber

[1] These statements in quotes "..." are, the authors believe, fully justified, since phase conjugation ensures an ontological and epistemological equivalence. For example, the use of touch (where the tactile object image phase conjugately coincides with the object) invokes an opposing reaction to any action or vice versa—an essential criterion of experimental science. As Dr Johnson remarked as he kicked a stone when discussing Bishop Berkeley's solipsistic theory of the non-existence of the material world—"I refute it thus".

model of quantum holography defined by means of harmonic analysis on the Heisenberg nilpotent Lie group G, algebra g and nilmanifold (Schempp, 1986). G represents the non-commutative group of symmetries to analyse and synthesise in terms of the unitary dual of G, the convolution structure of the wavelets generated from the mother wavelet for the case of phase coherence under Fourier transform action F. Thus the case of the three dimensional Heisenberg group, representation

$$\begin{pmatrix} 1 & x & z \\ 0 & 1 & y \\ 0 & 0 & 1 \end{pmatrix} \text{ written as } (x, y, z)$$

models the conditions appropriate to macroscopic quantum field theory for the phase coherence/synchronisation necessary for the holography. Subject to phase conjugation such information processing constitutes analogue computation based on non-local quantum interference properties and adaption/learning rather than instruction/algorithms, because G implements in an appropriate gauge the symmetries of phase conjugate based adaptive resonance at the quantum level appropriate to any geometric scale (Schempp, 1992), (Schempp, 1986). Furthermore, when holography is performed by the excitation of stationary modes inside a wave-propagating medium with reflecting boundaries, phase conjugation occurs spontaneously and both virtual and real images of recorded information are elicited by wave diffraction (Noboli, 1985), (Noboli, 1987). Thus the theory used here is postulated to be a model of adaptive self-organisation appropriate to all geometric scales, and very applicable to the modelling of the image and signal processing capabilities of the brain/mind and the neuron as non-classical machines.

4 Applying the Quantum Formalism

The harmonic analysis on the Heisenberg group (Schempp, 1986) concerns holography defined quantum mechanically (Schempp, 1992), so that the phased two-time average of the holographic transform of the coherent two wavelet mixing

$\psi(t')dt' \otimes \phi(t)dt$

$|H(\psi, \phi; x, y)|$
(where ψ and ϕ are the wavefunctions)

provides the probability of detecting the wave quantum within the unit area attached to the point (x, y) of $R \oplus R$ the hologram plane, where the wavelet mixing takes place, and

$$H(\psi, \psi; x, y)$$

is called the holographic trace transform and models the classic beam-splitter quantum self interference experiment.

That is, it is a methodology applicable to all forms of waves (i.e. optical, acoustic, chemical etc. where the wave quanta are photons, air molecules, etc., respectively) provided the wavelets are coherent enough to form the required stationary quantum interference pattern necessary for the holography in the hologram plane $R \oplus R$ where the wavelet mixing takes place so that H exists, H_v concerns the probability of detecting a quantum frequency v, and

$$\psi \otimes \phi \xrightarrow[\text{maps onto}]{} H_v(\psi, \phi; x, y) =$$
$$\int_R \psi(t - x)\overline{\phi}(t) \exp(2\pi i v y t) dt$$

describes the first step in the angle-image encoding procedure of the holography taking place (Schempp, 1986), where i is the $\sqrt{-1}$. That is, x encodes the path difference, and y the phase difference between the two signals ψ and ϕ having the same frequency centre $v \neq 0$, and so constitute a Fourier duality pair (x, y) embedding the complex plane in G.

In this first processing step each object to be globally stored by means of the coherent object image bearing signal beam is encoded in the hologram prior to its recording by mixing it with an unfocused linearly polarised coherent non-object reference signal beam having a particular angle between its wave vector and the normal vector of the hologram plane $R \oplus R$.

Thus an empirically falsifiable prediction of the model is that the brain/mind's sensory apparatus are quantum holographic transducers providing coherent, non-object reference signal beams. It is known, for example, that the human ear gives out an acoustic signal (Hudspeth, 1989) which the model says is essential to the holophony by which the ear would work. Similarly it is known that the ear in its most sensitive frequency range is capable of detecting the acoustic motion of a single air molecule or acoustic quantum, and the eye of detecting an incoming sensory signal of a few photons in the visible spectrum.

Further quantum holography can be extended to partially coherent illumination by what is called superresolution imaging (already referred to) (Schempp, 1992), (Schempp, 1993) with a simple modification of the model already under discussion. This concerns the orthogonality or sharp frequency adaptive coupling conditions

$$\langle H_v(\psi,\phi;\,..)\,|\,H_{v'}(\psi',\phi';\,..)\rangle = \\ = \begin{cases} 0 & v \neq v' \\ \langle \psi\otimes\phi\,|\,\psi'\otimes\phi'\rangle & v = v' \end{cases}$$

on the hologram plane $R \oplus R$ for all ψ, ψ', ϕ, ϕ'.

That is the adaptive coupling conditions specify very narrow spectral windows or "pages" with no cross talk, so the encoding of data for a demultiplexing reference beam "write" and the decoding of data for a corresponding multiplexing reference beam "read" indicate that the holographic storage in the case of imaging through an inhomogeneity takes the form of a frequency organised page oriented memory, the co-ordinates of which are given by the reference beam angle to $dx \wedge dy$ at (x, y) of the hologram plane $R \oplus R$.

A further empirically falsifiable hypothesis of the model is therefore that the brain cortices and at a lower level of scale the nuclear membrane of the neurons are hologram planes $R \oplus R$ where neural and dendritic arboresences (tree-like structures) respectively constitute the sources of holographic signals of both object bearing and non object bearing beams for the holography taking place. Thus learning/thought as phase conjugate adaptive resonance would for example both inhibit and enhance dendritic branching and connectivity with the neural synapses weighting the various dendritic processes when activated according to the re-inforcement (positive or negative), that sensory experience and thought/learning produce. This would also be the case with respect to the neural arboresences and cortical columns of the brain's cortices. The latter is in accord with the experimental evidence showing that incoming patterns of data not matching the resonant properties of the cortical columns produce only very little excitory and inhibitory synaptic activity and thus that there is a functional separation of dissimilar synchronised signal components, as indicated in the sharp adaptive coupling conditions given above.

The Second Stage of Encoding and the Inverse Process of Decoding or Reciprocity Principle

In the case of non-superresolution imaging, the second stage of encoding and the inverse process of holographic decoding is described by the filtered back propagation formulae of phase conjugate degenerate coherent four wavelet mixing where

$$\iint_{R\oplus R} H(\psi,\phi;x,y)\exp(-2\pi iyt)\overline{\psi}(t-x)dx\,dy \\ = \overline{\phi}(t),$$

$$\iint_{R\oplus R} H(\psi,\phi;-y,x)\exp(-2\pi iyt)F\overline{\psi}(t-x)dx\,dy \\ = F\overline{\phi}(t)$$

hold and describe the harmonic analysis of the Fourier transform action F (Schempp, 1992). In the case of superresolution imaging, the degeneracy is removed and there is non-degenerate four wavelet mixing/multiplexing yielding the sharp frequency adaptive coupling condition as stated above (Schempp, 1992, 1993).

That is the expanded conjugate reference signal beam acts as a scanner for the readout so that the holographic decoding procedure reconstructs the complete wavefront (including the object image) as a consequence of the Fourier transform action F on the Schwarz space $S(R)$ of complex-valued C^∞ wavelet packet amplitude densities on the real line R which specifies the multiplexed signal energies, and where $S(R)$ is a dense vector subspace of the complex Hilbert space $\mathcal{H}$ of square integrable complex-valued densities $L^2(R)$ with respect to Lebesque measure $dt \in R$ under its natural isometric embedding.

5 The Model of the Neuron Working by Quantum Holography

In accordance with Fig.1 illustrating the neurophysiology and nomenclature, quantum hologra-

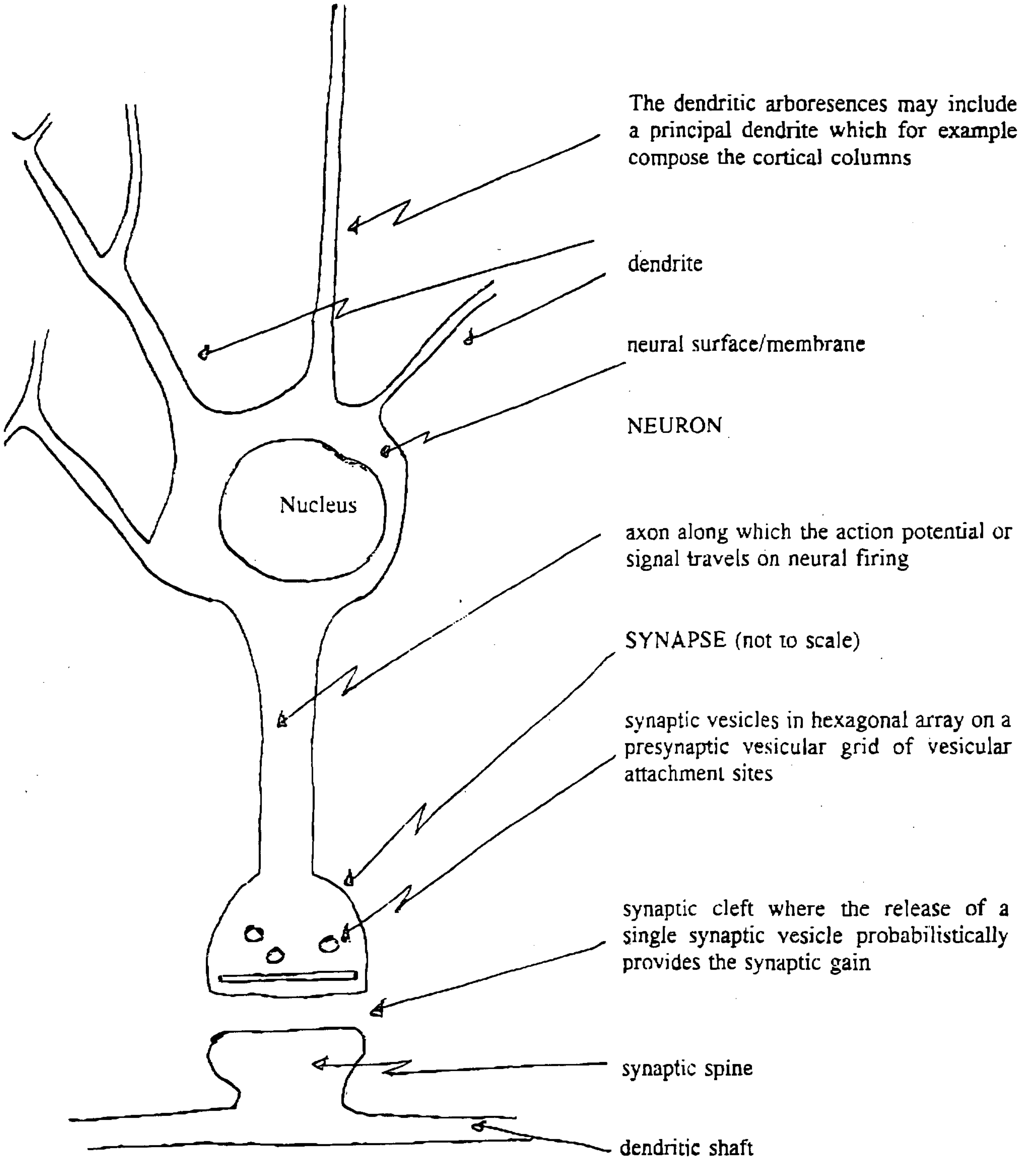

Figure 2: *Diagrammatic illustration of neurophysiological facts and nomenclature.*

phy identifies the various parts of the human neuron as functioning as follows, as summarised in Fig. 2. The mathematics follows that presented in (Schempp, 1992):

i) The neural surface/membrane is a hologram plane within the neural assembly/filter bank (Marcer and Schempp, in press), where the active dendrites provide the source of the beams for the wavelet mixing taking place. Thus, it can be postulated that, in particular modes of operation of the neuron, the principal dendrite and the axon of the neuron act as pump beams so that the remaining dendritic trees constitute a holographic filter bank/associative memory performed on the basis of wave front conjugation by means of real time quantum holography. The two pump beams, the axon and the principal dendrite to produce the required phase conjugation therefore are predicted to be co-linear and counterpropagating, and to overlap both spatially and temporally in the symplectic hologram plane $(R \oplus R, \Omega_v)$ where Ω_v denotes the symplectic or skew symmetry with respect to the frequency $v \neq 0$. For any other dendritic tree or beam, interference with each pump beam generates a transient phase grating consisting of a region of constructive and destructive interference corresponding to a modulation of the refractive index in the medium of the hologram plane. A probe beam is therefore deflected by the induced grating to produce a fourth wavefront conjugate beam which propagates back along the path of its own wave vector and is responsible for the modification or updating of the associative holographic memory/filterbank. Thus the modification or growth of dendritic trees takes place as sensory data is presented to the neuron. This growth may be positive or negative depending on whether the new data reinforces or attenuates the old.

ii) The neuron acts inside the neural surface or hologram plane as a resonating cavity such that the holographic associative memory has a net gain comparable with the losses within the cavity. That is in biological neurons which consist of neural membranes with holes through which ions or molecules may pass, the induced gratings above consist of real entropic holes or Maxwell demons (Marcer, 1992). These holes will open and close by means of the controlling inductions so as to admit or exclude particles according to the entropy production of the gain. Conversely such a gain inside the cavity can at the detection threshold regulated by the synaptic mechanism cause the neuron to fire releasing a signal along the axon.

In this case the images of the active probe beams of the associative holographic memory constitute the gain, and reverberate through the resonant cavity or neural body. Thus the strongest, i.e. greatest, complex-valued wavelet-packet density in the L^2 sense, is incrementally amplified and the others are incrementally attenuated so that before long only the probe beam corresponding to the best-matched example is left. In other words, at neural firing it is the stored image with the smallest distance to the input pattern which survives in mode competition at the expense of the more distant images. Thus, with respect to the cavity the output converges to a real image of a globally stored object and the best L^2 fitting holographic state vector appears at the entrance to the axon.

iii) This shows that axonal activity relates to the holographic trace transform $H_v(\psi, \psi; ..)$ and so compatible with the activity summarised earlier in relation to the brain as a conscious system, concerns the symmetries of the group of automorphisms of the nilpotent Heisenberg Lie group G which keep the centre C_G pointwise fixed. These symmetries, those of metaplectic group $Mp(l, R)$, the action of which in relation to the symplectic hologram plane $(R \oplus R, \Omega_v)$ preserves the centre frequencies $v \neq 0$ are described in the complex Hilbert space $L^2(R)$ by the metaplectic representation σ.

σ is a projective unitary linear representation of the symplectic group $Sp(l, R)$ the action of which includes dilations by real scaling factors $a \neq 0$ and the one dimensional Fourier transform F. Thus, the diagonal matrix

$$g_a = \begin{pmatrix} a & 0 \\ 0 & a^{-1} \end{pmatrix} \quad \text{in } Sp(1, R)$$

specifies the scaling or zooming identity $\sigma(g_a)\psi(t)dt = a^{-1/2}\psi(a^{-1}t)dt$ predicting the growth when ψ appears at the entrance to the axon.

For $g_0 = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$ of $Sp(l, R)$ such that

$$\sigma(g_0)\psi(t)dt = F\psi(t)dt \text{ for all } \psi \in S(R)$$

it can be shown that

$$\sigma(g_0^2)\psi(t)dt = -\psi(-t)dt.$$

This confirms that the hologram plane rotated 180^0 corresponds to time-reversed writing signals as is required if the neural body is to function as resonating cavity where the gain on one side of the plane is to match the loss in the page associative memory on the other and vice versa.

Similarly $g^u = \begin{pmatrix} 1 & 0 \\ u & 1 \end{pmatrix}$ are the generators of $Sp(l, R)$ where in radar applications $\sigma(g^u)$ defines the chirp-modulation operator

$$\sigma(g^u)\psi(t)dt = \exp(-i(u/2)t^2)\psi(t)dt$$

of chirp rate $u \neq 0$, and

$$\sigma(g^u) \in U(L^2(R)),$$

where U is U_v summed over v, therefore defines an up-chirp amplitude density modulation for $u < 0$ and a down-chirp amplitude density modulation for $u > 0$, and specifies the axonal signal. Further since it is known the chirp amplitude density modulation $u \neq 0$ is corrected by a thin cylindrical lens of focal length $f = l/u$, the drift-length transfer matrix $g = \begin{pmatrix} 1 & u \\ 0 & 1 \end{pmatrix}$ defines the identity

$$F(\sigma(g)\psi)(t)dt = \exp(-i((\pi/4)\operatorname{sign} u)\sigma(g^{-u})F\psi(t)dt$$

where $\operatorname{sign} u = u/|u|$, says that the axon itself is predicted to consist of a thin cylindrical lens of focal length f so ensuring the correct chirp amplitude density modulation travels along the axon when there is a Gouy effect of $\pi/2 = \pi/4 - (-\pi/4)$ in relation to the drift-length transfer matrix identity. This sets the criterion for neural firing.

The extent of growth of an axon can thus be interpreted as a correction process, so that the chirp pulse density

$$\sigma(g^u)\psi_T(t)dt \text{ of duration } T$$

admits the holographic trace transform

$$H(\sigma(g^u)\psi_T; x, y).dx \wedge dy$$

Since this trace transform describes the signal that enters the synapse, the synaptic bouton can be postulated by exact analogy to the neural body to be a reverberating cavity. It can then be shown in accordance with neurobiological fact, that on neural firing the quantum holographic model predicts such a reverberating cavity will release a single quantum or synaptic vesicle probabilistically from an hexagonal hololattice or presynaptic vesicular grid so as to provide a synaptic gain across the synaptic cleft equivalent to the loss in the bouton (Schempp, 1992). This confirms the postulate of Eccles (1986).

Finally the action of the axon as a cylindrical lens, is appropriate to the transfer of a tube of rays as a signal carrying information as was first discovered by Gabor in 1965. The model for these rays therefore corresponds to the fact that G carries a sub-Riemannian metric and a sub-Laplacian $\Box_G$, which is a subelliptic linear differential operator given by

$$\Box_G = \left(\frac{\partial}{\partial x} + y\frac{\partial}{\partial z}\right)^2 + \left(\frac{\partial}{\partial y} - x\frac{\partial}{\partial z}\right)^2$$

This says that on the fibre $T_{(x,y,z)}(G)$ with base point $(x, y, z) \in G$ of the cotangent bundle $T^*(G)$ of G, the associated bundled quadratic form Q is given by

$$Q_{(x,y,z)}(\xi, \eta, \nu) = (\xi + \nu y)^2 + (\eta - \nu x)^2$$

where (ξ, η, ν) denote real co-ordinates. Thus, there is a Heisenberg group helix in relation to this tube of rays that is the analogue of a geodesic for the sub-Riemannian geometry of G defined by the subelliptic bundled quadratic form Q on $T^*(G)$. This well defined mathematical structure for the behaviour of axon signals, therefore represents yet another level of prediction of the model, which can be subject to experimental validation. It can thus be postulated that the fibre $T^*_{(x,y,x)}(G)$ models a microtubule in relation to the structure of the axon, which will consist of a bundle $T^*(G)$ of such microtubules, and that $Q_{(x,y,z)}$ may even therefore model the tubulin dimers, since such dimers are arranged in a hexagonal lattice which is slightly twisted resulting in helical pathways which repeat every 3,5,8 and other number of rows.

The Principal Dendrite

This must be considered as part of the brain's morphology for a reference signal system sparsely linking together all segments of the brain and its sensory apparatus so that the processes of geometric encoding and decoding of the holographic signals takes place in a partially coherent fashion throughout the brain. For example, the sensory data arriving at the retina or visual sensory apparatus must be combined with a reference signal in order to carry out the four wavelet mixing taking place. Such a reference signal system is particularly necessary since such signals are concerned with the conversion of time in all wavefields with which they are combined—from sequence to information and vice versa (See Appendix). And since the brain works electrochemically, it points to the existence of a subsystem or organ (or possibly two one electrical, one chemical) as the source of such reference or normalising signals.

Earlier in the process of wave conjugation specified for holographic encoding and decoding, it was postulated that the axon and the principal dendrite played the role of pump beams, and hence from the above it is the principal dendrite that must perform the task of normalisation of the complex-valued wavelet-packet amplitude densities essential to the reciprocity principle which governs the angle-image decoding procedure. That is to say, the elementary holograms of the principal dendrite $H(H_m, H_n; ..)$ must form a Hilbert basis of the complex Hilbert space $L^2(R \oplus R)$.

The orthogonality of the elementary holograms $(H(H_m, H_n; ., .))_{m>0,n>0}$ in the complex Hilbert space $L^2(R \oplus R)$ implies that in the Shannon sense the mutual information of the code coefficients $c_{m,n}$ is zero. Such non-redundant code coefficients thus form a statistically independent ensemble and result in image coding in terms of the decorrelating family of code primitives $(H(H_m, H_n; ., .))_{m>0,n>0}$ that is optimally efficient. It follows that if

$$\psi = \sum_{m,n} c_{m,n} H(H_m, H_n; ., .)$$
$$\text{then } |\psi|^2 = \sum_{m,n} |c_{m,n}|^2$$

so that if one switches to the time asymmetic state vector reduction procedure of quantics, the probability that $\psi \neq 0$ in $L^2(R \oplus R)$ collapses to the elementary hologram H is given by the ratio

$$|c_{m,n}|^2 / |\psi|^2$$

Such a collapse will occur at neural firing, when the corresponding action of the axon or other pump beam is given by the one-dimensional unitary linear representations of the polarised Heisenberg group G in terms of the assignment

$$U(\xi, \eta)(x, y, z)\psi(t) = \exp(2\pi i(\xi x + \eta y)\psi(t) \quad (t \in R)$$

These representations which are irreducible, are called the representations of linear Fraunhofer type of G. Under the Kirillov correspondence they admit one-point coadjoint orbits

$$\{(O(\xi, \eta) = \varepsilon_{\xi,\eta} \,|\, (\xi, \eta) \in R \oplus R\}$$

in the singular plane $v = 0$ spanned by (P^*, Q^*) in $g^* = T^*_{(0,0,0)}(G)$ which form a set of Plancheral measure zero. The Plancheral measure π_G of G is uniquely determined by the Haar measure $dx \otimes dy \otimes dz$ and is concentrated on $R - 0$. It is given by

$$\pi_G = |v| dv.$$

The character formula of G provides the radial fan-in/fan-out distribution on the symplectic hologram plane $R \oplus R$

$$\varepsilon_{(0,0)} = \int_R Tr_{G/C} U_v d\pi_G(v)$$

that the axon must provide. These tempered distributions $Tr_{G/C} U_v (v \neq 0)$ follow from the trace identity for the linear Schrodinger representation U of the Heisenberg group G

$$Tr_{G/C} U = \sum_{n>0} H(H_n; ., .)$$

by time scaling $t = |v|t$ as is required by exact analogy with the description of what is taking place in the principal dendrite.

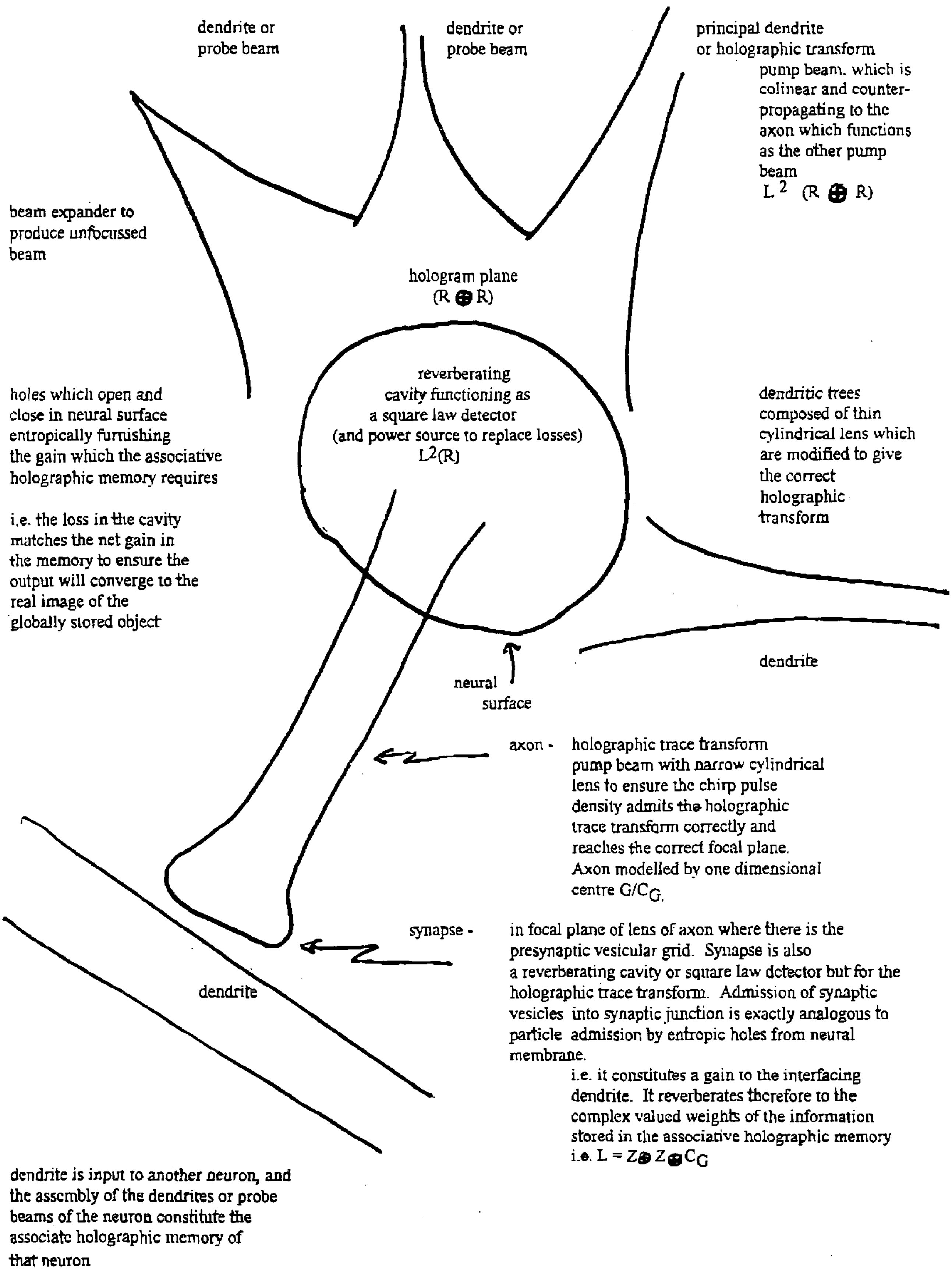

Figure 3: *Neuron performing quantum holography by wave conjugation.*

5.1 The Synapse

The above mathematics is the basis for the design of so called amacronics or micro-optic layers where the projection of the Kirillov corresponding paraboloids of revolution in the dual of the diamond Lie algebra along the axis permits the creation of microscopic multilevel surface-relief patterns of high-quality diffractive holographic optical elements or HOEs. The focal length f of the diffractive microlenses in such HOE arrays is then given (Schempp, 1992) by

$$f = |v|$$

and is therefore proportional inversely to the centre wavelength λ. The plane $v = 0$ in g^* therefore forms the focal plane layer of the amacrine structure, and thus such an amacrine structure can be expected in the synapse which will constitute that focal plane. This is indeed the case, since such synapses do indeed contain presynaptic vesicular grids which are hexagonal hololattices in the mammalian brain (Eccles, 1986). The synapse, as postulated earlier, consisting of a resonant cavity—the synaptic bouton—within which the amacrine structure of the hexagonal hololattices would on neural firing determine the release probabilistically of a single particle or synaptic vesicle to produce the synaptic gain across the synaptic cleft. This emergence of the synaptic vesicle or more precisely its contents into the synaptic cleft would be expected by exact analogy from an amacronic diffraction grating of entropic holes in the neural membrane predicted earlier. The opening and closing of the corresponding synaptic holes, or Maxwell demons, would admit the synaptic vesicle to the synaptic junction/cleft. Such a standardised mechanism/metric for the production of synaptic gain/weightings across a brain/neural network, is an essential requirement for its proper functioning.

From the Wiel-Zak isomorphism w between the linear Schrödinger representation U and the linear-lattice representation δ of G appropriate to the amacronics follows the identity

$$H(\psi, \phi; x, y).dx\,dy = \langle \delta(x, y, 0)w(\psi) \mid w(\phi)\rangle.dx \wedge dy$$

inside the pixel $]-1/2, +1/2]\times]-1/2, +1/2]$ in the symplectic hologram plane $R \oplus R$.

This therefore not only explains the hololattice structure of the amacronics of the presynaptic vesicular grid but would explain the pixelated nature of eye retina and the columnar structure of axons extending from the brain cortices.

It is this preceding identity, too, which has been used to show in mathematically rigorous way that the Bohr-Einstein dialogue can be decided in favour of quantum theory. The linear lattice representation δ of G overcomes the inadequacy of the classic Heisenberg uncertainty principle in describing by standard root-mean-square deviations the beam-splitter quantum-interference experiment and the holographic image-encoding procedure.

Indeed one can show by means of the Heisenberg group G, that the holographic image-encoding procedure implemented in the laboratory by a linear, Mach-Zehnder interferometer, generates an optical hologram if and only if quantum non-locality/parallelism holds between the reference and the object wavelets. And thus by configuring the neurons as described in this paper, one is able to use such quantum parallelism to activate all the appropriate neurons relevant to any massively parallel computation instantaneously, even though they are in quite spatially distinct segments of the brain. This can be observed in completely separated brain areas using tomography when the mind is changed, and was one of the principal reasons which led the Nobel Laureate neurophysiologist Sir John Eccles to postulate "Do mental events cause neural events analogously to the probability fields of quantum mechanics?".

Other Features of the Model

In fact, as already shown, the neuron may function as a more generalised "paged" associative holographic memory if the requirement for a spatially coherent wave source is dropped. Then the canonical differential 2-form on G/C_G becomes

$$w_v = v.dx \wedge dy \text{ replacing } w = dx \wedge dy$$

In this case for different centre frequencies $v \neq 0$, $v' \neq 0$, the symplectic affine planes are different and the irreducible unitary linear representations concern those of the non-unimodular affine Lie group

$$G_+ = \{(a, b)a \neq 0, b \in R\}$$

of the real line R ($at + b$ group). This is a non-Abelian solvable Lie group which may be represented as the group of real matrices

$$\begin{pmatrix} a & b \\ 0 & 1 \end{pmatrix}$$

under matrix multiplication. The left Haar measure of G_+ is given by $da \otimes db/a^2$ and the right Haar measure by $da \otimes db/a$.

Apart from the trivial one-point coadjoint orbits located on the real line R, the affine group G_+ of R admits exactly two non-trivial coadjoint orbits, the open upper half-plane O_+ and the open lower half-plane O_-. It follows from the Kirillov coadjoint-orbit picture of G_+ that every irreducible unitary linear representation of G_+ of dimension > 1 is unitarily isomorphic to either U or its contragredient representation $\overline{U}$ where U can be realised on the complex Hilbert space $L^2(R)$ by the assignment

$$U(a,b)\psi(t) = \exp(ib\exp(t))\psi(t + \log a)\ (t \in R),$$
$$\overline{U}(a,b)\psi(t) = \exp(-ib\exp(t))\psi(t + \log a)$$
$$\text{for } \psi \in S(R)$$

Both U and $\overline{U}$ are square integrable and their coefficient functions form the wide-band ambiguity functions.

The model of the neuron already presented is therefore essentially unchanged. It is however extended and simplified because only two unitary representations U and $\overline{U}$ cover the whole plane, and the role v the frequency in the action of such neurons is shown to be critical. It is also clear that the projective or dually affine Lie operators which enable the normalisation of non-Abelian gauge theories, provide the essential description of the mechanism of the entropic holes which open and close in the neural and synaptic membranes. A suitable wave analogy for such a dually affine Lie operator would in view of the above be a lens opaque or non-opaque to certain particles or molecules as indeed the case in biological membranes i.e. a threshold mechanism or logic.

6 Conclusion

The model of the neuron, (see Fig. 2), is therefore such that the action of the two reverberating cavities of the neural soma or body, and of the synaptic bouton, realise the projective or dually affine operator. Such projective or dually affine operations are those postulated by S. Amari (1991) in relation to the information geometry of the manifold of higher-order neurons, so providing independent confirmation of the model proposed.

This on going experimentally validatable mathematical explanation is in broad agreement with models of the brain and the neuron based

a) on Lie transformational theory in the extensive publications of W. C. Hoffman, and

b) of course the work and extensive publications of Pribram and his co-workers based on the quantum brain dynamics of Umezawa; Karl Pribram having first conceived of the concept of a holographic brain on the basis of the neurophysiological evidence.

These have proved inspirational as has the work of Sir John Eccles who has recently died, to whom this paper is therefore dedicated.

Appendix

Quantum mechanics is chosen as the basis for a model of the brain/mind and the neuron because

a) it offers the possibility of a dualist-interactionist model concerning both mental and neural events and processes,

b) the formalism can be used to define both digital and analogue (Deutsch, 1985),(Schempp, 1992) information processing to describe the brain/mind's image and signal processing capabilities,

c) it is now science's most established, accurate, tried and tested theory, and

d) the transactional interpretation (Cramer, 1986) is explicitly non-local and thereby consistent with recent tests of Bell's inequality, yet is relativistically invariant, fully causal and allows a long sought visualization of quantum phenomena denied not by the abstract quantum mechanical formalism, but by the Copenhagen interpretation.

The visualization chosen concerns the emitter/absorber model of quantum mechanics governed by the group of non-commutative symme-

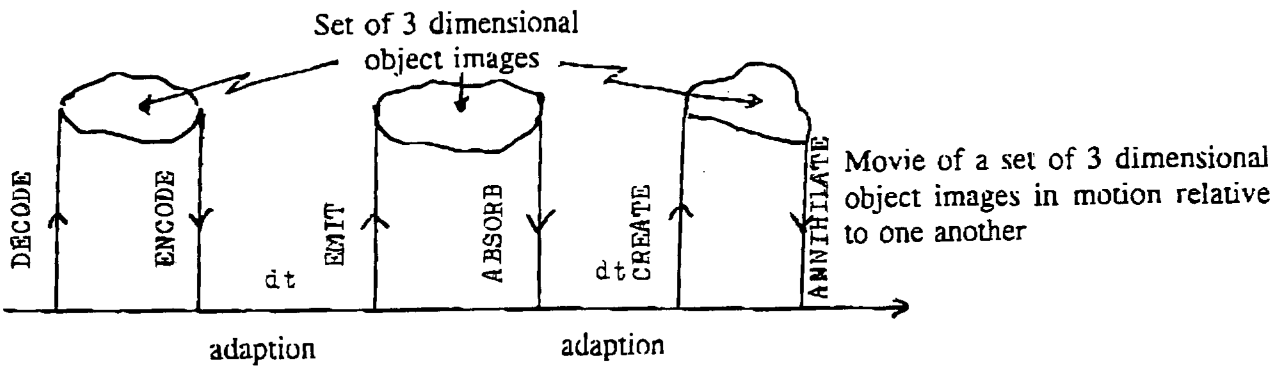

Figure 4: *This figure is a diagrammatic illustration of the emitter/absorber model of quantum holography mathematically set out in Appendix.*

tries that concern the three dimensional Heisenberg group applied to the processes of holography. This visualization therefore takes the format of a 3 dimensional movie, where each emission is a process of holographic decoding resulting in a set of three dimensional object images or movie frame, followed by an absorption or process of holographic encoding and a process of adaption to give the following movie frame (see Fig. 4).

Based on quantum interference and holism (as defined), it offers a solution to

e) the binding problem,

f) the unity of consciousness,

g) a physically valid model of external virtual projections in conscious perception which we set out to explain and which cannot be confined to the classical brain, and

h) the possibilities of non-local "anomalies" of consciousness, such as might apply to phenomena such as acupuncture, parapsychological and mystical altered states, for example (Raković, 1995).

The Emitter/Absorber Model of Quantum Holography (Schempp 1992, 1986)

The multiplicative group G of all unipotent real matrices

$$\begin{pmatrix} 1 & x & z \\ 0 & 1 & y \\ 0 & 0 & 1 \end{pmatrix} := (x, y, z)$$

with unit element (0,0,0) is a simply connected two step nilpotent Lie group diffeomorphic to the differential manifold $(R \oplus R) | \times R$ with one dimensional centre $C_G = \{(0,0,z) \,|\, z \in R\}$.

G is a realization of the three dimensional Heisenberg group.

The Haar measure of G is the Lebesque measure

$$dx \otimes dy \otimes dz$$

of the underlying differential manifold R^3 and the Lie algebra g of G is formed by the upper triangular matrices

$$\{(x, y, z) - (0,0,0) \,|\, x, y, z \in R\}$$

In terms of the canonical basis $\{P, Q, Z\}$ of g, given by the matrices

$$P := \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad Q := \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{pmatrix}$$

$$Z := \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

the Heisenberg commutation relations read as follows

$$[P,Q] = PQ - QP = Z;\ [P,Z] = 0;\ [Q,Z] = 0$$

and thus the centre c of the Heisenberg Lie algebra g modelled by Z is one dimensional and satisfies $\exp(c) = C_G$ under the natural Lie diffeomorphism.

The classic uncertainty principle takes the form of the Robertson relation

$$\Delta U_v(P).\Delta U_v(Q) > 1/2|U_v(Z)|\ (v \in R, v \neq 0)$$

where U_v is up to a unitary isomorphism a unique infinite-dimensional irreducible unitary linear representation of the Schrödinger type of G in the standard Hilbert space $H = L^2(R)$; Δ is the standard root mean square deviation and v is frequency.

That is, the standard quantum mechanical commutators of the group of symmetries of G are the structure relations of its Lie algebra g as was known to Weyl in 1928.

The emitter/absorber model then results by the introduction of the usual complex mode coordinates

$$R = 1/2(P+iQ) \text{ and } R^+ = 1/2(P-iQ)$$

These permit the different alternatives at the photon level that can co-exist in quantum complex linear superposition to be expressed in terms of the annihilation and creation operators of the emitter/absorber model

$$a = U(R);\ a^+ = U(R^+)$$

through the linear Schrödinger representation U of G where in terms of the number states $|n_k\rangle$ which are quantum states with n_k quanta occupying the mode k, these number states are the eigenstates of the number operator

$$N_k = aa^+ \quad \text{and} \quad [a, a^+] = \pi$$

is the bosonic commutation relation.

And thus if $H_v(\psi, \phi; x, y)$ expresses the probability of detecting a photon of energy hv within a unit area attached to (x,y) in the hologram plane $R \oplus R$, where wavelet mixing $\psi \otimes \phi$ takes place, then $H_v(\psi, \phi; ., .)$ and $\overline{H}_v(\psi, \phi; ., .)$ respectively can be considered as the wavelet transform of the retarded signal $\psi \in L^2(R, dt)$ with respect to the advanced reference response wavelet $\overline{\phi} \in L^2(R, dt)$ and vice versa so that time averaging performed by integration along the whole real line R by superposition of the net wavelets, which is expressed in the modular scalar product $\langle\ \rangle$ of the complex Hilbert space $L^2(R, dt)$, effectively freezes the time t of the advanced signal wavelet packets and the retarded response wavelet packets into the spatial synchronization variables (x,y) of the symplectic hologram plane $(R \oplus R, v.dx \wedge dy)$ where $v \neq 0$ is the frequency which concerns superresolution imaging through inhomogeneity. Thus the spatial encoding of the relative phase avoids the loss of phase information under wave packet reduction and the knowledge of the co-ordinates (x,y) with respect to the symplectic frame allows the identification of the split photon channels in accordance with the non-local quantum property of individual photons passing by different pathways, i.e. locally recording (x,y) makes the multiplexing coherent wavelet packet densities $\psi(t')dt'$ and $\phi(t)dt$ indistinguishable by relative time and phase corrections to the respective pathways. This conservation of information on wave packet reduction is the truly remarkable feature of quantum holography and of gating in this way by phase. It allows the brain/mind to function as a fully distributed, synchronously partitioned massively parallel processor as already described.

It also means because of the natural Lie diffeomorphisms (i.e. differentiable mapping with a differentiable inverse), G is such that

$$\begin{array}{lll} \exp : g \longrightarrow G & \text{and} & \log : G \longrightarrow g, \\ \exp : c = C_G & \text{and} & \log : C_G = c \end{array}$$

i.e. this form of holographic encoding, decoding and transmission of signals allows the treatment of arbitrary or exponential towers of complexity, i.e. it implies the essentially unlimited compression of data with regard to signal transmission and memory, because, at its most primitive level, the two, as in the brain/mind's dendritic arborescences, are one and the same.

References

[1] ANANDAN, J. 1992. The geometric phase. Nature 360:307–313. November 26.

[2] AMARI, S. 1991. Dualistic geometry of the manifold of higher-order Neurons. Neural Networks 4:443–451.

[3] CRAMER, J.G. 1986. The transactional interpretation of quantum mechanics. Review of Modern Physics 58:3:647–687. July.

[4] DEUTSCH, D. 1985. Quantum theory, the Church-Turing Principle, and the universal quantum computer. Proc.Roy.Soc.Lond. A 400:97–117.

[5] ECCLES, J.C. 1986. Do mental events cause neural events analogously to the probability fields of quantum mechanics? Proc.Roy.Soc.Lond. B 240:433–451.

[6] HUDSPETH, A.J. 1989. How the ear's world works. Nature 341:397–404. October 5.

[7] LEITH, E. & A. CUNHA. 1989. Holographic methods for imaging through inhomogeneity. Optical Engineering 28:6:574–579.

[8] MARCER, P.J. 1992. Designing new Intelligent Machines—the Huygens' Mmachine. CC-AI Journal 9:4:373–394.

[9] MARCER, P.J. & W. SCHEMPP. The brain as a conscious system. Intern. J. General Systems. In press.

[10] MOSS, F. PEI XING. 1995. Stochastic resonance—Neurons in parallel. Nature 376:211–212. July 20.

[11] NOBOLI, R. 1985. Schrödinger wave holography in brain cortex. Phys. Rev. A 3:6:3618–3626.

[12] NOBOLI, R. 1987. Ionic waves in animal tissue. Phys. Rev. A 35:4:1901–1922.

[13] PEPPER, DAVID M. 1985. Non-linear optical phase conjugation. Laser Handbook 3. North Holland. Amsterdam.

[14] RAKOVIĆ, D. 1995. Brainwaves, neural networks, and ionic structures: Biophysical model for altered states of consciousness. *In* D. Raković & Dj. Koruga, Eds. Consciousness : Scientific Challenge of the 21st Century. 291–316. ECPD of the United Nations University for Peace. Belgrade.

[15] RESTA, R. 1997. Polarization as a Berry Phase. Europhysics News 28:18–20. See inset p.19.

[16] SCHEMPP, W. 1986. Harmonic analysis on the Heisenberg group with applications in signal theory. Pitman Research Notes in Mathematics Series 14. Longman Scientific and Technica. London.

[17] SCHEMPP, W. 1990. "Quantum Holography and Neurocomputer Architectures" Holography. Commemorating the 90th Anniversary fo the Birth of Dennis Gabor. P. Greguss & T.R. Jeong, Eds. SPIE Institute Series 1S8:62–144. SPIE. Optical Engineering Press. Bellingham, W.A.

[18] SCHEMPP, W. 1992. Quantum holography and neurocomputer architectures. Journal of Mathematical Imaging and Vision 2:279–326.

[19] SCHEMPP, W. 1993. Bohr's indeterminacy principle in quantum holography, self-adaptive neural network architectures, cortical self-organisation, molecular computers, magnetic resonance imaging and solitonic nanotechnology. Nanobiology 2:109–164.

[20] SCHEMPP, W. 1997. Magnetic Resonance Imaging: Mathematical Foundations and Applications. John Wiley. New York.

[21] ZUREK, W.H. 1989a. Thermodynamic cost of computation, Algorithmic Complexity, and the information metric. Nature 341:119–124. September 14.

[22] ZUREK, W.H. 1989. Algorithmic randomness and physical entropy. Phys. Rev. A 40:8:4731–4751.

Some Brief Remarks on Information and Consciousness

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This paper is an outline for the examination of the validity of some fundamental assumptions encountered in the computational approach to consciousness.
The chief point is that the existence of two distinct and irreducible kinds of interactions, rules out the possibility of a computational strategy in the modelling or simulation of the energetic complexification of natural systems.
The work of Schempp on the use of group transforms for bridging the gap between adjacent strata in any energetic hierarchy is cited as the model for the analysis of the relation between consciousness and the physical substrate where information is generated.

1 Introduction

Information and consciousness are two notions that play a significant role in the scientific study of the human mind, the former denoting a causal source of inputs for the latter. Alternatively, one may view the former as the (physical) substrate out of which consciousness emerges. Other formulations are possible, but in each of them the dichotomy of the ontologies of the physical and the mental worlds remains, and it is in those terms that cognitive science approaches the problem of consciousness (even reductionist strategies presuppose the dichotomy, which is based on observables[1]).

The difficult question of course is to trace the path that links these two kinds of world. A large part of its difficulty has its origin in the complexity of the mind itself and in that of the organism that is said to have the mind. So it may be desirable to narrow down the focus of the enquiry to a single aspect of the problem, and to define the terms accordingly.

Two assumptions are widely shared by most of those who ponder such questions. The first one is that all natural processes are computational in nature. It is an assumption in the sense that, although it is an empirical claim about nature, it stands in need of justificatory evidence, for no compelling one has yet been offered. The second assumption that needs to be spelled out is more complex: it is that the mind is *constitutive of a natural system*, i.e. a human organism, and that it can be regarded as an emergent property of it. It is *emergent* in the sense that it is not distributed over any of the components of the organism, but is observable only in the whole living organism for which it provides a criterion of specific identity. This is an assumption because the claim of the mind's emergent status, which is reasonable given the evolutionary character of Nature, is something that remains to be substantiated, both theoretically and observationally.

Putting these two assumptions together leads straight to the situation to be examined in this paper: namely, that the emergence of the mind in a human organism is the result of natural processes that are computational in nature. If this is so, then the project of simulating consciousness by means of computational strategies is eminently reasonable and should be pursued, the benefits to

[1] Cf. e.g. Abner Shimony: *On Mentality, Quantum Mechanics and the Actualization of Potentialities* in R. Penrose (1997): The Large, the Small and the Human Mind (Cambridge: CUP), 144–148.

be derived therefrom being non negligible[2].

In what follows, I should like to adduce some reasons why this enterprise is likely not to succeed. In a coda, I will then point to some alternative strategies that are more promising, especially if they are coordinated.

The architecture of my argument is as follows (in Sections): (2) Definitions to set the stage; (3) The physics of the underlying substrate; (4) The limitations of digital computing; (5) The coda: wherein the future of this probe is likely to hide.

2 Definitions

It is desirable at the outset to introduce some key terms by way of definitions. In what follows, *information* is to be understood as a set of physical objects, such as data points, that are givens of experience or observation. A *cognitive sequence* is to be construed in the present context as an ordered sequence of physical objects, for example, as a particular set of ordered data points. More specifically, a cognitive sequence is ordered in terms of some *conceptual structure* which is projected onto the informational substrate to yield *intelligence* (Farre 1997b). Cognitive sequences are therefore conceptually laden (whence their name), their formal or intelligible aspect belonging to a different ontological domain from that of the underlying information. The ground for these distinctions is to be sought in the laws of Nature, and in particular in the existence of energetically hierarchized systems, to which I now turn.

3 The Physics of the Substrate

In this century, enormous progress has been made in our understanding of the ways of Nature and in the characteristics of the interactions that make the kind of world we live in possible. For example, it is a well established fact that without the Pauli exclusion principle, there would be no Mendeleev table of elements, and thus no chemistry nor all that it entails.

[2]For example, the exploration of deep space by intelligent robots that do not require either a life support system nor excessive shielding from radiation. The same would apply, *mutatis mutandis*, to the clean up of such sites as Chernobyl.

Perhaps more to the point, work done in recent decades in particle physics and in the physics of condensed matter has shown conclusively, first that Nature, defined in terms of observable interactions, is energetically stratified and second, that these strata can form energetically hierarchized systems, each emergent stratum being less energetic than the causal substrate on which it rests. Consequently, each stratum is characterised by its own set of laws, making the different strata inherently irreducible to one another. Because of the importance of these results for the question being examined, and because of their relative novelty for scientists from outside the physics community, a brief elucidation of these claims may be useful at this point (Belokurov & Shirkov 1991).

Laws of Nature may be distinguished from laws and principles of science by the fact that they are validated by cognitive sequences, i.e. they are expressed in terms of events (i.e. observables, data points, etc) (Wigner 1967). Laws of science, on the other hand, represent characteristic features of the scientific theories and models of Nature, whose relation to events is mediated by the laws of Nature. For example, extrema principles (e.g. Fermat's, Maupertuis'); the Pauli exclusion rules referred to above; symmetry groups; etc., may all be regarded as laws of science rather than of Nature, for they stand at some remove from events got in observation.

Laws of nature have, *inter alia*, two remarkable features which are of particular relevance to our present concern: they exhibit *specific symmetry* properties and they are applicable within a *well defined energy range*, outside of which they fail to represent patterns of events, and thus cease to be applicable (Anderson 1972).

These two characteristics warrant the representation of these laws by specific *symmetry groups*, a property first recognized by Poincaré in the Lorentz's equations for the electromagnetic field (the expression 'the Lorentz group' is due to him). Einstein was the first to introduce the group theoretical approach as a strategic instrument in the formulation of physical theory, a practice that has now become general in physics.

The *well defined energy range* of the laws of Nature was first discovered observationally, then accounted for theoretically as the Renormalization Theory and brought to successful completion in the seventies (Cao and Schweber 1993; Schweber 1995). As previously mentioned, its chief result from our point of view is that the interactions governed by these laws are specific to each stratum, so that the events mapped within them belong to a specific science (Schweber 1993). So far, four fundamental energetic types of interactions have been identified[3]; strong, weak, electromagnetic and gravitational, each obeying different laws represented by specific symmetry groups (Steiner 1989).

Notwithstanding the distinctive specificity and the consequent irreducibility of energetic strata, the existence of *natural energetic hierarchies* is symptomatic of the existence of an effective coupling between their different levels. However, this coupling is unlike that found to exist within the constituents belonging to the same energetic stratum, as for example oscillators; rather it appears that interactions within each stratum are largely autonomous and reasonably independent of those taking place in strata adjacent to it, in the sense that the specificity of the laws governing the interactions within them is not substantially affected (Schweber 1995). This is one of the most distinctive features of these systems[4].

Energetic hierarchies come about as a consequence of the existence of two main types of natural interactions. (a) First, there is the type made familiar by classical and relativistic mechanics, which are used to articulate the fundamental laws of nature effective within the confines of specific strata. Let these interactions be labelled *intralevel.* They define what may be considered the *classical* type of interactions, in the sense that we know how to represent them, and thus how to exploit their properties for modeling and related purposes useful for an understanding of Nature.

(b) Then, there is the type of interactions that binds the various strata together to form a single stable system within its energetic environment[5]; these will be referred to here as *inter-level.* This type of interaction, unlike the preceding one, bridges the energy gap between adjacent strata; it is accompanied by *symmetry breaks*, each stratum being characterised by specific symmetries, as previously noted.

These interactions are not governed by laws that can be represented mathematically in the same way as those that take place within a single energetic stratum. For such laws must be projectible onto a single semantic space (Farre 1996, 1997a), something which cannot be done if the observer is on one side of the energetic gap and the observation space on the other (Wigner 1967).

The difficulty is that we do not know how to represent these interactions in a manner that is consistent with the strict requirements of scientific discourse (Farre 1997b). We don't know how they are structured: a chief difficulty being that there is no type identification possible for events taken from the causal stratum and paired with others taken from the emergent one, a feature familiar to cognitive scientists as well.

Yet there persists the belief among many researchers that the gap between adjacent strata can be bridged by computational techniques, by which are meant the use of digital machines, such as the Turing machine and its variants (von Neumann, distributed parallel networks, etc.). This belief is based, more or less explicitely, on the assumptions mentioned in the beginning, that all natural processes are computational in the Turing sense. There is now evidence that this combined set of assumptions is not consistent with what is observed.

4 The Limits of Computation

The inadequacy of the computational approach should not come as a surprise, and this for several reasons, of which I will only sight a few.

[3]Three, to be more precise, since the discovery that the so-called weak force and the electromagnetic force are the same energetic type (Cf. Feynmann).

[4]We are talking here of energetic hierarchies, i.e. vertical ones, by contradistinction with the so-called lateral or branching hierarchies, which result from the same type of interactions, and unfold within the same energetic stratum. To help fix ideas, we may say that an inorganic molecule is an example of a lateral hierarchy, whereas an atom is an example of an energetic one, its internal structure being accountable in terms of laws not obeyed by the atom itself in its relation to other atoms.

[5]All observable systems exist within a pre-existing environment constituted by the universal (or background) radiation field internal to the universe. This primal environment is subsequently modified in significant ways by the specific characteristics of each emergent system, in particular by the appearance in its surround of various fields, e.g. gravitational, magnetic, etc. (Farre 1996).

(a) First, there are well known *limitations theorems and principles* (Gödel, Church, etc). When these are interpreted in Turing terms, they demonstrate the limitations inherent in strategies based on this mode of computation (Penrose 1989, 1993, 1994; Deutsch 1985; Deutsch & Jozsa 1992). And although a quantum computer can do calculations that are not possible for a Turing machine, these limitations apply to them *mutatis mutandis* since neither of these computers can exceed the bounds of computability theory (Penrose 1993b).

Some people have argued, Penrose preeminently, but others as well (Penrose 1990; Squires 1990, 1993), that the implications of the limitation theorems are such that the natural processes involved in the relation of mind to its substrate cannot be construed as computational in the ordinary sense, but that they are governed by laws that differ markedly from those now familiar to us. It should be clear, from has been said already, that interlevel interactions, which involve symmetry breaks, are among those the new physics is meant to look for.

(b) Additional considerations cast doubt on the correctness of the assumptions underlying the computational construal of the relation of information to consciousness. The belief that natural interactions and processes can be modeled by computational strategies is, at first blush, implausible. For gap bridging interactions relate, not singular events, but patterns of them. Some of these, sited in a causal stratum, are related to others sited in an emergent stratum where they order different types of events more directly accessible to the observer. The specific constraints on the interactions responsible for these patterns in the causal stratum, which are inherent in the emergence of the conjugate endogeneous characteristics of the more complex system, have a purely internal origin, energetic hierarchies growing from the bottom up[6] (Farre 1996). While these patterns can be represented by known laws of Nature, their transformations from one energetic milieu to another cannot, and no amount of wishing it to be otherwise can advance our understanding of Nature (Penrose 1990).

(c) Even if a morphism linking the two kinds of patterns were to be articulated in a form that is causal in the scientific sense, it could not be validated either empirically or computationally. First empirically, because observations (which are interactions) across energetic boundaries could not be carried out[7], the observer always being on one side of it and the events to be observed, which are internal to the system, are on the other. Second computationally, because such strategies exploit the properties of recursive functions, a use which dictates that inputs and outputs be given the same semantic interpretation. However the representation of gap bridging causal interactions, which do not themselves give rise to either events nor to patterns of them, calls for a more complex semantics, one spanning two irreducible universes of discourse a situation where recursive processes are patently inapplicable.

These considerations, jointly and individually, point to the ineluctable fact that computations, useful and even essential as they may be for the modeling of intralevel interactions and for the simulation of lateral complexification (branching), are quite useless when it comes to the modeling of gap bridging interactions. Yet, these processes are fundamental to an understanding of Nature and to its evolutionary history, punctuated as it is by the emergence of new, more complex energetic hierarchies. For there is more to natural processes than is dreamt of in the whole theory of computation.

What kind of laws are we seeking here? No one knows yet, though we do know a few things about them; for instance that they bridge energetic gaps, a process that entails breaks in specific symmetries. We also know, based on the nature of the physical substrate of any kind of observable system, that these interactions are quantal rather than classical. They belong to a world that is strange when compared to the one we live in, and our intuitions about it are still in the formative stage.

In the past few years, much thought has been

[6]All observable systems exist within a pre-existing environment constituted by the universal (or background) radiation field internal to the universe. This primal environment is subsequently modified in significant ways by the specific characteristics of each emergent system, in particular by the appearance in its surround of various fields, e.g. gravitational, magnetic, etc. (Farre 1996).

[7]An energetic boundary may be defined in this context as the boundary of a complex system separating two distinct energetic milieux in which internal interactions exhibit different specific symmetry properties.

given to these and related matters in the physics community, though no general resolution has yet been agreed upon, and so I will not say much about them in this paper. Nonetheless, some of the tacks taken by researchers are worth mentioning, however briefly.

One tack frequently taken rests on the same assumptions as the computational strategy referred to earlier. In Quantum computing, q-bits play the key role, and logic gates are designed to make the theory of computability applicable. In such cases the limitation theorems apply with full force, and so the gains to be obtained through these efforts, should they ever materialize, are not of such a nature as to constitute a breakthrough sufficient to vindicate the belief in the computational character of natural processes.

An alternative strategy is to modify the sense of the expression 'computability', and to so generalize it as to be in a position to exploit the phase characteristics of the wave function. This is somewhat opaque, a chief difficulty being the so-called 'collapse of the wave front', a phenomenon which still has the character of a mystery.

A further difficulty with this strategy comes from the non-local character of QM, which is at variance with the constraints of the theory of relativity regarding the speed of light. In either case, it should be clear that to the extent that Quantum Physics describes, however incompletely, the nature of reality, quantum computation is not to be construed in the way traditionally imagined when it is said that natural processes are computational in nature.

An experiment, which embodies the quantal paradigm and all of its mysteries, is that of the double slit. Its analysis involves the principle of superposition, wherein phase relations play the key role. I shan't go into the details of this, and instead refer the interested reader to a short bibliography (Squires 1990, Maudlin 1994, Schempp 1996). What the clarification of the mystery calls for, among other things, is a reinterpretation of quantum mechanics, a process now well underway (Bohm 1984; Cramer 1986; Aspect 1990; Schempp 1996; Gershenfeld & Chuang 1997; Cory et al 1997).

In this spirit, I'll also leave aside energetic considerations, which would take us too far afield and require a different treatment than is possible here, even though they play a key role in the asymmetry of the energetic boundaries which separate the internal régime of dynamical systems from their less dynamical environment. Coda: Wherein the Future is Likely to be Hiding In closing, I should like to make brief mention of two developments that hold the promise of opening the way to an understanding of the pervasive and largely ignored gap-bridging interactions. One is the strategy recently detailed by Walter Schempp in the case of NMRI (Schempp 1997); the second, a new appreciation of the implications of the violation of Bell's inequalities.

First to the strategy developed by Schempp. It is a mathematical treatment designed to represent how a pattern of events at a quantum level, in this case the patterns due to the precess-ion of protonic spins under the influence of magnetic stimulation, are causally related to patterns found in NMRI at the macroscopic level of the tomographic slices. In the terms of what has been said, this involves interactions between two energetically distinct strata, each of which is characterized internally by different kinds of interactions. Since events in each stratum cannot be correlated according to type with events in the other stratum, Schempp's original strategy is to account, not for the individual events, which are accountable for in terms of intralevel interactions, but for patterns of events specific to each stratum[8]. This he shows by the way these patterns can be transformed as one crosses the energy gap between the micro and macro worlds. The basic causal groupoid is the *Heisenberg nilpotent Lie Group* G, which represents the quantum electrodynamical interactions responsible for the pattern of protonic precession. It is transformed through a series of astute mathematical moves. A Fourier non commutative analysis creates a bank of unitary filters in the symplectic affine space, where they are implemented in the form of a phase differentiated network. This makes possible the identification of the coadjoint orbit fibration in the dual Lie group G^* of the Heisenberg Lie Algebra with

[8]This strategy is, interestingly enough, implicit in the work of one of his distant forebears, J. Keppler, on the determination of planetary orbits using the area law. Cf. Schempp. W. (1996): Mysterium Cerebrotopographicum, in N.A. Kuznetsov, V.A. Soifer (eds): SPIE-The International Society for Optical Engineering, Volume 2363, 13–30.

the stack of energy strata constituting the observable tomographic slices, now lying open to a different kind of analysis in the observation space of the emergent level.

A further avenue of research in interlevel interactions, alluded to earlier, lies in the transactional interpretation of quantum theory in the light of the works of Cramer, Bell and Aspect (Bell 1987; Aspect 1982, 1990; Cramer 1986). It is still too early to venture predictions along this line of research, but a return to the intuitions of Schrödinger concerning the undulatory character of matter, and to those that guide many quantum field theorists, hold the promise of a new kind of causal interactions that are non local in the traditional sense, with all that this might entail. In any case, the work of Schempp remains of fundamental importance, and its generalisation is likely to be the cornerstone of the science of evolution, properly understood.

References

[1] ANDERSON, P.W. 1972. More is different: Broken symmetry and the nature of the hierarchical structure of science. Science 177:40–47.

[2] ASPECT, A. & B. GRANGIER. 1990. Wave-particle duality: A case study. *In* A.I. Miller, Ed. Sixty Two Years of Uncertainty. Plenum. New York.

[3] ASPECT, A., J. DALIBARD & G. ROGER. 1982. Experimental tests of Bell's inequalities using time-varying analyzers. Physical Review Letters 49:1804–1807.

[4] BELL, J.S. 1987. Speakable and Unspeakable in Quantum Mechanics. CUP. Cambridge. Cf. in particular, Chapter 2.

[5] BELOKUROV, V.V. & D.V. SHIRKOV. 1991. The Theory of Particle Interactions. American Institute of Physics. New York.

[6] BOHM, D.J. & B.J. HILEY. 1984. The de Broglie pilot wave theory and further development of new insights arising out of it. *In* A. Barut, A. van der Merwe & J.P. Vigier, Eds. Quantum, Space and Time: The Search Continues. CUP. Cambrige.

[7] CAO, T.Y. & S.S. SCHWEBER. 1993. The conceptual foundations and the philosophical aspects of renormalization theory. Synthese 97:1.

[8] CRAMER, J. 1986. The transactional interpretation of quantum mechanics. RMP 58:3:647–687.

[9] DEUTSCH, D. 1985. Quantum theory, the Church Turing principle and the universal quantum computer. Proc. Royal Soc. London A 400:97–117.

[10] DEUTSCH, D. & R. JOZSA. 1992. Proc. Royal Soc. London A 439:553–558.

[11] FARRE, G.L. 1997a. Foreword to W. Schempp: Magnetic Resonance Imaging: Mathematical Foundations and Applications. J. Wiley. New York.

[12] FARRE, G.L. 1997b. The Energetic Structure of Observation: A Philosophical Disquisition. American Behavioral Scientist 40:6:717–728.

[13] FARRE, G.L. 1996. Cybernetics and evolution: A philosophical examination in a Wittgensteinian light. *In* R. Trappl, Ed. Cybernetics and Systems, Volume I:184–188. : Austrian Society for Cybernetic Studies. Vienna.

[14] HARRÉ, R. 1996. AI rules: Okay? J. Expt. Theor. Artif. Intell. 8:109–120.

[15] PENROSE, R. 1994. Shadows of the Mind. OUP. Oxford.

[16] PENROSE, R. 1993a. Setting the scene: The claims and the issues. *In* D. Broadbent, Ed. The Simulation of Human Intelligence. Blackwell. Oxford.

[17] PENROSE, R. 1993b. An emperor still without mind, Behavioral and Brain Sciences 16:3:616–622.

[18] PENROSE, R. 1989. The Emperor's New Mind: Concerning Computers, Minds and the Laws of Physics. OUP. Oxford.

[19] PENROSE, R. 1990. The non-algorithmic mind. Behavioral and Brain Sciences 13:692–705.

[20] SCHEMPP, W. 1997. Magnetic Resonance Imaging: Mathematical Foundations and Applications. John Wiley. New York. In press.

[21] SCHEMPP, W. 1996. Geometric analysis: The double-slit interference experiment and magnetic resonance imaging. *In* R. Trappl, Ed. Cybernetics and Systems, Volume I: 179–183. Austrian Society for Cybernetic Studies. Vienna.

[22] SCHWEBER, S.S. 1993. Physics, community and the crisis in physical theory. Physics Today. November.

[23] SCHWEBER, S.S. 1995. QED and the Men Who Made It. PUP. Princeton.

[24] SQUIRES, E.J. 1990. Conscious Mind in the Physical World. Adam-Hilgers.

[25] SQUIRES, E.J. 1993. Quantum theory and the relation between conscious mind and the physical world. Synthese 97.

[26] STEINER, M. 1989. The application of mathematics to natural science, J. of Phil. 86:9:449–480.

[27] WIGNER, E.P. 1967. Symmetries and Reflections. Indiana University Press. Bloomington.

Quantum Holography and Magnetic Resonance Tomography: An Ensemble Quantum Computing Approach

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Coherent wavelets form a unified basis of the multichannel perfect reconstruction analysis–synthesis filter bank of high resolution radar imaging and clinical magnetic resonance imaging (MRI). The filter bank construction is performed by the Kepplerian temporospatial phase detection strategy which allows for the stroboscopic and synchronous cross sectional quadrature filtering of phase histories in local frequency encoding multichannels with respect to the rotating coordinate frame of reference. The Kepplerian strategy and the associated filter bank construction take place in symplectic affine planes which are immersed as coadjoint orbits of the Heisenberg two–step nilpotent Lie group G into the foliated three–dimensional real projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$. Due to the factorization of transvections into affine dilations of opposite ratio, the Heisenberg group G under its natural sub–Riemannian metric acts on the line bundle realizing the projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$. Its elliptic non–Euclidean geometry without absolute quadric, associated to the unitary dual $\hat{G}$, governs the design of the coils inside the bore of the MRI scanner system. It determines the distributional reproducing kernel of the tracial read–out process of quantum holograms excited and coexisting in the MRI scanner system. Thus the pathway of this paper leads from Keppler's approach to projective geometry to the Heisenberg approach to the sub–Riemannian geometry of quantum physics, and finally to the enormously appealing topic of ensemble quantum computing.

Dedicated to the pioneers of magnetic resonance technology,
Raymond V. Damadian
and
Paul C. Lauterbur

There is no task more difficult than that of modifying accepted ideas.
— Jean Alexandre Dieudonné (1906–1995)

There is nothing that nuclear spins will not do for you, as long as you treat them as human beings.
— Erwin Louis Hahn (1949)

In order to understand the principles of MR *imaging one must successfully navigate through an elaborate structure whose essence is very much like a mathematical structure.*
— Alfred L. Horowitz (1995)

The sense we make of the world is governed by our conceptual means. More specifically, sense is made of nature by projecting a conceptual structure onto observed events. This is accomplished by means of a semantic filter, which transforms raw data into semantically significant events.
— George L. Farre (1997)

One might ask, if this MRI *is so wonderful, why*

are so many radiologists reluctant to "get into" it? In a word: "physics."
— Ray H. Hashemi and William G. Bradley, Jr. (1997)

A radar system employs a directional antenna that radiates energy within a narrow beam in a known direction. One unique feature of the synthetic aperture radar (SAR) imaging modality is that its spatial resolution capability is independent of the platform altitude over the subplatform nadir track. This is a result of the fact that the SAR image is formed by simultaneously storing the phase histories and the differential time delays in local frequency encoding subbands of wideband radar, none of which is a function of the range from the radar sensor to the scene. It is this unique capability which allows the acquisition of high resolution images from satellite altitude as long as the received response wavelet has sufficient strength above the noise level.

Magnetic resonance imaging (MRI) scanners are cognitive systems which reconstruct cross–sectional images of objects and perform the reconstructive amplification by coherent quantum *stochastic resonance* as a form of multichannel parallelism. The reconstructive process from multichannel phase histories is through probing the magnetic moments of nuclei employing strong magnetic flux densities and radiofrequency radiation. The whole process of MRI is based on perturbing the equilibrium magnetization of the object with a train of pulses and observing the resulting time–evolving response signal produced as a free induction decay (FID) in a coil.

What has made nuclear magnetic resonance (NMR) such a prominent and exciting modern spectroscopic technique? One fundamental reason, of course, is that spectroscopy provides direct and incontrovertible evidence of quantization of energy, and that nowhere this is more simply illustrated than in NMR experiments. There is no doubt that textbooks on quantum physics would have chosen spin ensembles as their starting point, rather than atomic spectra, had NMR been discovered at an earlier date. The resonance lines which are observed in high resolution NMR spectra are transitions between these energy levels. However, in contrast to conventional spectroscopy, the separation between energy levels depends of the applied magnetic flux density.

Nuclear spins and the arrays of quantum bits ("qubits") they represent can be manipulated in a multitude of different ways in order to extract site information about molecular structure and dynamic information about molecular motion. Due to the spin dynamics, a preparation of the sample can be achieved such that the reconstructive amplification process by coherent quantum stochastic resonance is a well posed problem. With NMR tomography it is possible to observe, non–invasively, cross–sections through objects, and thus obtain SAR like image information about density, flow, and spectrally localized chemical composition ([25]). The preparation procedures of NMR and MRI turn the reconstruction into a well posed problem. Specifically, an application of the blood oxygen level dependent (BOLD) contrast method of human brain mapping to morphological cranial anatomy ([39]) allows for an observation of activation of the brain *in vivo*.

The moment of birth of the temporal magnetic resonance phenomenon was marked by Felix Bloch's *dynamical* approach. The great Felix Bloch (1905–1983), the first graduate student and assistant to Werner Karl Heisenberg in Leipzig, outlined the NMR experiment in his source paper of 1946 as follows ([24], [34]):

"The first successful experiments to detect magnetic resonance by electromagnetic efects have been carried out recently and independently at the physics laboratories of Harvard and Stanford Universities. The considerations upon which our work was based have several features in common with the two experiments, previously mentioned, but differ rather essentially in others. In the first place, the radiofrequency field is deliberately chosen large enough so as to cause at resonance a considerable change of orientation of the nuclear moments. In the second place, this change is not observed by its relatively small reaction upon the driving circuit, but by directly observing the induced electromotive force in a coil, due to the precession of the nuclear moments around the constant field and in a direction perpendicular both to this field and the applied r–f field. This appearance of a magnetic induction at right angles to the r–f field is an effect which is of specifically nuclear origin and it is the main characteristic feature of our experiment. In essence, the observed perpendicular nuclear induction indicates a rotation of the total oscillating field around the constant magnetic field."

"Not only a weak r–f field, acting at resonance over very many Larmor periods, can produce an appreciable nuclear change of orientation, but also a strong field pulse, acting over only a few periods. Once the nuclear moments have been turned into an angle with the constant field, they will continue to precess around it and likewise cause a nuclear induction to occur at an instant when the driving pulse has already disappeared. It seems perfectly feasible to receive thus an induced nuclear signal of radiofrequency well above the thermal noise of a narrow band receiver. It is true that, due to the broadening of the Larmor frequency by internuclear fields or other causes, this signal can last only a comparatively short time, but for normal fields it will still contain many Larmor periods, i.e., it will be essentially monochromatic. The main difference between this proposed experiment and the one which we have actually carried out lies in the fact that it would observe by induction the free nuclear precession while we have studied the forced precession impressed upon the nuclei by the applied r–f field. The existence of a resultant macroscopic moment of the nuclei within the sample under investigation is a common prerequisite for all electromagnetic experiments with nuclear moments. It is in fact a change of orientation of this macroscopic moment which causes the observed effects, and irrespective of the changes of orientation of the individual nuclei which might be induced by a r–f field, their moments would always cancel each other, if they did so initially, and thus escape observation."

Because the computer performance was severely limited at the time of the discovery of NMR spectroscopy, and the fast Fourier transform (FFT) algorithm was not available to Bloch and his coworkers, the enormously appealing perspective to spin isochromat computers is not present in his dynamical approach. Such a machine performs a calculation using quantum parallelism at the molecular level and then amplifies the results to the macroscopic level via coherent quantum stochastic resonance as a form of multichannel parallelism. Recent experiments in neurobiology verified the amplification effect of stochastic resonance in the information transfer performed by weak signals in biological neural networks ([20]).

From the dynamical approach to NMR spectroscopy, however, Hahn's spin echo method popped up. Due to its favorable signal–to–noise ratio, his spin echo pulse sequence is extensively used both in clinical MRI, NMR spectroscopy and NMR microscopy ([6]). It plays a major role in the emulation of quantum computers by NMR spectroscopy ([11], [26], [33]).

The immersion aspect of the *spectroscopic* approach has been summarized by Nicolaas Bloembergen, Edward Mills Purcell (1912–1997), and Robert V. Pound as follows ([24], [34]):

"In nuclear magnetic resonance absorption, energy is transferred from a radiofrequency circuit to a system of nuclear spins immersed in a magnetic field, H_0, as a result of transitions among the energy levels of the spin system."

"The exposure of the system to radiation, with consequent absorption of energy, tends to upset the equilibrium state previously attained, by equalizing the population of the various levels. The new equilibrium state in the presence of the radiofrequency field represents a balance between the processes of absorption of energy by the spins, from the radiation field, and the transfer of energy to the heat reservoir comprising all other internal degrees of freedom of the sustance containing the nuclei in question."

"Finally we review briefly the phenomenological theory of magnetic resonance absorption, before describing the experimental method. The phenomenon lends itself to a variety of equivalent interpretations. One can begin with static nuclear paramagnetism and proceed to paramagnetic dispersion, or one can follow Bloch's analysis, contained in his paper on nuclear induction, of the dynamics of a system of spins in an oscillating field, which includes the absorption experiments as a special case. We are interested in absorption, rather than dispersion or induction, in the presence of *weak* oscillating fields, the transitions induced by which can be regarded as non–adiabatic. We therefore prefer to describe the experiment in optical terms."

Bloch and Purcell shared the 1952 Nobel Prize in Physics in recognition of their pioneering achievements in condensed matter. The methods due to Bloch and Purcell are not only of high intellectual beauty leading finally to quantum computing, they also place an analytic method of high efficacy in the hands of scientists. Therefore, during the next quarter of a century NMR spectroscopy flourished, and more than 1000 NMR units were manufactured. The award of the Nobel Prize in Chemistry to Richard Robert Ernst in 1991 later served to highlight the fact that high resolution NMR spectroscopy is not only an essential physical technique for chemists and biochemist, but also offers a fascinating application of non–commutative Fourier analysis to system theory. Ernst summarized the application of Fourier transform spectroscopy to NMR as follows ([24], [34]):

"It is well-known that the frequency response function and the unit impulse response of a linear system forms a Fourier transform pair. Both functions characterize the system entirely and thus contain exactly the same information. In magnetic resonance, the frequency response function is usually called the spectrum and the unit impulse is represented by the free induction decay. Although a spin system is not a linear system, Lowe and Norberg (1957) have proved that under some very loose restrictions the spectrum and the free induction decay after a 90° pulse are Fourier transform of each other. The proof can be generalized for arbitrary flip angles."

"For complicated spin systems in solution, the spectrum contains the information in a more explicit form than does the free induction decay. Hence it is generally assumed that recording the impulse response does not give any advantages compared to direct spectral techniques. The present investigations show that the impulse response method can have significant advantages, especially if the method is generalized to a series of equidistant identical pulses instead of a single pulse. In order to interpret the result, it is usually necessary to go to a spectral representation by means of a Fourier transformation. The numerical transformation can conveniently be handled by a digital computer or by an analog Fourier analyzer."

"Here are some features of the pulse technique: (1) It is possible to obtain spectra in a much shorter time than with the conventional spectral sweep technique. (2) The achievable sensitivity of the pulse experiment is higher. All spins with resonance frequencies within a certain region are simultaneously excited, increasing the information content of the experiment appreciably compared with the spectral sweep technique where only one resonance is observed at a time."

Based on the work of the Nobel laureates Pauli, Bloch, Bloembergen, Purcell, Gabor and Ernst, a whole new science culminating in Fourier transform MRI has been created where none existed before ([34], [46], [45]). This new science of ensemble quantum computing needs its own mathematical foundation based on elliptic geometric analysis. Surprisingly, spin isochromat computing by NMR spectroscopy has its deep roots in the Kepplerian dynamics of physical astronomy.

The Kepplerian temporospatial phase detection strategy of physical astronomy is derived from the quadrature conchoid trajectory stratification and the second fundamental law of planetary motion analysis ([47]), as displayed in Keppler's Astronomia Nova of 1609. The dynamics of the quadrature conchoid trajectory stratification which seems to have almost escaped notice in literature, is best understood from the viewpoint of projective geometry. Although Keppler described the projective approach to astronomical observations in the Paralipomena of 1604, he is not recognized, along with Desargues, as one of the pioneers of projective geometry which then culminated in Poncelet's investigations.

Projective geometry, which is since about the mid 1980's standard in the computer vision and robotics literature, allows for the stroboscopic and synchronous cross sectional quadrature filtering of phase histories in local frequency encoding multichannels with respect to the rotating coordinate frame of reference ([23]), and provides the implementation of a matched filter bank by orbit stratification in a symplectic affine plane. An application of this procedure leads to the landmark observation of the earliest SAR pioneer, Carl A. Wiley, that motion is the solution of the high resolution radar imagery and phased array antenna problem of holographic recording by quasi-optical systems ([32], [52]). Whereas the Kepplerian temporospatial strategy is realized in SAR imaging by the range Doppler principle ([13], [31]), it is the Lauterbur spectral localization principle ([45]) which takes place in clinical MRI. Having Damadian's approach to tumor detection in mind, Lauterbur wrote the following observation into his 1971 notebook under the title of "Spatially Resolved Nuclear Magnetic Resonance Experiments" ([34]):

"The distribution of magnetic nuclei, such as protons, and their relaxation times and diffusion coefficients, may be obtained by imposing magnetic field gradients (ideally, a complete set of orthogonal spherical harmonics) on a sample, such as an organism or a manufactured object, and measuring the intensities and relaxation behavior of the resonance as functions of the applied magnetic field. Additional spatial discrimination may be achieved by the application of time-dependent gradient patterns so as to distinguish, for example, protons that lie at the intersection of the zero-field (relative to the main magnetic field) lines of three linear gradients."

"The experiments proposed above can be done most conveniently and accurately by measurements of the Fourier transform of the pulse response of the system. They should be capable of providing a detailed three-dimensional map of the distributions of particular classes of nuclei (classified by nuclear species and relaxation times) within a living organism. For example, the distribution of mobile protons in tissues, and the differences in relaxation times that appear to be characteristic of malignant tumors, should be measurable in an intact organism."

Thus the Lauterbur spectral localization is based on affine dilations. These are implemented on a modular stratification basis by *linear* magnetic field gradient matrices into which transvections admit factorizations ([45]). The measurements of the one-dimensional Fourier transform have been refined by the two-dimensional Fourier transform spectroscopy contributed by Ernst, and the spin-warp version of Fourier transform MRI developed by W.A. Edelstein, J.M.S. Hutchinson, and J. Mallard of the Aberdeen University group in Scotland.

With regard to possible applications of his spectral localization method, Lauterbur drew the following conclusions without explicit citation of Damadian's paper ([34]):

"Applications of this technique to the study of various inhomogeneous objects, not necessarily restricted in size to those commonly studied by magnetic resonance spectroscopy, may be anticipated. A possible application of considerable interest at this time would be the *in vivo* study of malignant tumors, which have been shown to give proton nuclear magnetic resonance signals with much longer water spin–lattice relaxation times than those in the corresponding normal tissues."

At the background of both the SAR and MRI high resolution imaging techniques lies the construction of a multichannel coherent wavelet reconstruction analysis–synthesis filter bank of matched filter type ([15], [38], [23]). Beyond these applications to local frequency encoding subbands, the Kepplerian temporospatial phase detection strategy leads to the concept of Feynman path integral or summation over phase histories.

As approved by quantum electrodynamics, geometric quantization allows for a semi–classical approach to the interference pattern of quantum holography and the spin excitation profiles of MRI ([42], [43], [44], [45]). Implementation of interference needs, of course, phases coherency and therefore the transition to the frequency domain by a *duality* procedure. Indeed, the unitary dual $\hat{G}$ of the Heisenberg group G consisting of the equivalence classes of irreducible unitary linear representations of G allows for a coadjoint orbit foliation of symplectic affine leaves $\mathcal{O}_\nu$ $(\nu \neq 0)$, spatially located as a stack of tomographic slices, and decomposing the dual vector space $\text{Lie}(G)^\star$ of the real Heisenberg Lie algebra $\text{Lie}(G)$ ([40]). This fact is a consequence of the Kirillov homeomorphism

$$\hat{G} \longrightarrow \text{Lie}(G)^\star/\text{CoAd}_G(G)$$

which establishes the canonical foliation of the three–dimensional super–encoding projective space $\mathbf{P}(\mathbf{R} \times \text{Lie}(G)^\star)$.

- The connected, simply connected Heisenberg two–step nilpotent Lie group G admits a realization by a faithful matrix representation $G \longrightarrow \mathbf{SL}(3, \mathbf{R})$.

In terms of standard coordinates, the Heisenberg group G is realized by the set of unipotent matrices

$$\left\{ \begin{pmatrix} 1 & x & z \\ 0 & 1 & y \\ 0 & 0 & 1 \end{pmatrix} \middle| \, x, y, z \in \mathbf{R} \right\}$$

under the matrix multiplication law of the *dual pairing* presentation

$$\begin{pmatrix} 1 & x_1 & z_1 \\ 0 & 1 & y_1 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & x_2 & z_2 \\ 0 & 1 & y_2 \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & x_1 + x_2 & z_1 + z_2 + x_1 . y_2 \\ 0 & 1 & y_1 + y_2 \\ 0 & 0 & 1 \end{pmatrix}.$$

The form of rank one defining the non–commutative matrix multiplication of G is neither antisymmetric nor non–degenerate. However, it is *cohomologous* to the non–degenerate alternating determinant form. It suffices to use any form which is cohomologous to a non–degenerate alternating bilinear form to define the multiplication law of G.

The differential operator associated to the natural sub–Riemannian metric of G is the sub–Laplacian $\mathcal{L}_G$ on G. Notice that the sub–Riemannian geometry is to the sub–Laplacian in the sub–elliptic realm what Riemannian geometry is to the Laplacian in the elliptic realm.

- The geodesics with respect to the natural sub–Riemannian metric of G are the Heisenberg helices.

In terms of the coordinates of the dual pairing presentation of G, the sub–Laplacian $\mathcal{L}_G$ takes the form of a Hörmander sum of squares

$$\boxed{\mathcal{L}_G = -\frac{1}{2}\Big(\big(\frac{\partial}{\partial x} - y\frac{\partial}{\partial z}\big)^2 + \big(\frac{\partial}{\partial y} + x\frac{\partial}{\partial z}\big)^2\Big)}$$

The Heisenberg group G has two presentations that are particularly important in applications. It is standard that the radical of a bundled alternating bilinear form is the only invariant of the bundled form. Therefore, the dual pairing presentation of G is isomorphic to the *basic* presentation of the Heisenberg group G which is given by the multiplication law of the unipotent matrices

$$\left\{\begin{pmatrix} 1 & \bar{w} & \frac{1}{2}|w|^2 + zi \\ 0 & 1 & w \\ 0 & 0 & 1 \end{pmatrix} \middle| w \in \mathbf{C}, z \in \mathbf{R}\right\}.$$

Computations are usually easiest in the basic presentation of G because the straight lines through the origin are the one–parameter–subgroups. Due to the planetary orbit stratification, the Keplerian temporospatial phase detection strategy leads to the basic presentation ([45]).

- There is a realization of the Heisenberg group G by a faithful matrix representation $G \longrightarrow \mathbf{Sp}(4, \mathbf{R})$ defining the image group as an extension via matrix multiplication.

In terms of the left–invariant vector fields

$$W = \frac{\partial}{\partial w} - \bar{w}\frac{\partial}{\partial z}, \qquad \bar{W} = \frac{\partial}{\partial \bar{w}} + w\frac{\partial}{\partial z},$$

the sub–Laplacian $\mathcal{L}_G$ takes the form

$$\boxed{\mathcal{L}_G = -\frac{1}{2}(W\bar{W} + \bar{W}W)}$$

The spectrum of the sub–elliptic operator $\mathcal{L}_G$ is absolutely continuous with uniform multiplicity on the longitudinal center frequency axis $\mathbf{R}$, transverse to the symplectic affine plane $\mathbf{R} \oplus \mathbf{R}$. The density of the spectrum on the longitudinal center frequency axis $\mathbf{R}$ is given by the Pfaffian of G.

- The symmetries of the sub–elliptic differential operator $\mathcal{L}_G$ are reflected in the time reversal, which is implicit in the spin echo methods and the conjugation of the gradient echo imaging methods.

The idea of time reversal appears to challenge the validity of the second law of thermodynamics since it is possible to prepare a nuclear spin system in such a way that, although it appears to be in an equilibrium state, at some later time its degree of order grows spontaneously from a previosly negligible level. The spontaneous ordering is a spin echo.

The coordinate functions

$$\begin{pmatrix} 1 & x & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & y \\ 0 & 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 0 & z \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

of G define *transvections* or shearings of a three-dimensional real vector space ([19]). The multiplicative group of longitudinal *dilations* transforms the transvections into the transvections

$$\begin{pmatrix} 1 & ax & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & ay \\ 0 & 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 0 & a^2 z \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

for $a \neq 0$. Conversely, it is easy to verify that transvections admit factorizations into affine dilations of opposite ratio. With respect to the sub–Riemannian metric of G, each dilation multiplies lengths by the fixed value $|a|$. The existence of dilations shows that small neighborhoods are similar to large neighborhoods in G. The reflections implementing the time reversal implicit in the spin echo method and the gradient echo technique are given by the improper matrices

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

in the rotating coordinate frame of reference, and

$$\begin{pmatrix} -1 & 1 \\ 0 & 1 \end{pmatrix}$$

in the laboratory coordinate frame of reference, respectively.

The contact geometry of the quotient projection

$$G \longrightarrow G/\text{center}$$

gives rise to the contact one–form

$$\eta = \mathrm{d}z + \frac{1}{2}(x.\mathrm{d}y - y.\mathrm{d}x)$$

where

$$\mathrm{d}\eta = \mathrm{d}x \wedge \mathrm{d}y$$

holds with respect to the laboratory coordinate frame of reference.

If the unipotent matrices $\{P, Q, I\}$ denote the canonical basis of the three-dimensional real vector space Lie(G), where the elementary matrices

$$\exp_G P = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad \exp_G Q = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{pmatrix},$$

$$\exp_G I = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

are given by the matrix exponential diffeomorphism

$$\exp_G : \mathrm{Lie}(G) \longrightarrow G,$$

the coadjoint action of G on Lie$(G)^\star$ is given by

$$\mathrm{CoAd}_G \begin{pmatrix} 1 & x & z \\ 0 & 1 & y \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & -y \\ 0 & 1 & x \\ 0 & 0 & 1 \end{pmatrix}.$$

Therefore the action CoAd$_G$ reads in terms of the coordinates $\{\alpha, \beta, \nu\}$ with respect to the dual basis $\{P^\star, Q^\star, I^\star\}$ of the real vector space dual Lie$(G)^\star$ as follows:

$$\mathrm{CoAd}_G \begin{pmatrix} 1 & x & z \\ 0 & 1 & y \\ 0 & 0 & 1 \end{pmatrix} (\alpha P^\star + \beta Q^\star + \nu I^\star) =$$
$$(\alpha - \nu y)P^\star + (\beta + \nu x)Q^\star + \nu I^\star.$$

- In radar imaging, $\nu \neq 0$ denotes the center frequency of the transmitted coherent pulse train, whereas in clinical MRI the center frequency ν is the frequency of the rotating coordinate system defined by tomographic slice selection.

In clinical MRI, the Pfaffian of G allows to select the tomographic slice by an application of linear magnetic field gradients.

- The pitch of the Heisenberg helices is inversely proportional to the polarity of the linear slice select gradients.

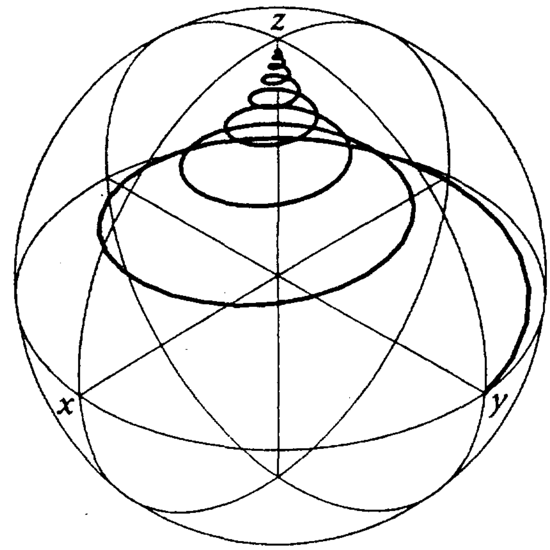

Figure 1: *Recovery trajectory of FID: Heisenberg helix off resonance losing amplitude due to the transverse relaxation effect but also gaining energy due to the longitudinal relaxation effect.*

For an illustration of the Heisenberg helix after excitation by a nutation $\frac{\pi}{2}$ pulse, see Fig. 1. The pitch of the Heisenberg helix indicates the energy gain due to the longitudinal relaxation effect. This is typical of a single–frequency FID.

The linear varieties

$$\boxed{\mathcal{O}_\nu = \mathrm{CoAd}_G(G)(\nu I^\star) = \mathbf{R}P^\star + \mathbf{R}Q^\star + \nu I^\star \quad (\nu \neq 0)}$$

actually are symplectic affine planes in the sense that they are in the natural way compatibly endowed with both the structure of an affine plane and a symplectic structure. Therefore the trivial line bundle $\mathbf{R} \oplus \mathbf{R}$ on the symplectic affine plane $\mathcal{O}_\nu \hookrightarrow \mathrm{Lie}(G)^\star$ $(\nu \neq 0)$ of *connection* differential 1–form

$$\boxed{\nu.(x.\mathrm{d}y - y.\mathrm{d}x)}$$

and *rotational curvature* differential 2–form

$$\boxed{\omega_\nu = \nu . \mathrm{d}x \wedge \mathrm{d}y}$$

in the cohomology group

$$\bigwedge^2(\mathcal{O}_\nu) \cong \mathrm{H}^2(\mathbf{R}\oplus\mathbf{R},\mathbf{R}) \qquad (\nu \neq 0)$$

forms the predestinate planar mathematical structure to implement the Kepplerian temporospatial phase detection strategy over the bi-infinite stratigraphic time line $\mathbf{R}$ of time cycles or repetition times. The closed exterior differential 2-form

$$\boxed{\omega_\nu = \frac{1}{2}\nu i\, \mathrm{d}w \wedge \mathrm{d}\bar{w} \qquad (\nu \neq 0)}$$

is a representative of the magnetic moment referred to in Bloch's dynamical approach. In the NMR experiment, the intrinsic dynamics is due to the driving flat radiofrequency circuit.

In MRI, the symplectic affine linear varieties $\mathcal{O}_\nu \hookrightarrow \mathrm{Lie}(G)^\star\,(\nu \neq 0)$ are predestinate to carry quantum holograms or spin excitation profiles acting as multichannel perfect reconstruction analysis–synthesis filter banks ([41], [22]). The quantum holograms are implemented by the frequency modulation action of G.
The stationary singular plane $\mathcal{O}_\infty \hookrightarrow \mathrm{Lie}(G)^\star$ of equation

$$\nu = 0$$

consists of the single point orbits or focal points

$$\mathcal{O}_\infty = \left\{\varepsilon_{(\alpha,\beta)} \;\middle|\; (\alpha,\beta) \in \mathbf{R}\oplus\mathbf{R}\right\}$$

corresponding to the one-dimensional representations of G. The elements of the plane $\mathcal{O}_\infty$ are the analogs of the resonance "sweet spots" of the conventional spectral sweep technique employed in the early NMR spectroscopy, as well as the prototype whole-body MRI scanner. The world's first whole-body scanner, dubbed "Indomitable" by Damadian to capture the spirit of its seven-year construction ([45]), provided a technique named FONAR to achieve the first MRI scan of the human body *in vivo*, and to convince the medical community that MRI scanning was, in fact, a reality.

The infinite dimensional irreducible unitary linear representations of G associated to the symplectic affine leaves $\mathcal{O}_\nu\,(\nu \neq 0)$ *collapse* down to characters of G. The state-vector reduction, or collapse of coherent wavelet can be described by the transition

$$\boxed{\omega_\nu \rightsquigarrow \varepsilon_{(\alpha,\beta)}\, \mathrm{d}\alpha \otimes \mathrm{d}\beta \qquad (\nu \neq 0)}$$

As an energetic edge, the confocal plane at infinity $\mathbf{P}(\mathbf{R}\times\mathcal{O}_\infty)$ plays a fundamental role in the energetic structure of observation ([22]), and specifically in the coherent optical processing of radar data ([13]), morphological MRI studies, and neurofunctional MRI detection for the mapping of the activities of the human brain to morphological cranial anatomy (Fig. 7). From there the reconstructive amplification via the multichannel parallelism of coherent quantum stochastic resonance takes place.

The quantum holograms which are generated by neurofunctional MRI experiments represent "matière à pensée" ([9]), or shadows of the mind implemented by the rotationally curved planes of immanence in the philosophy of constructivism ([16], [17]), or symplectic affine planes of incidence ([22]).

"Ein maschinelles "agencement" ist den Schichten zugewandt, reinen Intensitäten, die sie zirkulieren läßt um die Selektion der "Konsistenzebene" zu sichern und der sich die Subjekte zuordnen, welchen sie einen Namen nur als Spur einer Intensität läßt."

The shadows of the mind emulated by MRI scanner systems seem to provide a promising conceptual approach to the missing science of *consciousness*.

- The canonical foliation of the three-dimensional super-encoding projective space $\mathbf{P}(\mathbf{R}\times\mathrm{Lie}(G)^\star)$ allows to deduce the phase coherent wavelet collapse phenomenon.
- There exists no equivalent of the state-vector reduction, or coherent wavelet collapse phenomenon in the realm of classical physics.
- The amount of information that can be extracted from a spin isochromat computer is limited by the phenomemon of phase coherent wavelet collapse.

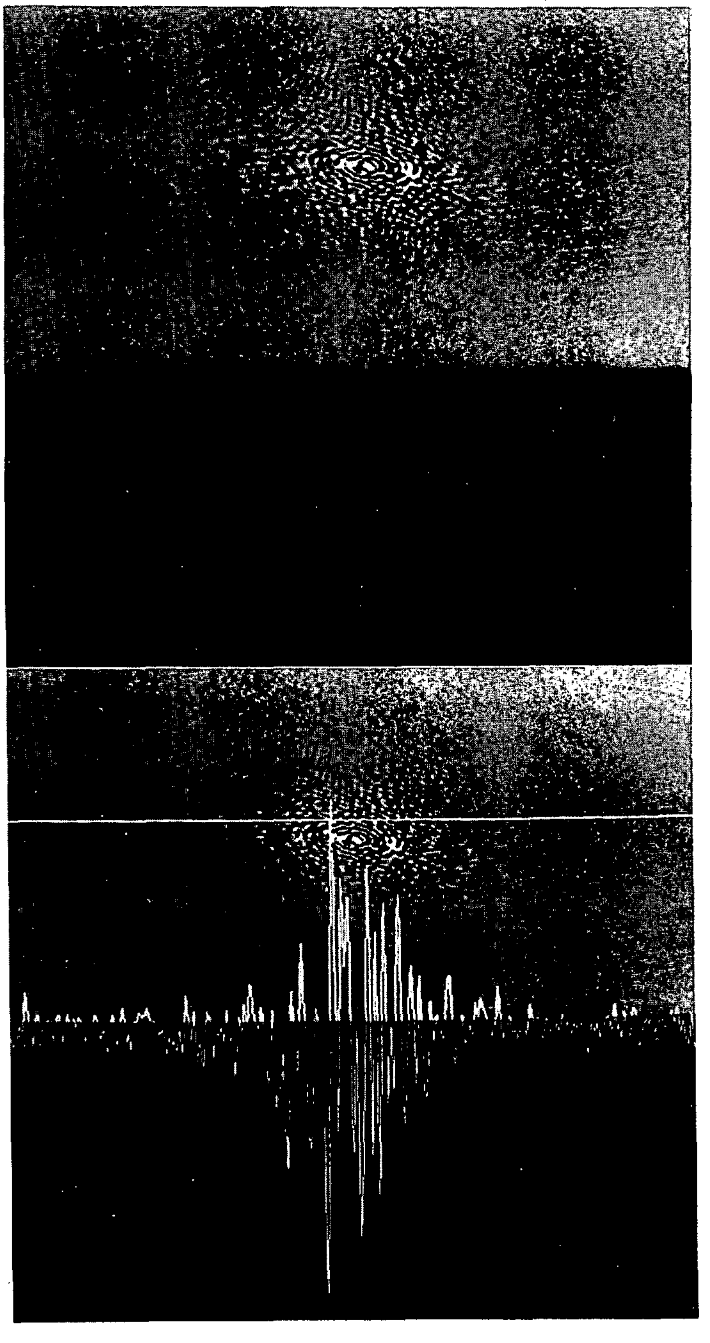

Figure 2: *Quantum hologram of a morphological MRI cranial study (A). The data line near the center corresponds to a decaying response wavelet of moderately high amplitude (B).*

In contrast to the coadjoint orbit visualization of the unitary dual $\hat{G}$, the standard bra-ket procedures of quantum mechanics provide no implication that there be any way to deduce the collapse phenomenon as an instance of the deterministic Schrödinger evolution. Whereas the weak containment of the identity representation 1 in the tensor product representation provides a

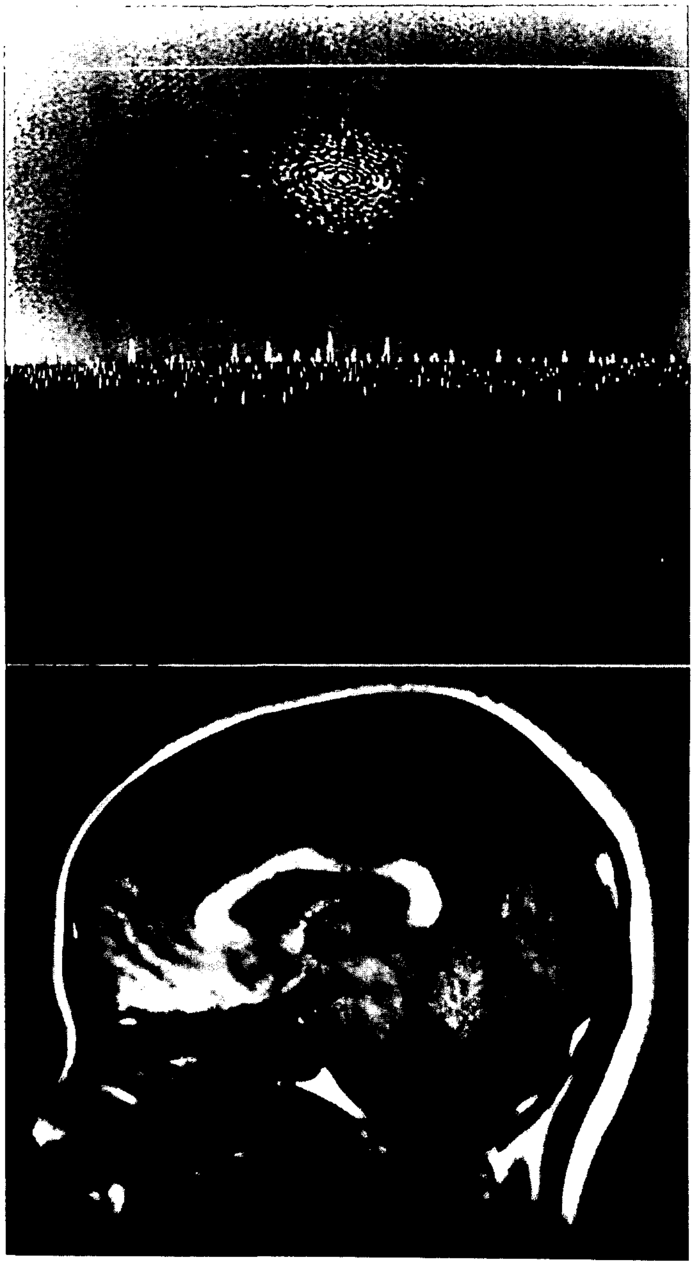

Figure 3: *Quantum hologram of the morphological MRI cranial study of Fig. 2. The data line near the periphery corresponds to a decaying response wavelet of low amplitude (C). The tracial read-out process in the laboratory frame of reference (D).*

geometric symmetry condition for the decryption of quantum information from the holographic encryption, there is in standard quantum mechanics no clear rule as to when the probabilistic collapse rule should be invoked, in place of the deterministic Schrödinger evolution. This establishes the extraordinary *power* of the coadjoint orbit visualization in terms of the three-dimensional real projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$, and the confocal plane at infinity $\mathbf{P}(\mathbf{R} \times \mathcal{O}_{\infty})$ included.

In order to define the transvectional G-action of $\hat{G}$, it is convenient to immerse the $\mathrm{CoAd}_G(G)$-foliation of $\mathrm{Lie}(G)^{\star}$ with typical fiber $\mathbf{R} \oplus \mathbf{R}$ into its projective completion $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$ by the bi-infinite stratigraphic time line $\mathbf{R}$. It will be shown that the concept of projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$ which is helpful in the realms of computerized geometric design, computer vision and robotics, is also useful in non-invasive radiodiagnostics.

- The intrinsic construction provides the foliated three-dimensional super-encoding projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$ as the projective completion of the dual vector space of the affine dual of any of the tomographic slices $\mathcal{O}_{\nu} \hookrightarrow \mathrm{Lie}(G)^{\star}\,(\nu \neq 0)$ by the bi-infinite stratigraphic time line $\mathbf{R}$.
- The stratigraphic time line $\mathbf{R}$ records simultaneously the time cycles or repetition times of the MRI protocol as well as the superposition of spin up and spin down states, and the arrays of qubits they are representing in coexistence.
- The unitary dual $\hat{G}$ of the Heisenberg group G can be immersed into the foliated three-dimensional projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$. The confocal plane $\mathbf{P}(\mathbf{R} \times \mathcal{O}_{\infty})$ is the plane at infinity of $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$. The two-dimensional projective varieties $\mathbf{P}(\mathbf{R} \times \mathcal{O}_{\nu})$ $(\nu \neq 0)$ are contained in its complement.
- Due to the factorization of transvections into affine dilations of opposite ratio, the Lauterbur spectral localization controls the transvectional action of G on the line bundle model $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$ of $\hat{G}$.
- The three-dimensional elliptic non-Euclidean space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$ is homeomorphic to the compact unit sphere $\mathbf{S}_3 \hookrightarrow \mathbf{R}^4$ under antipodal point identification via the action of the group $\{\mathrm{id}, -\mathrm{id}\}$.
- The three-dimensional elliptic non-Euclidean space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$ is homeomorphic to the compact solid ball $\mathbf{B}_3 \hookrightarrow \mathbf{R}^3$ with the antipodal (diametrically opposite) points of its boundary $\mathbf{S}_2 = \partial\mathbf{B}_3$ identified.

It follows from the classification of the coadjoint orbits of G in the foliated projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^{\star})$ the highly remarkable fact that there exists no finite dimensional irreducible unitary linear representation of G having dimension > 1. Hence the irreducible unitary linear representations of G which are not unitary characters are infinite dimensional and unitarily induced. Their coefficient cross sections for the Hilbert bundle sitting over the bi-infinite stratigraphic time line $\mathbf{R}$ define the holographic transforms which sum the free induction decays.

- In the data acquisition process, the holographic transform collects the decaying response wavelets of the radiofrequency pulse trains in quantum holograms, or FIDs in spin excitation profiles.

Let C denote the one-dimensional center of G, transverse to the plane carrying the quantum holograms or spin excitation profiles. Then

$$C = \mathbf{R}.\exp_G I$$

is spanned by the central transvection $\exp_G I$. In coordinate-free terms, G forms the non-split central group extension

$$C \lhd G \longrightarrow G/C$$

where the plane G/C is transverse to the line C. Thus G is defined to be the unique central extension

$$\{0\} \longrightarrow \mathbf{R} \longrightarrow G \longrightarrow \mathbf{R} \oplus \mathbf{R} \longrightarrow \{0\}$$

which does not contain any line $\mathbf{R}$ as a direct factor. This condition of not containing $\mathbf{R}$ as a factor is equivalent to the 2-cocycle of the extension which always can be taken to be alternating bilinear, being non-degenerate. The uniqueness follows from the fact that every pair of non-degenerate such forms are congruent in $\mathbf{GL}(2, \mathbf{R})$, the outer automorphism group of the plane $\mathbf{R} \oplus \mathbf{R}$.

The irreducible unitary linear representations of G associated to the projective coadjoint orbits

$\mathbf{P}(\mathbf{R} \times \mathcal{O}_\nu) \hookrightarrow \mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$ ($\nu \neq 0$) are unitarily induced in stages by the unitary characters of closed normal abelian subgroups which provide a fibration of G sitting over the bi-infinite stratigraphic time line $\mathbf{R}$. The elements $w \in \mathcal{O}_1$ of the typical fiber are represented by complex numbers of the form

$$\begin{pmatrix} x & -y \\ y & x \end{pmatrix} = \begin{pmatrix} x & 0 \\ 0 & x \end{pmatrix} + \begin{pmatrix} y & 0 \\ 0 & y \end{pmatrix} \cdot \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

including the differential phase

$$\begin{pmatrix} x & 0 \\ 0 & x \end{pmatrix}$$

and the local frequency

$$\begin{pmatrix} y & 0 \\ 0 & y \end{pmatrix}$$

as real coordinates with respect to the frame of reference rotating with center frequency $\nu \neq 0$. The alternating matrix

$$J = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

of Pfaffian

$$\mathrm{Pf}(J) = 1$$

acts as imaginary unit of the basic presentation of G. It generates the special orthogonal group $\mathbf{SO}(2, \mathbf{R}) \hookrightarrow \mathbf{O}(2, \mathbf{R})$. Together with the reflection defined by the data routing matrix

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix},$$

the non diagonalizable matrix J generates the orthogonal group $\mathbf{O}(2, \mathbf{R})$. The group $\mathbf{O}(2, \mathbf{R})$ can be lifted to the group of all isometries of G with respect to the natural sub-Riemannian metric of G.

It becomes obvious that $|w|^2 = \det w$ and that the rotational curvature differential 2-form ω_ν of $\mathcal{O}_\nu$ is exactly the standard symplectic form of $\mathbf{R} \oplus \mathbf{R}$, dilated by the center frequency $\nu \neq 0$. Thus G implements the *oscillator driven* dynamical system

$$\mathbf{R} \triangleleft \mathbf{R} \oplus \mathbf{R}$$

of longitudinal center frequency axis $\mathbf{R}$, transverse to the symplectic affine plane $\mathbf{R} \oplus \mathbf{R}$. Keppler described the idea of an oscillator driven cyclic clockwork as an act of profanation:

"Mein Ziel ist es, zu zeigen, daß die himmlische Maschinerie nicht von der Art eines göttlichen Lebewesens, sondern von der eines Uhrwerks ist, daß die ganze Mannigfaltigkeit ihrer Bewegungen von einer einfachsten magnetischen körperlichen Kraft herrührt, so wie alle Bewegungen des Uhrwerks allein von dem es treibenden Gewicht."

The $\mathbf{R}$-linear isomorphism

$$(x, y) \rightsquigarrow \begin{pmatrix} x & -y \\ y & x \end{pmatrix}$$

of $\mathcal{O}_1$ onto the realification $\mathbf{C}(\mathbf{R} \oplus \mathbf{R})$ of the field $\mathbf{C}$ of complex numbers suggests an extension from two dimensions to three dimensions via the real quaternion skew-field $\mathbf{H}$. The $\mathbf{R}$-linear mapping

$$(w, w') \rightsquigarrow \begin{pmatrix} w & w' \\ -\bar{w}' & \bar{w} \end{pmatrix}$$

provides an isomorphism from the image of $\mathbf{C}^2$ onto $\mathbf{H}$. In terms of the matrices of this type, the multiplication in $\mathbf{H}$ reads

$$\begin{pmatrix} w_1 & w_1' \\ -\bar{w}_1' & \bar{w}_1 \end{pmatrix} \cdot \begin{pmatrix} w_2 & w_2' \\ -\bar{w}_2' & \bar{w}_2 \end{pmatrix} = \begin{pmatrix} w_1 w_2 - w_1' \bar{w}_2' & w_1 w_2' + w_1' \bar{w}_2 \\ -(\bar{w}_1 \bar{w}_2' + \bar{w}_1' w_2) & \bar{w}_1 \bar{w}_2 - \bar{w}_1' w_2' \end{pmatrix}$$

The tangent space of $\mathbf{S}_3 \hookrightarrow \mathbf{R}^4$ at the neutral element of $\mathbf{SU}(2, \mathbf{C})$ is isomorphic to the vector space $\mathbf{R}^3$. The isomorphism suggests to introduce the Pauli spin matrices forming the canonical basis of the Lie algebra associated to $\mathbf{SU}(2, \mathbf{C})$, and the real Clifford algebra $C\ell_{(3,0)}(\mathbf{R})$. These matrices generate analyzing one-parameter subgroups of the group $\mathbf{SU}(2, \mathbf{C})$. The corresponding elements in the skew-field $\mathbf{H}$ are given by the pure or traceless quaternions.

- The group $\mathbf{S}_3$ is the non-trivial covering $\mathrm{Spin}(3, \mathbf{R})$ of the rotation group $\mathbf{SO}(3, \mathbf{R})$. The group $\mathbf{SO}(3, \mathbf{R})$ contains two normal subgroups, both isomorphic to $\mathbf{S}_3$, which give rise to the Clifford translations acting transitively on the foliated projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$.
- Identification of the group $\mathbf{S}_3 \hookrightarrow \mathbf{R}^4$ with the unit sphere of the skew-field $\mathbf{H}$ provides the multi-slice imaging capability of

the MRI modality via the abelian groups $\mathbf{SO}(2,\mathbf{R})$ of Clifford translations of tomographic slices in the elliptic non–Euclidean space $\mathbf{P}(\mathbf{R}\times \mathrm{Lie}(G)^\star)$.

- Identification of the unit sphere $\mathbf{S}_3 \hookrightarrow \mathbf{R}^4$ with the compact group $\mathbf{SU}(2,\mathbf{C})$, or the compact homogeneous manifolds $(\mathbf{SU}(2,\mathbf{C}) \times \mathbf{SU}(2,\mathbf{C}))/\mathbf{SU}(2,\mathbf{C})$, or $\mathbf{SO}(4,\mathbf{R})/\mathbf{SO}(3,\mathbf{R})$ provides the design of pairs of surface coils of the MRI scanner bore via zonal spherical harmonics.

The interleaving of data acquisition through multi–slice imaging provides a simple means of acquiring data in all three dimensions, and is widely used in clinical imaging. Due to the multiplanar imaging capability of MRI, direct transverse slices of superior to inferior orientation of the plane normal, sagittal slices of anterior to posterior orientation of the normal, and coronal slices of left to right orientation of the normal, as well as oblique plane selections can be performed without changing the patient's position. In X–ray computed tomography (XCT) imaging, sagittal and coronal images are reconstructed from a set of contiguous images. The orthogonal and oblique scan plane selection offer clinical advantages of MRI over XCT. Actually, MRI is closer to high resolution radar imaging than to XCT. The high soft–tissue contrast resolution is another advantage over XCT. Neuroradiologists think that if history of science was rewritten, and XCT invented after MRI, nobody would bother to pursue XCT imaging. For whole–body imaging radiologists, however, the predictions of XCT's imminent demise and MRI's ascendency no longer seem so prescient.

The bundle–theoretic interpretation of the inducing mechanism gives rise to the pair of isomorphic irreducible unitary linear representations

$$(U^\nu, V^\nu) \qquad (\nu \neq 0)$$

of G unitarily induced in quadrature by the unitary characters of the associated closed normal abelian subgroups of G. The induced Hilbert bundles sitting in quadrature over the bi-infinite stratigraphic time line $\mathbf{R}$, admit for any Fourier transformed pair of exciting phase coherent wavelets

$$(\psi, \varphi)$$

in the frequency modulation space $L^2_{\mathbf{C}}(\mathbf{R})$, and element $z \in C$ the contiguous cross–sections of a phase–splitting network of uncorrelated multichannels in quadrature format ([23], [22])

$$\boxed{\begin{gathered}\left(x_0\,,\, e^{2\pi i\nu\left(z-(x-x_0)y\right)}.\psi(-x)\right),\\ \left(y_0\,,\, e^{2\pi i\nu\left(z+x(y-y_0)\right)}.\varphi(y)\right)\\ \left((x_0,y_0)\in T\oplus S\right)\end{gathered}}$$

where $x_0 \in T$ denotes the phase reference of the stroboscopic phase cycling at which system state change. Moreover, $y_0 \in S$ denotes the intermediate frequency reference of the synchronous period cycling clockwork of transitions determined by the computer's programming, and

$$\varphi = \mathcal{F}_{\mathbf{R}}\psi$$

where the phase coherent wavelet φ is the Fourier transform of ψ. The linear representation U^ν of G and its swapped copy V^ν are globally square integrable mod C. Indeed, it is well known that a coadjoint orbit is a linear variety if and only if one (and hence all) of the corresponding irreducible unitary linear representations is globally square integrable modulo its kernel. An equivalent characterization of square integrability mod C is that the Pfaffian of G does not vanish at the center frequency ν.

It is reasonable to regard global square integrability as an essential part of the Stone–von Neumann theorem of quantum physics, because a representation of a nilpotent Lie group is determined by its central unitary character χ_ν if and only if it is globally square integrable mod C. Thus χ_ν allows for selection in the tomographic slice $\mathbf{P}(\mathbf{R}\times \mathcal{O}_\nu) \hookrightarrow \mathbf{P}(\mathbf{R}\times \mathrm{Lie}(G)^\star)$ $(\nu \neq 0)$ a coordinate frame rotating with center frequency $\nu \neq 0$ via an affine dilation in the longitudinal direction of the line C. The corresponding equivalence classes of irreducible, unitarily induced, linear representations U^ν of G acting on the complex Hilbert space of globally square integrable cross sections for the Hilbert bundle sitting over the bi-infinite stratigraphic time line $\mathbf{R}$ are infinite dimensional and can be realized as Hilbert-Schmidt integral operators with kernels $K^\nu \in L^2(\mathbf{R}\oplus\mathbf{R})$

([40], [42], [43], [44], [45]). The derived representation

$$U^\nu(\mathcal{L}_G),$$

evaluated on the sub-Laplacian $\mathcal{L}_G$ of G in the universal enveloping algebra of Lie(G), is the harmonic oscillator Hamiltonian of center frequency $\nu \neq 0$. Due to the global square integrability mod C of U^ν for $\nu \neq 0$, the center of Lie(G) coincides with the center of the universal enveloping algebra of Lie(G).

The center of the product group $\mathbf{S}_3 \times \mathbf{S}_3$ is given by the set

$$\{1,-1\} \times \{1,-1\},$$

and therefore has order 4. It contains the kernel

$$\{1,1\} \times \{-1,-1\}$$

of order 2 of the natural group epimorphism $\mathbf{S}_3 \times \mathbf{S}_3 \longrightarrow \mathbf{SO}(4,\mathbf{R})$.

Due to the antipodal point identification of $\mathbf{S}_3$, the realization of the foliated three-dimensional super-encoding projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$ is diffeomorphic to the quotient of $\mathbf{S}_3$ by the action of the group $\{\mathrm{id}, -\mathrm{id}\}$. As a result, the center of $\mathbf{S}_3 \times \mathbf{S}_3$ in the direction plane $\mathbf{R} \oplus \mathbf{R}$ of $\mathbf{P}(\mathbf{R} \times \mathcal{O}_\nu)$ $(\nu \neq 0)$ gives rise to the distributional reproducing kernel

$$1_\nu \otimes 1_\nu$$

on $\mathbf{P}(\mathbf{R} \times \mathcal{O}_\nu) \hookrightarrow \mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$ corresponding to the rotational curvature differential 2-form

$$\omega_\nu \in \mathrm{H}^2(\mathbf{R} \oplus \mathbf{R}, \mathbf{R}) \qquad (\nu \neq 0).$$

It defines the symplectically reformatted two-dimensional Fourier transform

$$\boxed{\star(1_\nu \otimes 1_\nu)}$$

acting as a spectral sweep by *symplectic convolution* ([44], [45]) on the symplectic spinors of $\mathbf{P}(\mathbf{R} \times \mathcal{O}_\nu) \hookrightarrow \mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$ $(\nu \neq 0)$. In contrast to the conventional two-dimensional Fourier transform of order 4, the symplectic Fourier transform admits order 2 ([43], [44]). This corresponds to the involutory *entangling* map $W \rightsquigarrow \bar{W}$ of quantum computation ([45]).

- The kernel function $K^\nu \in L^2(\mathbf{R} \oplus \mathbf{R})$ associated to the irreducible unitary linear representation U^ν of central unitary character $\chi_\nu = U^\nu \mid C$ implements a multichannel coherent wavelet perfect reconstruction analysis-synthesis filter bank of matched filter type.

In order to paratactically synchronize the rotating coordinate frame to the laboratory frame of reference, the kernel function K^ν has to be composed with the symbol map σ which is defined by the Hopf fibration

$$\mathbf{S}_3 \longrightarrow \mathbf{S}_2$$

with fiber $\mathbf{S}_1$ into Clifford parallel circles $\mathbf{S}_1 \hookrightarrow \mathbf{S}_3$. The Clifford parallelism is understood in the sense of the elliptic non-Euclidean geometry.

- The decomposition of the complement of $\mathbf{P}(\mathbf{R} \times \mathcal{O}_\infty)$ in the real projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$ by the canonical foliation $\mathbf{P}(\mathbf{R} \times \mathcal{O}_\nu)$ $(\nu \neq 0)$ corresponds to the decomposition of the unit sphere $\mathbf{S}_3 \hookrightarrow \mathbf{R}^4$ by the Hopf fibration.

In terms of a partial Fourier cotransform, the symbol of K^ν takes the explicit form

$$\sigma(K^\nu)(x,y) = e^{-2\pi i \nu x y} \bar{\mathcal{F}}^2_{\mathbf{R}\oplus\mathbf{R}} K^\nu(x,y) \qquad ((x,y) \in \mathbf{R} \oplus \mathbf{R})$$

The excitation profile, generated by the density f of proton-weighted spin isochromats, takes the form of the symplectic spinor extension

$$U^\nu(f)$$

corresponding to $U^\nu(\mathcal{L}_G)$. If the tempered distribution

$$K^\nu = K^\nu_f$$

represents the kernel associated to $U^\nu(f)$, the symbol $\sigma(K^\nu_f)$ of K^ν_f results from the standard spin echo pulse sequence.

- The continuous affine wavelet transform performing the spectral localization of the proton-weighted spin isochromat density f in the leaf $\mathbf{P}(\mathbf{R} \times \mathcal{O}_\nu)$ $(\nu \neq 0)$ by linear gradient stratification lifts to the central spectral transform for the sub-Laplacian $\mathcal{L}_G$.

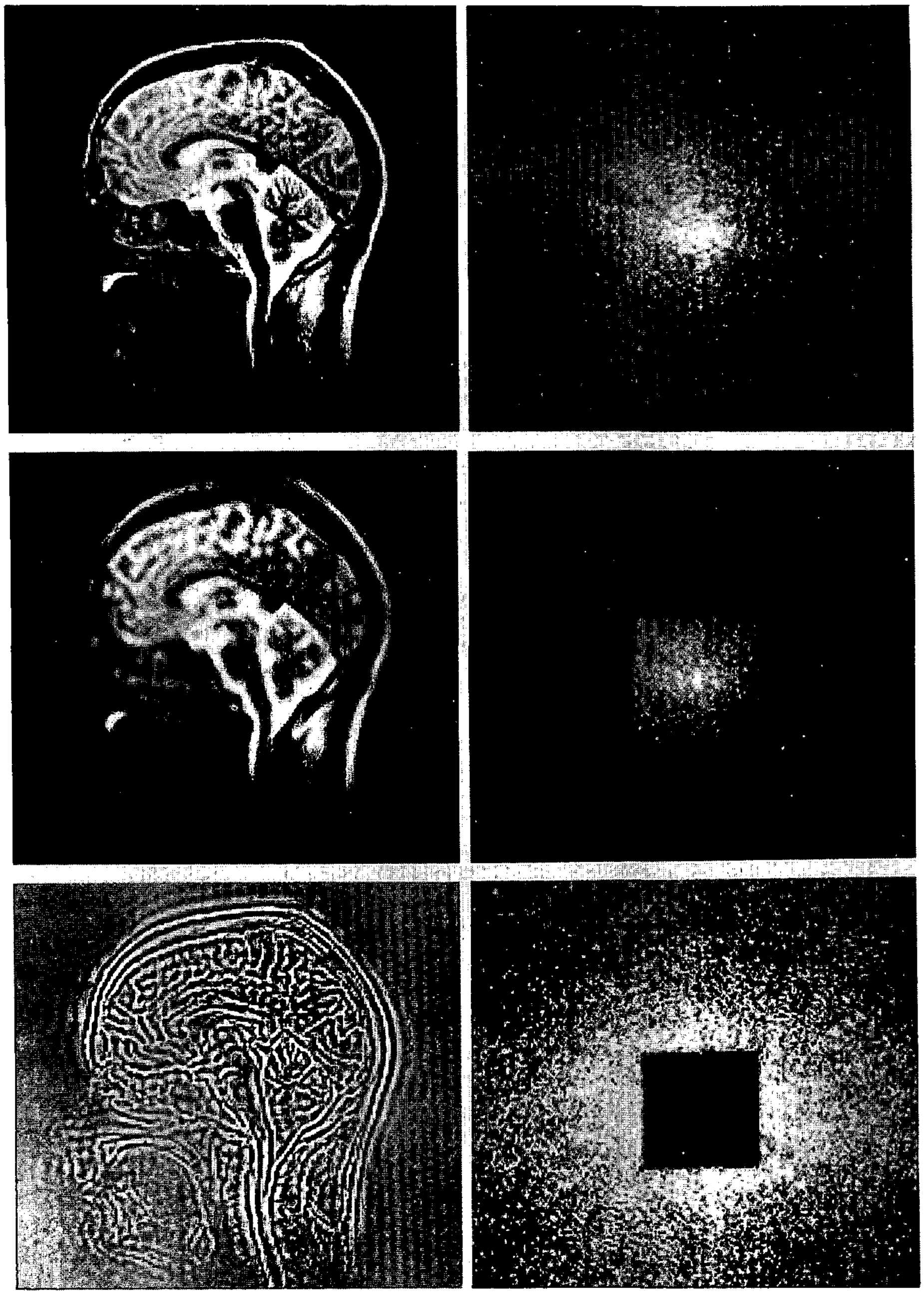

Figure 4: *Quantum hologram of a morphological MRI cranial study. The data near the center determine the contrast resolution so that the details are reduced due to the exclusion of the periphery. The peripheral data determine the edges of the midline sagittal cross–section of the cranium.*

- The central spectral transform for $\mathcal{L}_G$ diagonalizes the weak action of $\mathcal{L}_G$ on the symplectically reformatted two–dimensional Fourier transform. It gives rise to the distributional reproducing kernel $1 \otimes 1$ for the tracial read–out process of quantum holograms in the laboratory frame of reference.

- The Karhunen–Loëve expansion associated to the central spectral transform provides the information distribution within the quantum hologram.

- The reconstructive amplification process is performed by coherent quantum stochastic resonance as a form of multichannel parallelism.
- The multichannel reconstruction of the phase histories in local frequency encoding subbands from the symbol $\sigma(K_f^\nu)$ is performed by the symplectic Fourier transform $\star(1_\nu \otimes 1_\nu)$.

The Karhunen–Loëve transform is a unitary transform of $L^2(\mathbf{R} \oplus \mathbf{R})$ matched to the statistics of the input signal in such a way that it decorrelates the input and packs a maximum amount of information into the central components of the transformation. Fig. 4 illustrates the information distribution within the quantum hologram.

The spin echo method and the Lauterbur spectral localization method are closely related refocusing techniques. Why Lie group theory in the field of spin isochromat computing? Because the the Heisenberg group G allows to describe the *synergy* between radiofrequency pulse trains and linear gradient stratification. This synergy actually is the core of the tracial encoding procedure performed by MRI protocols. The Heisenberg group approach leads to the *explicit* tracial reconstruction formula

$$\boxed{f(x,y) = \frac{1}{2} e^{\pi i \nu x y} \sigma(K_f^\nu) \star (1_\nu \otimes 1_\nu)\left(\frac{1}{2}x, \frac{1}{2}y\right)}$$

The two-dimensional Fourier transform method, contributed by the physical chemist Ernst, forms the completion of the Lauterbur spectral localization method. It is remarkable, that the elliptic non-Euclidean geometry of the projective space $\mathbf{P}(\mathbf{R} \times \mathrm{Lie}(G)^\star)$ provides the unifying fundament for both of the achievements.

The Heisenberg group approach leads to the non-local entangling phenomenon of quantum physics ([41], [45]), and to major application areas of pulse train recovery methods, the corner turn algorithm in the digital processing of high resolution SAR data ([51]), the spin–warp procedure in clinical MRI via an application of the FFT algorithm, the gradient echo imaging methods, and finally to the variants of the ultra–high–speed echo–planar imaging technique of functional MRI ([45]). Combined with multi–slice imaging via interleaving of data acquisition, the spin–warp version of Fourier transform MRI is used almost exclusively in current routine clinical examinations ([12], [37], [46]).

Moving from the technology to the pathophysiology, the basis for clinical MRI is the intensive enhancement of neoplasms after application of a strongly *paramagnetic* contrast agent such as a gadolinium chelate. Frequently, MRI is the definitive examination procedure, providing invaluable information to help the surgeon not only to understand the underlying pathology, but also to make the critical decision regarding surgical intervention. For updated surveys of practical magnetic resonance tomography, see the monographs [4], [5], [7], [27].

The speed with which clinical MRI spread throughout the world as a diagnostic imaging tool was phenomenal. In the early 1980s, it burst onto the scene with even more intensity than XCT imaging in the 1970s. The superiority in spectroscopic sensivity of MRI over XCT imaging was first approved by the non–invasive detection of demyelinating plaques in multiple sclerosis (MS) patients (Fig. 5). For the MRI based diagnosis of demyelinating disorders such as MS, several chelates of gadolinium are available for use as intravenous paramagnetic contrast agents ([29], [36]).

Similarly, MRI is more sensitive than XCT for detecting the epileptogenic zones and is superior to XCT for predicting seizure outcome after surgery (Fig. 6).

Whereas at the end of 1981 there were only three working MRI scanner systems available in the United States, presently there are more than 4.000 imagers performing in a non–invasive manner more than 8.5 million examinations per year. Due to its spectroscopic sensitivity and specificity, MRI provides the techniques of choice to assess MS plaques of demyelination in the periventricular white matter, cerebral cortex, cerebellum, brainstem, and spinal cord, and to monitor the short–term as well as the long–term evolution of MS ([4], [29]). The contrast developed by lesions depends on the orientation of myelinated white matter tracts relative to the

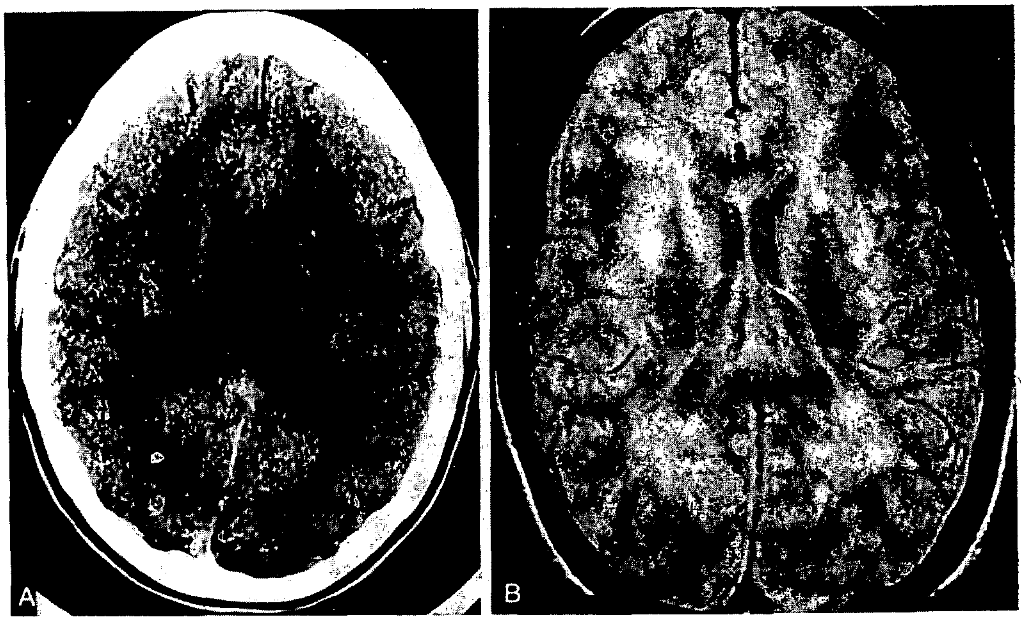

Figure 5: *Multiple sclerosis (MS): XCT imaging versus morphological MRI. (A) Nonenhanced XCT scan is normal. Following contrast administration, a single small focus of enhancement was observed. (B) Morphological MRI study obtained one day later reveals numerous areas of increased signal intensity in MS plaques. Several demyelinating plaques enhanced following gadolinium chelate administration. MRI is the imaging test of choice for MS.*

linear magnetic field gradients. With gradients perpendicular to the predominant fiber direction, the lesions are poorly seen. With gradients parallel to the fibers, they are readily seen. XCT imaging is not reliable for the diagnosis of MS.

The speed of growth is a testimony of the clinical significance of this sophisticated technique. Today the modality is firmly established as a core diagnostic tool in the fields of neuroradiology ([1], [2], [3], [14], [28], [30], [35], [49]) and musculoskeletal imaging ([8], [18], [21], [48], [50]), routinely used in all medical centers in Western Europe and the United States. The ability to display the morphological anatomy of living individuals in remarkable detail has been a tremendous boon to clinical practice. It etablishes that non–trivial mathematics can be applied to the benefit of humankind. Due to the inclusions

$$\mathbf{R} \hookrightarrow \mathbf{C} \hookrightarrow \mathbf{H},$$

the claim that four–dimensional spaces are quite *exceptional*, is no idle talk, at least from the point of view of clinical MRI which offers a fascinating intellectual study in its own right.

Summarizing the significant breakthrough which MRI represents in conjunction with the recent hardware and software developments, the future of clinical MRI as a non–invasive diagnostic imaging modality seems to be bright. With its many advantages, including unrestricted multiplanar imaging capability, high spatial resolution imaging, exquisite contrast imaging of soft tissues, in addition to great versatility offering the ability to image blood flow, motion during the cardiac cycle, temperature effects, and chemical shifts, morphological MRI studies are a well–recognized tool in the evaluation of anatomic, pathologic, and functional processes. Specifically, clinical MRI allows for greater

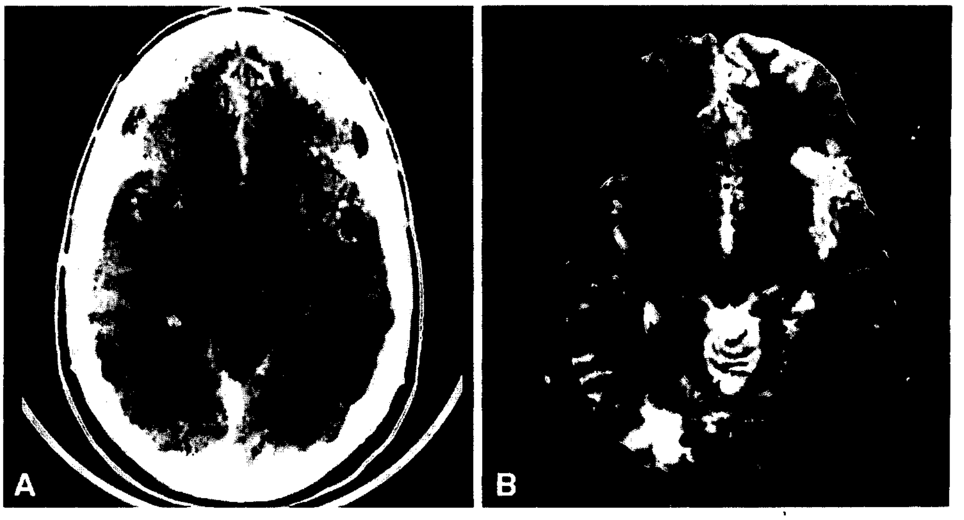

Figure 6: *Right occipital lobe astrocytoma: XCT imaging versus morphological MRI. (A) Contrast–enhanced XCT scan of the infiltrating glioma. The tumor cannot be detected on the XCT scan. (B) The tumor is clearly visualized by the morphological MRI study. This patient has remained seizure free for five years after surgery.*

depiction of tumor extension and staging ([21], [37], [46]).

In light of the several dozens of scans that need to be analyzed and semantically interpreted in order to acquire comprehensive information from morphological MRI studies which give consistent help in terms of earlier diagnosis, lesion characterization, and definition of the extent of disease, it is worth looking for some laborious routine tasks which could be automated and done by computers. As the applications of functional MRI in clinical radiology become more evident, automation is an even more important requirement for neurofunctional MRI studies which are based on the evaluation of hundreds of scans to detect signal changes well below the visual detection threshold under exclusion of changes that originate in head motion which correlate with the motor or visual stimuli, and simulate activiation of the human brain (Fig. 7).

Radiologists are skilled at interpreting original cross–sectional scans. Nevertheless, more advanced techniques such as magnetic resonance angiography need computer–based medical three–dimensional imaging. Despite formidable challenges, technical advances have already made it possible to develop multiple surface and volume algorithms to generate clinically useful three–dimensional renderings from MRI data sets.

Although MRI has not reached the end of its development, this diagnostic imaging modality has already undoubtedly saved many lives, and patients the world over enjoy a higher quality of life, thanks to MRI. The previously impenetrable black holes of lung air spaces are finally yielding their secrets to MRI. Utilizing inhaled ^{3}He or ^{129}Xe gases that are hyperpolarized by laser light, MRI scans can be acquired in a breath–hold that promise to reveal new insights into pulmonary anatomy and function. Because the exhaled gases can be recycled, MRI will play a role also in the earlier detection of chest diseases and bronchiectasis, and surgical planning of lung transplantation.

Laser technology has been developed sufficiently that is now reliable, portable, and deliverable in

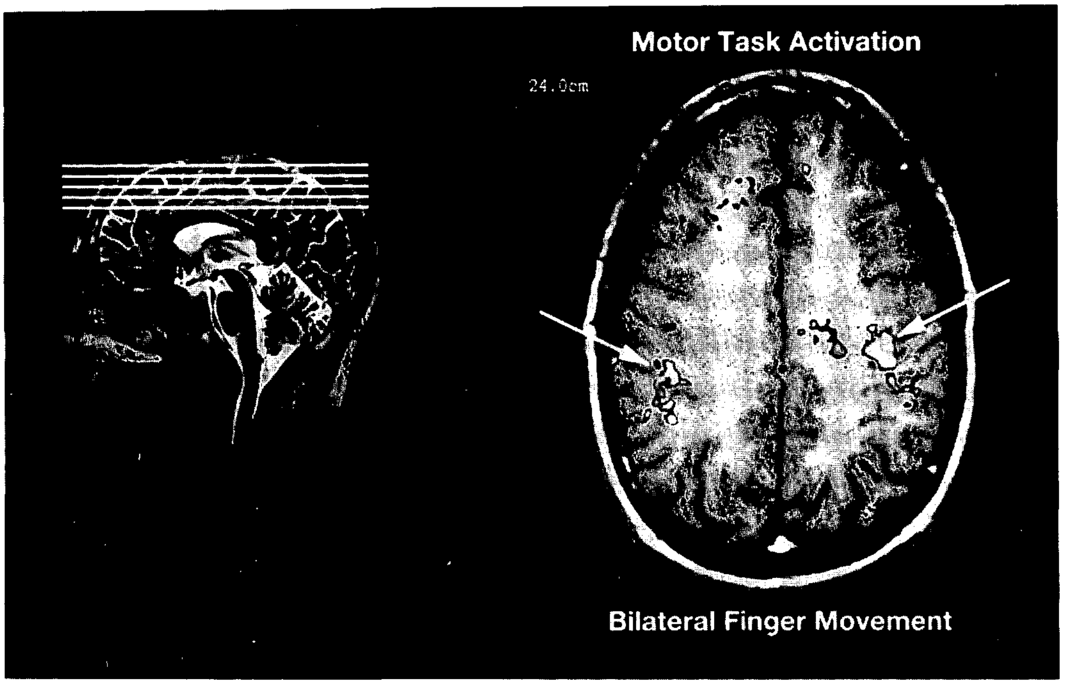

Figure 7: *Human brain mapping: Coadjoint orbit foliation of the transverse morphological cranial anatomy, and motor task activation mapping of the cerebral cortex by a neurofunctional MRI study of bilateral finger movement.*

an MRI environment. The high spectroscopic sensitivity of contrast-enhanced MRI to detect and show the local extent of mamma carcinoma is now well established. Further, it offers a method of monitoring the thermal effects of laser ablation during treatment. Neither ultrasound nor XCT imaging can accurately map the tumor or the therapeutic effect. For these reasons, MRI has been used for the development of interstitial laser photocoagulation therapy for local tumor destruction within the breast. To date, it had been shown that large areas of laser necrosis can be generated under MRI-guidance, and that these can be documented during treatment using fast imaging techniques, and after treatment by follow-up contrast-enhanced MRI studies of the breast. Thus MRI is not only useful for diagnostic imaging and loco-regional staging, but also forms a valuable tool for minimally invasive interventional procedures.

The dramatic advances made in clinical MRI within the last few years, the resulting enhancement of the ability to evaluate morphological and pathologic changes ([12], [46]), and the non-invasive window on human brain activation offered by neurofunctional MRI studies to the preoperative assessment ([10], [30], [39]), demonstrate the *unity* of mathematics, science, and engineering in an impressive manner. This unity of sciences proves that the frontiers between different disciplines are only conventional. The frontiers change according to the state of human knowledge, the understanding of nature, and the computer performance *in silicio* available. They can be penetrated by mathematical methodology which allows to support the semantic filter needed as an essential component of all observations and interpretations in biology and medicine.

In conclusion, it can only be assumed that the inexorable progress of quantum holography and MRI will continue, and that there are many more improvements and discoveries of new clinical applications around the corner. The reader should try to accept these extensions of human knowledge and understanding of nature as part of interesting mathematics for the benefit of humankind.

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References

[1] BALL, W.S., Jr., Ed. 1997. Pediatric Neuroradiology. Lippincott–Raven Publishers. Philadelphia. New York.

[2] BARKOVICH, A.J. 1995. Pediatric Neuroimaging. Second edition. Raven Press. New York.

[3] BARKOVICH, A.J. & C.L. TRUWIT. 1990. Practical MRI Atlas of the Neonatal Brain Development. Raven Press. New York.

[4] BELTRAN, J., Ed. 1995. Current Review of MRI. First edition. Current Medicine. Philadelphia.

[5] BROWN, J.J. & F.J. WIPPOLD, II. 1995. Practical MRI: A Teaching File. Lippincott–Raven Publishers. Philadelphia. New York.

[6] CALLAGHAN, P.T. 1995. Principles of Nuclear Magnetic Resonance Microscopy. Clarendon Press. Oxford. New York. Toronto.

[7] CARDOZA, J.D. & R.J. HERFKENS. 1994. MRI Survival Guide. Raven Press. New York.

[8] CHAN, W.P., P. LANG & H.K. GENANT. 1994. MRI of the Musculoskeletal System. W.B. Saunders. Philadelphia. London. Toronto.

[9] CHANGEUX, J.–P. & A. CONNES. 1992. Gedankenmaterie. Springer–Verlag. Berlin. Heidelberg. New York.

[10] COHEN, M.S. 1996. Rapid MRI and functional applications. *In* Brain Mapping: The Methods, A.W. Toga & J.C. Mazziotta, Eds. 223–255. Academic Press. San Diego. New York. Boston.

[11] CORY, D.G., A.F. FAHMY & T.F. HAVEL. 1997. Ensemble quantum computing by NMR spectroscopy. Proc. Natl. Acad. Sci. USA 94:1634–1639.

[12] CROOKS, L.E. & P. ROTHSCHILD. 1992. Clinical imaging. *In* Pulsed Magnetic Resonance: NMR, ESR, and Optics: A Recognition of E.L. Hahn. D.M.S. Bagguley, Ed. 346–361. Clarendon Press. Oxford. New York. Toronto.

[13] CUTRONA, L.J., E.M. LEITH, L.J. PORCELLO & W.E. VIVIAN. 1966. On the application of coherent optical processing techniques to synthetic–aperture radar. Proc. IEEE 54:1026–1032.

[14] DAMASIO, H. 1995. Human Brain Anatomy in Computerized Images. Oxford University Press. Oxford. New York. Athens.

[15] DAVIES, E.R. 1993. Electronics, Noise and Signal Recovery. Academic Press. London. San Diego. New York.

[16] DELEUZE, G. & F. GUATTARI. 1980. Mille Plateaux. Les Éditions de Minuit. Paris.

[17] DELEUZE, G. & F. GUATTARI. 1991. Q'est–ce que la philosophie? Les Éditions de Minuit. Paris.

[18] DEUTSCH, A.L. & J.H. MINK. 1997. MRI of the Musculoskeletal System: A Teaching File. Second edition. Lippincott–Raven Publishers. Philadelphia. New York.

[19] DIEUDONNÉ, J.A. 1971. La Géométrie des Groupes Classiques. Troisième édition. Springer–Verlag. Berlin. Heidelberg. New York.

[20] DOUGLASS, J.K., L. WILKENS, E. PANTAZELOU & F. MOSS. 1993. Noise enhancement of information transfer in crayfish mechanoreceptors by stochastic resonance. Nature 365:337–340.

[21] EDELMAN, R.R., J.R. HESSELINK & M.B. ZLATKIN. 1996. Clinical Magnetic Resonance Imaging. Two volumes. Second edition. W.B. Saunders Company. Philadelphia. London. Toronto.

[22] FARRE, G.L. 1997. The energetic structure of observation. Amer. Behavioral Scientist 40:717–728.

[23] FREEMAN, R. 1997. Spin Choreography: Basic Steps in High Resolution NMR. Spektrum Academic Publishers. Oxford.

[24] FUKUSHIMA, E., Ed. 1989. NMR in Biomedicine: The Physical Basis. Key Papers in Physics. No. 2. The American Institute of Physics. New York.

[25] GILLIES, R.J. 1994. NMR in Physiology and Biomedicine. R.J. Gillies, Ed. Academic Press. San Diego. New York. Boston.

[26] GERSHENFELD, N.A. & I.L. CHUANG. 1997. Bulk spin–resonance quantum computation. Science 275:350–356.

[27] HEUSER, L. & M. OUDKERK, Eds. 1996. Advances in MRI. Blackwell Science. Oxford. London. Edinburgh.

[28] JACKSON, G.D. & J.S. DUNCAN. 1996. MRI Neuroanatomy: A New Angle on the Brain. Churchill Livingstone. New York. Edinburgh. London.

[29] KNAAP, M.S. VAN DE & J. VALK. 1995. Magnetic Resonance of Myelin, Myelination, and Myelin Disorders. Second edition, Springer–Verlag. Berlin. Heidelberg. New York.

[30] KRETSCHMANN, H.J. & W. WEINRICH. 1996. Dreidimensionale Computergraphik neurofunktioneller Systeme. Georg Thieme Verlag. Stuttgart. New York.

[31] LEITH, E.N. 1978. Synthetic aperture radar. *In* Optical Data Processing. Applications. D. Casasent, Ed. 89–117. Springer–Verlag. Berlin. Heidelberg. New York.

[32] LEITH, E.N. 1994. Optical processing of synthetic aperture radar data. *In* Photonic Aspects of Modern Radar. H. Zmuda & E.N. Toughlian, Eds. 381–401. Artech House. Boston. London.

[33] LLOYD, S. 1996. Universal quantum simulators. Science 273:1073–1078.

[34] MATTSON, J. & M. SIMON. 1996. The Pioneers of NMR and Magnetic Resonance in Medicine: The Story of MRI. Bar–Ilan University Press. Ramat Gan.

[35] PATEL, V.H. & L. FRIEDMAN. 1997. MRI of the Brain: Normal Anatomy and Normal Variants. W.B. Saunders. Philadelphia. London. Toronto.

[36] PATY, D.W. 1994. Multiple sclerosis. *In* Functional Neuroimaging. R.E. Kelley, Ed. 395–413. Futura Publishing Company. Armonk. New York.

[37] REISER, M. & W. SEMMLER, Hrsg. 1997. Magnetresonanztomographie. 2. Auflage. Springer–Verlag. Berlin. Heidelberg. New York.

[38] RIHACZEK, A.W. 1996. Principles of High–Resolution Radar. Artech House. Boston. London.

[39] SANDERS, J.A. & W.W. ORRISON, Jr. 1995. Functional magnetic resonance imaging. *In* Functional Brain Mapping. W.W. Orrison, Jr., J.D. Lewine, J.A. Sanders & M.F. Hartshorne, Eds. 239–326. Mosby Year Book. St. Louis. Baltimore. Boston.

[40] SCHEMPP, W. 1986. Harmonic Analysis on the Heisenberg Nilpotent Lie Group, with Applications to Signal Theory. Pitman Research Notes in Mathematics Series. Vol. 147. Longman Scientific and Technical. London.

[41] SCHEMPP, W. 1996. Geometric analysis: The double–slit interference experiment and magnetic resonance imaging. Cybernetics and Systems '96. Vol. 1. 179–183. Austrian Society for Cybernetic Studies. Vienna.

[42] SCHEMPP, W. 1997. Wavelets in high–resolution radar imaging and clinical magnetic resonance tomography. Cybernetics and Systems 28:1–23.

[43] SCHEMPP, W. 1997. Wavelet modelling of high resolution radar imaging and clinical magnetic resonance tomography. Result. Math. 31:195–244.

[44] SCHEMPP, W. Geometric analysis and symbol calculus: Fourier transform magnetic resonance imaging and wavelets. Acta Applicandae Mathematicae. In print.

[45] SCHEMPP, W. Magnetic Resonance Tomography: Mathematical Foundations and Applications. John Wiley & Sons. New York. Chichester. Brisbane. In print.

[46] STARK, D.D. & W.G. BRADLEY, Jr. 1992. Magnetic Resonance Imaging, Volumes I and II. Second edition. Mosby Year Book. St. Louis. Baltimore. Boston.

[47] STEPHENSON, B. 1994. Kepler's Physical Astronomy. Princeton University Press. Princeton, NJ.

[48] STOLLER, D.W. 1997. Magnetic Resonance Imaging in Orthopaedics & Sports Medicine. Second edition. Lippincott–Raven Publishers. Philadelphia. New York.

[49] TRUWIT, C.L. & T.E. LEMPERT. 1994. High Resolution Atlas of Cranial Neuroanatomy. Williams & Wilkins. Baltimore. Philadelphia. Hong Kong.

[50] VAHLENSIECK, M. & M. REISER, Hrsg. 1997. MRT des Bewegungsapparats. Georg Thieme Verlag. Stuttgart. New York.

[51] WEHNER, D.R. 1987. High Resolution Radar. Artech House. Norwood, MA.

[52] WU, T.K. 1995. Frequency Selective Surface and Grid Array. John Wiley & Sons. New York. Chichester. Brisbane.

Call for Papers

Working Group 8.3 of the International Federation for Information Processing invites you to participate in its 1998 working conference on

CONTEXT-SENSITIVE DECISION SUPPORT SYSTEMS

LOCATION: Bled, Slovenia

DATES: 13-15 July 1998 (opening reception on Sunday, July 12th)

ORGANIZED BY: IFIP Working Group 8.3 on Decision Support Systems; The University of Maribor, Faculty of Organizational Sciences and The Slovene Society Informatika

The focus of this conference is on issues related to developing context-sensitive decision support systems (DSS). There are a number of contexts that need to be taken into account (e.g., cultural, organizational, task-, role- or individual-related), depending on the purpose of the DSS and its target user(s). These contexts interact with and influence each other and an appreciation of their importance, in their totality, in design decisions can give rise to DSS which are adaptable to different environments and circumstances.

The adaptability of a decision support system should be considered along two different dimensions. On one hand, we have the horizontal dimension which considers changes though time within a particular context. That is, organizations and their practices change their requirements for decision support and technology continuously progresses to the effect that designers are given a much wider range of technical possibilities for providing decision support in a manner that could be more effective. Moreover, specific DSS face the problem where data, information and knowledge are continuously evolving. On the other hand, we have the vertical dimension of adaptability which relates to the transferability of the DSS to different (cultural or organizational) contexts. DSS, designed on the basis of an image of a generalizable task or role, irrespective of its context, will fail their purpose because they may be too general to support fully even the original intended user(s) because his/her cultural and organizational context has not been taken into account.

This conference aims to initiate a discussion on these issues which are of vital importance to designing effective and adaptable DSS. It will welcome contributions from all disciplines as the issues in question cut across different disciplines, each making its unique contribution to the topic. The Conference Goal is:
How can we bring about a more useful, context-sensitive, generation of DSS?

The pivotal issues the conforence wishes to address are:
How one can understand the context within which one designs and implements a DSS?
How one can model, represent and use context in a DSS?
How may context-sensitivity improve the effectiveness of DSS?

We invite papers and panel proposals related to:

- design of DSS for reasoning about context
- design of a DSS that takes into account its context
- interaction of choice and context
- impact of context on DSS success
- role of context in the decision maker-DSS interaction/cooperation
- role of context in the decision maker-DSS complementarity
- role of context in the knowledge organization of the DSS and its reasoning
- context and alternatives (selection, argumentation, explanation)
- context and decision criteria
- change and adaptability of DSS within one organization

SUBMISSION DATES:

- Full abstract (500-600 words):1 October 1997
- Deadline for submission of paper: 9 January 1998
- Notification of acceptance:13 February 1998
- Camera-ready copy due:16 March 1998

INSTRUCTIONS TO AUTHORS:

Only original unpublished papers should be submitted. All submissions will be reviewed. Selection for presentation at the conference and publication in the proceedings will be based on originality, contribution to the field, and relevance to the conference theme. The conference book, published by Chapman and Hall, will be distributed at the conference and at least one author for each paper must register for the conference and present the paper.

Papers must not exceed 12-15 pages when single spaced. All submissions must include on the first page: title, author's name(s), affiliation, complete mailing address, phone number, fax number, and email address. An abstract of 100 words maximum and up to five keywords should be included before the body of the paper. Papers must be submitted in electronic form, using the Chapman and Hall Word template UKdoc.doc, which can be found on the web at ¡http://www.itch.com/itch/authors/macros.html¿. This template contains detailed guidelines on how to format your paper. It is very important that you load the template and type within it using the automatic style guidelines it gives.

We would like to request that a 500-600 word abstract for your paper be submitted by 1 October 1997 for comments. Submissions can be sent by e-mail to: Dina Berkeley at the London School of Economics.

For further information, please contact program committee members:

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Call for Papers

Joint Conference on Knowledge-Based Software Engineering

ABOUT THE CONFERENCE

Joint Conference on Knowledge-Based Software Engineering aims to provide a forum for researchers and practitioners to discuss topics in knowledge engineering and in software engineering. Special emphasis is given to application of knowledge-based methods to software engineering problems. The conference originated from efforts to provide a suitable forum for contacts for scientists mainly from Japan, the CIS countries and the countries of the Central and Eastern Europe while always being open for participants from the whole world. JCKBSE will continue in this tradition and expand for even greater international participation. Also, the scope of the conference as indicated by its topics is being updated to reflect the recent development in all three areas i.e.,

- knowledge engineering,
- software engineering,
- knowledge-based software engineering.

The conference will also include an invited talk and a tutorial.

TOPICS include, but are not limited to:

- Architecture of knowledge, software and information systems including collaborative, distributed and multi-agent systems, internet and intranet
- Automating software design and synthesis
- Domain modeling, distance learning
- Knowledge acquisition, knowledge discovery and data mining
- Process management, maintenance and evolution
- Program understanding, programming knowledge
- Reuse, re-engineering, reverse engineering
- Requirements engineering
- User interfaces and human interaction
- Testing, verification & validation
- Knowledge-based methods and tools for software engineering, CASE
- Decision support methods for software engineering
- Object-oriented and other programming paradigms, metaprogramming
- Knowledge system development tools and environments
- Software engineering education
- Learning of programming, modeling programs and programmers

Second Call for Papers

PAKDD-98

The 2nd Pacific-Asia Conference on Knowledge Discovery and Data Mining

Melbourne Convention Centre, Melbourne, Australia,
15-17 April 1998

Invited Speakers:
Jiawei Han (ACSys Keynote Speaker, Simon Fraser U.); Chris Wallace (Monash U.)

The Second Pacific-Asia Conference on Knowledge Discovery and Data Mining (PAKDD-98) will provide an international forum for the sharing of original research results and practical development experiences among researchers and application developers from different KDD related areas such as machine learning, databases, statistics, knowledge acquisition, data visualization, software re-engineering, and knowledge-based systems. It will follow the success of PAKDD-97 held in Singapore in 1997 by bringing together participants from universities, industry and government.

Papers on all aspects of knowledge discovery and data mining are welcome. Areas of interest include, but are not limited to:

Data and Dimensionality Reduction
Data Mining Algorithms and Tools
Data Mining and Data Warehousing
Data Mining on the Internet
Data Mining Metrics
Data Preprocessing and Postprocessing
Data and Knowledge Visualization
Deduction and Induction in KDD
Discretisation of Continuous Data
Distributed Data Mining KDD Framework and Process
Knowledge Representation and Acquisition in KDD
Knowledge Reuse and Role of Domain Knowledge
Knowledge Acquisition in Software Re-Engineering and Software Information Systems
Induction of Rules and Decision Trees
Management Issues in KDD Machine Learning, Statistical and
Visualization Aspects of KDD (including Neural Networks, Rough Set Theory and Inductive Logic Programming)
Mining in-the-large vs Mining in-the-small
Noise Handling
Security and Privacy Issues in KDD
Successful/Innovative KDD Applications in Science, Government, Business and Industry

Both research and applications papers are solicited. All submitted papers will be reviewed on the basis of technical quality, relevance to KDD, significance, and clarity. Accepted papers will be published in the conference proceedings by Springer-Verlag (in the LNAI series). A selected number of the accepted papers will be expanded and revised for inclusion in a special issue of an international journal.

All submissions should be limited to a maximum of 5,000 words. Four hardcopies should be forwarded to the following address:

Professor Ramamohanarao Kotagiri
(PAKDD '98)
Department of Computer Science,
The University of Melbourne
Parkville, VIC 3052, Australia

Please include a cover page containing the title, authors (names, postal and email addresses), a 200-word abstract and up to 5 keywords. This cover page must accompany the paper.

4 copies of full papers by:	October 16, 1997
Acceptance notices:	December 22, 1997
Camera-readies due by:	January 30, 1998
Conference:	April 15-17, 1998

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Call for Papers

GKPO'98: 5th International Conference on Computer Graphics and Image Processing

The 5th GKPO'98 intends to group the best researchers active in the field of pictorial information exchange between computer and its environment. The reviewing process and strict acceptance criteria assure high quality of the accepted papers (only about half of the submitted papers were accepted for the previous GKPO'96 Conference). Number of participants is limited to 80 persons.

The conference will be a forum for presentation of theoretical aspects, methods, applications and systems of image processing. Unpublished research papers are solicited, particularly concerning the following topics:

- Physical-based and multisensor models of image formation
- Image enhancement, restoration and compression
- Image analysis and scene understanding
- Models for recognition of objects and scenes
- Modeling of human visual perception and mental imagery
- Structure reconstruction, 3D imaging and image synthesis
- Visualization and graphical data presentation
- Virtual reality and pictorial interaction
- Pictorial data bases and archivisation
- Parallel and neural networks image processing
- Computational geometry
- Computer-aided graphic arts and animation
- Industrial, medical and other applications

The programme will include: invited papers by leading researchers, selected contributions, exhibition of software and hardware products, and social events.

Conference information

Date: 18–22 of May, 1998

Location: Borki near Tomaszow Mazowiecki, a little resort in middle of Poland, about 110 km south-west of Warsaw

Submissions: Authors are requested to submit three copies of manuscript in English (max. 8 pages). Upon acceptance by the reviewers and programme committee, authors will be asked to submit a PC diskette (in DOS format), containing the text of the paper, prepared with LaTeX (an ASCII form of the text is admissible too), with pictures in POSTSCRIPT or PCX format (at 600 dpi), in accordance with Instruction for Authors of the journal Machine GRAPHICS & VISION.

Procedings:

Proceedings od the Conference will be published as a special issue vol. 7, nos. 1/2 of the Machine GRAPHICS & VISION Journal.

Deadlines:

Declaration form: 30 July 1997

Paper submission: 30 October 1997

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Call for Paper

BUSINESS INFORMATION SYSTEMS - BIS'98

2nd International Conference
Poznan, Poland 22-24 April 1998

(during the International Fair of Electronics, Telecommunication and Computer Engineering - INFOSYSTEM'98)

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Glos Wielkopolski (Poznan region newspaper); Informatyka (magazine); PCKurier (magazine); Teleinfo (magazine)

CONFERENCE SCOPE AND MISSION

The International Conference on Business Information Systems provides a forum for presenting and discussing research and industrial reports in the area of development and implementation of information systems as well as exploitation and improvement of information technology as applicable to business processes. Competitive market forces lead to shorter innovation cycles and to technological improvements and cost reductions that necessitate significant changes within enterprises: flattening and simplification of organizational structures, orientation on implementation rather than function, tasks fulfillment based on their priority and not chronological order, customization of products to satisfy specific needs of individual people, etc. The topics of BIS conferences derive from a fundamental observation that IT systems must support these evolving business objectives and processes. The conference builds on the success of the BIS'97 event attended by speakers from all over the world. This three-day forum is the initiative of the University of Economics in Poznanand the PoznanInternational Fair Inc. A strict refereeing process imposed on the Program Committee members ensures the quality of the papers. The Proceedings of the conference papers are edited and published. For BIS'98, we will attempt to achieve wider dissemination of BIS papers by inviting a recognized publishing house to print a number of selected papers and invited presentations in a book form. Papers can be presented in any of the three conference languages (English, German or Polish - with simultaneous translation to delegates).

TOPICS OF INTEREST

BIS'98 invites researchers and practitioners to submit papers that contribute to research in business information systems as well as papers that report on industrial IT projects. The Program Committee particularly encourages presentation of practical papers reporting on industry experiences or validated by prototype implementations. Topics are only restricted by the scope of the conference as defined above and they include inter alia:

* IT support for different levels of decision making: operational control, business management, and strategic planning.

* Information systems for different business sectors: industry, commerce and services, banks, insurance, public and local administration, etc.

* Integration of information systems: workflow, data warehouses, data replication, distributed databases, groupware, decision support, data mining, archiving and retrieval systems, coping with legacy systems, etc.

* Lifecycle process and methods: architectures and modeling of information systems, business

process reengineering, structured and object development methods, self learning organizations, quality management, metrics, project management, requirements trace-ability, training, outsourcing, etc.

* Electronic transactions: commerce and payments in the Internet, information systems communication, virtual organizations, hypertext, distributed object computing, standards, etc.

* Enabling technologies: relational and object databases, networks, mobile computing, multimedia, interoperability issues, data security, object reuse, patterns and frameworks, information superhighways, CASE tools, etc.

INVITED PAPERS:

The Program Committee has invited a number of internationally recognized experts to present invited papers (this list will be extended):

Prof. Andrzej Baborski, University of Economics in Wroclaw, Poland: Data Mining for Management Information Systems.

Prof. Hans-Peter Frei (UBILAB Zurich), Switzerland: Information Systems for Financial Institutions

Dr. Marc Girault, SEPT, France Smart Cards in BIS

Dr. Wojciech Kozaczynski, SSA Research & Development Labs, Chicago, USA: Very Large Distributed Business Systems for the Global Market

Prof. Hermann Krallmann, Technical University in Berlin, Germany: Life Cycle of Workflow

Prof. Bernard Kubiak, University of Gdansk, Poland: Information Systems in Virtual Organization

Prof. Leszek Maciaszek, Macquarie University, Sydney, Australia: Object Oriented Development of Business Information Systems - Approaches and Misconceptions

Prof. Serge Miranda, University of Nice Sophia Antipolis, Nice, France: New Trends in DB-Centric Enterprise Computing

Prof. Ludwig Nastansky, University of Paderborn, Germany: Workflow

Prof. Marek Mike Papazoglou, University of Tilburg, The Netherlands: Intelligent and Cooperative Information Systems (tentative title)

Prof. Marek Podgorny, Syracuse University, USA: (Title to be announced)

Prof. August-Wilhelm Scheer, University of Saarland, Germany: Modeling of Information Systems

Prof. Horst Strunz, Dortmund University, Germany: Logistics Workflow Simulation

Prof. A Min Tjoa, University of Technology of Vienna, Switzerland: Integrating Executive Information Systems and Data Warehouses

Prof. Rainer Thome, University of Wuerzburg, Germany: Electronic Commerce.

TUTORIALS:

The Program Committee invites proposals for additional activities supporting the major conference subject. We are particularly interested in tutorials presenting:

* new research directions,
* overviews of a discipline or a research area,
* technological innovations and new products.

The four and eight hour tutorials will take place on 21 April 1998.

MINISYMPOSIA:

The Program Committee invites proposals of Minisymposia addressing one or more of the conference topics. A Minisymposium should consist of 4-8 thirty-minute presentations. Minisymposia will take place on April 21, 1998. To contribute a Minisymposium, please submit the Minisymposium title, an extended abstract (one page) and a list of speakers (including their affiliations and presentation titles) to the Program Committee.

PROGRAM COMMITTEE:

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SUBMISSIONS:

* Long papers - max. 5000 words, not exceeding 16 double-spaced pages.
* Short papers - reports from projects, work in progress - max. 2500 words (8 double-spaced pages).
* Submissions through hard copies as well as by e-mail (more details on our web page).
* The text should be prepared in A-4 format using Times New Roman or similar, 11pt font with the margins: top - 5.7 cm, bottom - 5 cm, left and right - 4.2 cm. Preferably, the text should be prepared using Microsoft Word or ASCII code.
* Figures within text should be black and white /gray scale/ (max. 12,6 x 19 cm). Separate graphic file will be appreciated.
* Language of publication: English, German, Polish, with a strong preference for English.
* About 60-word abstracts in English should be included at the beginning of the paper.
* In addition, a cover page that includes the title, the author(s)'s name, affiliation and complete address, as well as the abstract should be submitted by e-mail.

* If the paper is accepted, the author(s) will be required to sign the following commitment: "All organizational approvals for the publication of this paper have been obtained. The author(s) will prepare the final manuscript in time for inclusion in the conference proceedings and will present the paper at the conference."

IMPORTANT DATES:

* 30 October 1997 - submission of Minisymposia Proposals

* 10 November 1997 - submission of contributed papers

* 20 December 1997 - notification of acceptance/rejection

* 20 December 1997 - notification of Minisympsia acceptance/rejection

* 15 January 1998 - submission of proposals for tutorials

* 31 January 1998 - submission of corrected and ready-to-print contributions

* 31 January 1998 - notification of tutorial acceptance/rejection

* 21 April 1998 - tutorials and minisymposia

* 22-24 April 1998 - the Conference

AFFILIATED EVENT

In December 1995 the Congress of Polish Informatics was held in Poznanresulting in the report: "Strategy for the Development of Informatics in Poland - The State, Perspectives and Suggestions". This was the Polish answer to Bangeman Report: "Europe and Global Information Society". During BIS'98 a special plenary discussion is planned that will be devoted to the preparation of the 2nd Congress of Polish Informatics. Polish and international experts will take part in this discussion.

MEDOC

Delegates will have access to selected scientific literature as electronic fulltexts. The documents covering computer science topics will be made available over the Internet by the owners. Textbooks, conference proceedings, electronic journals and technical reports will be made available.

VENUE

Poznan is situated at the crossroads of important international railway and road routes, midway between Berlin and Warsaw. It is one of the most important industrial, trade, cultural, academic and educational centers in Poland. In Poznan the social and economic changes of the past few years are most evident.

INFOSYSTEM is the biggest and the most important trade fair of all the electronics, telecommunications and computer engineering events organized in Poland. Every year Infosystem meets with a great interest from exhibiting companies, experts, buyers and public at large. A versatile and interesting program of promotional and educational events always accompanies the fair.

ADDRESSES FOR CORESPONDENCE

Program Committee:
University of Economics in Poznan, Department of Computer Science, Al. Niepodleglosci 10, 60-987 Poznan Poland, tel. +48/61/869 92 61 fax. +48/61/866 89 24, e-mail: bis@sylaba.poznan.pl, URL: http://www.bis.pozn.com

Organizing Committee:
Technical Information Office of Poznan International Fair, Glogowska 14, 60-734 Poznan Poland, tel. +48/61/869 22 06 fax. +48/61/866 66 50, e-mail: fagir@capella.ae.poznan.pl.

Call for Papers
4th International Conference on Numerical Methods and Applications: NM&A'98

August 19 - 23, 1998, Sofia, BULGARIA

The Bulgarian Academy of Sciences and Sofia University in cooperation with SIAM are organizing the 4th International Conference on Numerical Methods and Applications. The first three conferences served as a forum where scientists from the strongest research groups from the East and the West were provided an opportunity to exchange ideas and establish research cooperation. We plan to continue this tradition.

During the conference a wide range of problems concerning recent achievements in numerical methods and their applications in mathematical modeling will be discussed. We also plan to provide a forum for exchange of ideas between scientists who develop and study numerical methods, and researchers who use them for solving real world problems.

International Program Committee: Chairman: Bl. Sendov, O. Axelsson, J.H. Bramble, P.G.Ciarlet, B.N. Chetverushkin, I. Dimov, R.E. Ewing, R.P. Fedorenko, S. Godunov, W. Hackbusch, P. Hemker, U. Jaeckel, Z. Kamont, M.S. Kaschiev, S.P Kurdyumov, Yu.A. Kuznetsov, R.D. Lazarov, H. Niederreiter, B. Philippe, J. Popenda, Yu.P. Popov, I.V. Puzynin, S. Radev, S. Rjasanov, A.A. Samarskii, M. Schaefer, V. Thomee, P.N. Vabishchevich, P.S. Vassilevski, H.A. van der Vorst, L. Xanthis, Z. Zlatev

List of key and invited lecturers, who already accepted invitation of the Org.Commitee:
O. Axelsson, J.H. Bramble, B.N. Chetverushkin, R.E. Ewing, R.P. Fedorenko, S. Godunov, P. Hemker, U. Jaeckel, Z. Kamont, S.P Kurdyumov, Yu.A. Kuznetsov, R.D. Lazarov, H. Niederreiter, B. Philippe, Yu.P. Popov, I.V. Puzynin, S. Rjasanov, A.A. Samarskii, M. Schaefer, V. Thomee, P.N. Vabishchevich, H.A. van der Vorst, L. Xanthis, Z. Zlatev

Organizing Committee:
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Secretary: O. Iliev,
I. Bazhlekov, P. Binev, P. Entchev, A. Karaivanova, M. Koleva, N. Kol'kovska, T. Kostova, I. Lirkov, S. Margenov, M. Neytcheva, M. Paprzycki, S. Petrova, D. Vassileva, P. Yalamov, L. Zikatanov

Accommodation and Registration Fees: The living expenses (single room accommodation and full board) will be approximately of amount of $250 for 5 days. The registration fee will cover the Proceedings, the Conference Booklet and the Conference Dinner. Conference fee is $180 until May 31, 1998 and $230 thereafter.

Schedule:
Minisymposia proposals due: November 30, 1997
Contributed papers and registration forms due: February 15, 1998
Notification of acceptance: May 01, 1998
Preregistration (accommodation forms due): June 15, 1998

Please, contact us at the mailing address of the Organizing Committee:
NM&A - O(h4)'98, c/o Dr. Oleg Iliev,
Institute of Mathematics and Informatics,
Bulgarian Academy of Sciences,
Acad. G. Bonchev Str., Bl.8,
1113 Sofia, BULGARIA,
fax: (+359 2) 971 364,
e-mail: NMA98@MATH.ACAD.BG

E-mail communication is preferred. Detailed information will be updated on the World Wide Web server of the Institute of Mathematics:
http://banmatpc.math.acad.bg/ nma98/

Call for Papers

IASTED conferences

16th IASTED International Conference on Applied Informatics
February 23-25, 1998
Garmisch, Germany

For further information, contact:
IASTED Secretariat AI'98,
#80, 4500 - 16 Avenue NW,
Calgary, AB T3B 0M6,
Canada
tel: 403-288-1195,
fax: 403-247-6851,
email: iasted@cadvision.com,
http://www.iasted.com

IASTED International Conference on Artificial Intelligence and Soft Computing
May 27-30, 1998
Cancun, Mexico

For further information, contact:
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THE MINISTRY OF SCIENCE AND TECHNOLOGY OF THE REPUBLIC OF SLOVENIA

Address: Slovenska 50, 1000 Ljubljana, Tel.: +386 61 1311 107, Fax: +386 61 1324 140.
WWW:http://www.mzt.si
Minister: Lojze Marinček, Ph.D.

The Ministry also includes:

The Standards and Metrology Institute of the Republic of Slovenia
Address: Kotnikova 6, 61000 Ljubljana, Tel.: +386 61 1312 322, Fax: +386 61 314 882.

Slovenian Intellectual Property Office
Address: Kotnikova 6, 61000 Ljubljana, Tel.: +386 61 1312 322, Fax: +386 61 318 983.

Office of the Slovenian National Commission for UNESCO
Address: Slovenska 50, 1000 Ljubljana, Tel.: +386 61 1311 107, Fax: +386.61 302 951.

Scientific, Research and Development Potential:

The Ministry of Science and Technology is responsible for the R&D policy in Slovenia, and for controlling the government R&D budget in compliance with the National Research Program and Law on Research Activities in Slovenia. The Ministry finances or co-finance research projects through public bidding, while it directly finance some fixed cost of the national research institutes.

According to the statistics, based on OECD (Frascati) standards, national expenditures on R&D raised from 1,6 % of GDP in 1994 to 1,71 % in 1995. Table 2 shows an income of R&D organisation in million USD.

Objectives of R&D policy in Slovenia:

- maintaining the high level and quality of scientific technological research activities;
- stimulation and support to collaboration between research organisations and business, public, and other sectors;
- stimulating and supporting of scientific and research disciplines that are relevant to Slovenian national authenticity;
- co-financing and tax exemption to enterprises engaged in technical development and other applied research projects;
- support to human resources development with emphasis on young researchers; involvement in international research and development projects;
- transfer of knowledge, technology and research achievements into all spheres of Slovenian society.

Table source: Slovene Statistical Office.

Total investments in R&D (% of GDP)	1,71
Number of R&D Organisations	297
Total number of employees in R&D	12.416
Number of researchers	6.094
Number of Ph.D.	2.155
Number of M.Sc.	1.527

Table 1: Some R&D indicators for 1995

	Ph.D.			M.Sc.		
	1993	1994	1995	1993	1994	1995
Bus. Ent.	51	93	102	196	327	330
Gov. Inst.	482	574	568	395	471	463
Priv. np Org.	10	14	24	12	25	23
High. Edu.	1022	1307	1461	426	772	711
TOTAL	1565	1988	2155	1029	1595	1527

Table 2: Number of employees with Ph.D. and M.Sc.

	Basic Research		Applied Research		Exp. Devel.		Total	
	1994	1995	1994	1995	1994	1995	1994	1995
Business Enterprises	6,6	9,7	48,8	62,4	45,8	49,6	101,3	121,7
Government Institutes	22,4	18,6	13,7	14,3	9.9	6,7	46,1	39,6
Private non-profit Organisations	0,3	0,7	0,9	0,8	0,2	0,2	1,4	1,7
Higher Education	17,4	24,4	13,7	17,4	8,0	5,7	39,1	47,5
TOTAL	46,9	53,4	77,1	94,9	63.9	62,2	187,9	210,5

Table 3: Incomes of R&D organisations by sectors in 1995 (in million USD)

JOŽEF STEFAN INSTITUTE

Jožef Stefan (1835-1893) was one of the most prominent physicists of the 19th century. Born to Slovene parents, he obtained his Ph.D. at Vienna University, where he was later Director of the Physics Institute, Vice-President of the Vienna Academy of Sciences and a member of several scientific institutions in Europe. Stefan explored many areas in hydrodynamics, optics, acoustics, electricity, magnetism and the kinetic theory of gases. Among other things, he originated the law that the total radiation from a black body is proportional to the 4th power of its absolute temperature, known as the Stefan–Boltzmann law.

The Jožef Stefan Institute (JSI) is the leading independent scientific research institution in Slovenia, covering a broad spectrum of fundamental and applied research in the fields of physics, chemistry and biochemistry, electronics and information science, nuclear science technology, energy research and environmental science.

The Jožef Stefan Institute (JSI) is a research organisation for pure and applied research in the natural sciences and technology. Both are closely interconnected in research departments composed of different task teams. Emphasis in basic research is given to the development and education of young scientists, while applied research and development serve for the transfer of advanced knowledge, contributing to the development of the national economy and society in general.

At present, the Institute, with a total of about 700 staff, has 500 researchers, about 250 of whom are postgraduates, over 200 of whom have doctorates (Ph.D.), and around 150 of whom have permanent professorships or temporary teaching assignments at the Universities.

In view of its activities and status, the JSI plays the role of a national institute, complementing the role of the universities and bridging the gap between basic science and applications.

Research at the JSI includes the following major fields: physics; chemistry; electronics, informatics and computer sciences; biochemistry; ecology; reactor technology; applied mathematics. Most of the activities are more or less closely connected to information sciences, in particular computer sciences, artificial intelligence, language and speech technologies, computer-aided design, computer architectures, biocybernetics and robotics, computer automation and control, professional electronics, digital communications and networks, and applied mathematics.

The Institute is located in Ljubljana, the capital of the independent state of **Slovenia** (or S♡nia). The capital today is considered a crossroad between East, West and Mediterranean Europe, offering excellent productive capabilities and solid business opportunities, with strong international connections. Ljubljana is connected to important centers such as Prague, Budapest, Vienna, Zagreb, Milan, Rome, Monaco, Nice, Bern and Munich, all within a radius of 600 km.

In the last year on the site of the Jožef Stefan Institute, the Technology park "Ljubljana" has been proposed as part of the national strategy for technological development to foster synergies between research and industry, to promote joint ventures between university bodies, research institutes and innovative industry, to act as an incubator for high-tech initiatives and to accelerate the development cycle of innovative products.

At the present time, part of the Institute is being reorganized into several high-tech units supported by and connected within the Technology park at the Jožef Stefan Institute, established as the beginning of a regional Technology park "Ljubljana". The project is being developed at a particularly historical moment, characterized by the process of state reorganisation, privatisation and private initiative. The national Technology Park will take the form of a shareholding company and will host an independent venture-capital institution.

The promoters and operational entities of the project are the Republic of Slovenia, Ministry of Science and Technology and the Jožef Stefan Institute. The framework of the operation also includes the University of Ljubljana, the National Institute of Chemistry, the Institute for Electronics and Vacuum Technology and the Institute for Materials and Construction Research among others. In addition, the project is supported by the Ministry of Economic Relations and Development, the National Chamber of Economy and the City of Ljubljana.

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Public relations: Natalija Polenec

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AN INTERNATIONAL JOURNAL OF COMPUTING AND INFORMATICS

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