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A SOLUTION TO FUNDAMENTAL PROBLEMS OF COGNITIVE SCIENCES

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ABSTRACT: Problems laying at the foundation of cognitive sciences, such as the mind-body problem, the existence of qualia or the symbol grounding problem are all due to the lack of proper language to describe mind events. Such language is introduced in this paper. Cognitive systems are viewed primarily from the mentalistic point of view. Concepts and symbols interact strongly forming "mind objects". Mind states are identified with activations of these objects. An abstract, multidimensional "mind space" is defined, with the axes (dimensions) of the coordinate system corresponding to features of internal representations, such as preprocessed sensory data and abstract qualities. This space serves as a theater for mental events. A neural network, or a brain, is a natural realization for such model of the mind. Activation of objects of the mind space is governed by psychophysical laws and brings casual changes in the neural hardware. From the neuropsychological point of view mind objects result from activity of the neural cell assemblies. No fundamental problems with understanding of the real minds arise and the way to computational models of artificial minds is clear. The problem of free will and consciousness is also discussed.

KEYWORDS: cell assemblies, cognitive philosophy, cognitive science, consciousness, inner space, mental representation, mind, mind evolution, mind-body problem, philosophy of mind, psychophysics, symbol grounding.

1.0 INTRODUCTION: FUNDAMENTAL PROBLEMS

1.1. Foundations of cognitive sciences are plagued with many serious problems. Mind-body problem is one of the most difficult in the history of philosophy. How can the non-material mind, or the B-world in terms of Popper (1972), have influence on the material body and vice versa? In more technical terms: mind states appear to be "causally inert" (Fodor 1987) and yet they influence the brain and matter. Mind-body problem is basic to cognitive sciences: mental representations require cognitive agents and cognitive agents require mental representations. Some experts believe that the mind-body problem may never be solved and no new ideas to solve it are in sight (Rakover 1993 and the discussion following his paper). Rakover (1990) claims that problems with explanation of the mind-body relationship create discontinuity in psychological research and prevent continuous progress in significant part of psychology.

1.2. The problem of qualia, or of the qualitative character of our experiences, is another manifestation of the fundamental problems in cognitive science. Symbolic systems do not admit qualia and for many people it seems obvious that artificial systems cannot have genuine experiences, feel pain, have hopes or any autonomous purposes, that something mysterious is missing in computational approach to cognition (Penrose 1989). Yet it is hard to pinpoint what that "something" should be. I am not counting here the naive statements that quantum mechanics has something to do with it since the concept of consciousness based on quantum effects, advocated by some physicists, does not help to explain the numerous psychological facts related to conscious human behavior nor does it address the problem of qualia.

1.3. The symbol grounding problem (Harnad 1990) captures the difficulty of connecting the purely formal world of symbols and rules for creating other symbols with the mental world. "How can the meanings of the meaningless symbol tokens [...] be grounded in anything but other meaningless symbols?" (Harnad 1990). The frame problem may be treated as one of the symptoms of the symbol grounding problem (Harnad 1993). Most of the philosophical objections to the strong version of artificial intelligence, like Searle's "Chinese Room" argument (cf. the discussion in Hofstadter and Dennett, 1981), or formal arguments of Penrose (1989), are problems with defining a meaning in symbolic systems. The Central Paradox of Cognition (Smolensky et al 1992) is yet another statement of the same problem: how can the structure and meaning, expressed in symbols and ideas at the mental level result from numerical processing at the brain level? How can the formal theories of grammar, logical reasoning and higher mental faculties explain the full richness of human behavior?

1.4. Solution to all these problems, in full agreement with intentional realism as well as causal efficaciousness of naturalistic properties, is proposed below. It is based on a better understanding of mind events and their relation to symbols. The price to be paid for this solution is not high: contrary to the hypothesis of Newell and Simon (1976) the physical symbols system is not a sufficient basis for intelligence. Scientific theories require precise, realistic language to speak about the objects and events in their specific domains. The language of rules, logic and symbol processing does not describe real mind events. The language of neuronal excitations is also inadequate. A language more suitable for cognitive science is described below.

2.0 THE LANGUAGE OF MIND EVENTS

2.1. Mindless bodies and disembodied minds are products of imagination. There are many reasons to believe that minds are emergent properties of brains rather than to believe that brains are just receivers of minds, as Eccles (1994) does. Paleoantropological data slowly uncovers the origin of mental concepts (Sheets-Johnstone 1994) showing that the living body was essential to generate, by tactile–kinesthetic experiences, the basic concepts used in hominid thinking. Computational models of the infant's development (Rutkowska 1994) show little doubt that basic human concepts emerge from complexity of neural systems interacting with environment. Experience is intimately connected with bodily reactions that may be evoked by sensory stimuli or by recollection of previous such events. Memories are really "chunks of experiences" that left their imprints in the neural hardware. Mind develops in neuronal systems by "en-folding its environment" (including one's own body), therefore mind is a reflection of the Universe with its unpredictable events.

2.2. It is impossible to talk about mind events in terms of computational processes of neural hardware, as it is impossible to talk about properties of the liquid water in terms of properties of the hydrogen and oxygen gases or even properties of the individual molecules of water. Cooperative properties in interacting systems are always qualitatively different from properties of the constituents. It is not surprising that specific interactions of a large number of neurons give rise to qualitatively new properties. There is nothing strange in the emergence of the higher cognitive functions from the complexity of the brain. At each level of description an appropriate language and theory should be used. The flow of water in a river is described by hydrodynamics, the theory that uses specific concepts that cannot be directly derived from quantum mechanics. It is impossible to speak about mental events using directly the language of neural events as it is impossible to speak about turbulence in quantum mechanical terms. An appropriate language should be created for cognitive sciences. Mind events are given by direct experience while the existence of all other events is inferred from this experience by reasoning. Therefore cognitive science has to be based on mind events and has to connect these mind events with the computational processes in the brain.

2.3. The question "what is the mind" begs for a model, a language to speak of the mind. Is it possible to answer such question? Ultimately we may only explain what is the structure of the mind, as we can explain what is the structure of the matter, even though we cannot define what the matter is. In physics we use with great success concepts such as energy, space or time, concepts that are not reducible to simpler concepts. Ultimately the meaning of fundamental concepts should be grounded in direct common sensory experiences. The vicious circle of self-referential definitions is stopped by pointing directly to real events. What is the taste of chocolate? Only when you taste it you will know. What kind of an answer can we expect to the question: "what is the mind" ? Will an answer based on physical concepts, such as "the mind is a result of zero point vibration vacuum fluctuation interactions with the coherent states of microtubles" satisfy us? Or an answer claiming that the mind is a result of logical properties of some mathematical structures? Such answers are irrelevant to the understanding of cognitive processes and to cognitive sciences in general. A meaningful language to describe mind events is needed. It should allow for more precise description and should lead to models of the mind that can be tested in computer simulations. The language should be extendable but at the initial stage it should only cover the basic features of the mind, in a similar way as the mathematical language of classical physics allowed to describe planetary motions and other simple physical systems. The "time" of classical physics has little to do with the perception of time and yet proved to be a very useful concept. In the same way we should define a set of simple, useful concepts that will allow for more precise description of mind events.

2.4. In the Platonic world there are only abstract concepts, represented by symbols. Since language is based on linear sequences of symbols we tend to think that minds work by symbol manipulation. Two-years old children may not yet use symbols and yet their minds are already quite complex. What are the real mind events made from? They are composed primarily from the preprocessed sensory data and are mostly recognitions, recollections and memorizations. The preprocessing stage of sensory information is very important and much of the research in cognition is devoted to understanding how the low-level cognitive stages operate. Direct sensory perceptions and iconic memories of past experiences form primary mind objects, while secondary, more abstract objects acquire their meaning through their relations with the primary objects. Once a primary object, an experience involving bodily sensations as well as the internal mind states, is committed to the long-term memory it can be recalled back and the experience repeated (mental training, for example in music, really works). Some mind objects, even though conventionally designated by a single symbol, are very complex. They should be treated rather as a collection of interrelated simpler objects, occupying relatively large volume of the mind space, than as a single object. Probably the representation of the cognitive system itself, referred to as "myself", is the most complex of all mind objects.

2.5. The process of formation of mind objects takes many months of cognitive development. In the "inner space" infants reify very slowly their experiences as combinations of shapes, colors, smells and somatosensory data into fuzzy objects that are distinguishable from each other and are committed to long-term memory. My son once remarked when he was 7 years old that "words never end". Even a child can see the problem, as well as the solution: some words refer directly to sensory experiences, reactions of organisms. Words, labels for the concepts that we use, acquire their meaning via mutual interactions and mutual referencing, via context in which they appear. Mind cannot be based on the labels of objects only, as suggested by the formal symbolic approach to artificial intelligence, but should be based on the multidimensional mind objects. If sufficient time is given for recollection or contemplation of these objects they are experienced by the body. For example, thinking of an apple we recollect not just an abstract idea but colors, shapes, smells and taste. It is convenient to imagine that these objects are in some space called here "the mind space". Mind events are activations of entrained collections of mind objects.

2.6. It is easy to imagine mind objects corresponding to some physical object. How about more abstract concepts? Most of the symbols or concepts that we use do not have separate existence, i.e. if we had no facts entangling these concepts with other concepts we could not define them. Any time we learn a new concept we have to define it in relation to what we already know. The more features (dimensions) are entangled, the more relations to the existing facts are defined, the more precisely defined the mind object becomes. Children ask over and over questions "what is this", "is it like that" etc, and the formation of objects in their minds requires many years. The real grounding of the meaning of these objects is in sensory experiences. Even for blind and deaf people like Helen Keller it was the sensory experience of water flowing on her hand that opened the world of symbols to her. A concept such as "heavy" relates to the experience of trying to lift different objects and is defined in reference to different life events; a concept of the "even number" to experiences with division of numbers. Any concept we can think of is either related to direct sensory experiences or defined in reference to other concepts. Mind space is useful to accommodate mind objects and model relations among these objects, as a stage for mental events. We are free to build models of the mind spaces starting from a universal mind space that can 0 all imaginable mind events and ending at a very small spaces, constructed for the problem at hand. Every sensory or abstract feature or quality may define an independent variable for representation of the data received by a cognitive system, i.e. define a new dimensions in the mind space used to accommodate the data. How to give adaptive structures "feeling" of what is interesting and what is boring, what is right and what is wrong? How do we develop such feeling? In the learning process the input data and the symbols appear in different context and relations among these symbols are established, facilitating automatic associations (cf. Miikkulainen 1993 to see how such associations are created in a natural processing system). These relations are subjective, depending on the data selected for training and even on the order of presentation of the data. The sense of judgement developed in this way, purely subjective, is sufficient to answer such questions as "do you like it?", or determine the author of a literary work from the "feeling" of his style.

2.7. The multidimensional space spanned by the axes corresponding to the primitive features of inner representations is called the mind space or the inner space. Combination of these features define mind objects. Some features of representation are of binary type: existing-nonexisting. Other features have various degrees, for example numerical values or sizes. A "horse" has size, shape, head, tail, mane, makes sounds, likes to run, eats grass and is defined by all these and many other properties. Each of these features is to some degree fuzzy. The symbol "horse", as well as the few features of a horse just mentioned, activates the corresponding object in our mind. This particular combination of features forms a unique category. The meaning of the object is grounded in the combination of all relevant features of inner representation, some of them related to analog sensory data. More abstract information is represented as objects in form of kinestethic image schemas (Johnson 1987; Lakoff 1987) and time-related information is converted to spatial relations (Griniasty et.al. 1993). One way of modelling the mind objects is to represent them in the mind space as fuzzy areas of non-vanishing density around the combination of features that define them. The shape of an object in the mind space has of course nothing to do with its physical shape. Ancient Indian and Chinese philosophers understood the process of formation of the mind objects quite well, for example in the Lankavatara Sutra (quoted from Wilber 1985) the following description is given: "By appearance is meant that which reveals itself to the senses and to the discriminating mind and is perceived as form, sound, odor, taste and touch. Out of these appearances ideas are formed, such as clay, water, jar etc, by which one says: this is such and such thing and is no other - this is name."

2.8. Mind space is thus defined by the coordinate system based on all features of internal representation. Objects in the mind space are defined by "mind function" $M(X_i)$ for all relevant features X_i. Nonzero values of the mind function define these objects as a fuzzy regions in the mind space. Topographical relations of objects in this space are very difficult to imagine because of the large number of dimensions involved. Problems with understanding how the mind works are to a large degree connected with the difficulties in imagining relations in multidimensional spaces. The mind function, defined in the mind space, represents all objects that such system is able to recognize (i.e. correctly classify using partial description or distorted input). Cognitive system is able to modify the contents of the mind space by adding more objects (learning and remembering), modifying existing objects or learning new associations (changing topographical relations between existing objects).

2.9. Mind states may have symbolic label as one of the features in the mind space. Symbolic name is not different from other features of representation except that it is less fuzzy than most other features, thus allowing for faster retrieval of mind objects. We usually think about symbolic names as some unambiguous (sharply defined) codes, string of letters. The low-level preprocessing may remove some ambiguities from the sensory data reaching our minds but in general sounds or written words are also fuzzy. This fuzziness, expressed in different styles of handwriting or different pronunciations leads sometimes to a confusion. In such cases symbolic names do not match the labels of mind objects and additional properties are needed for correct activation of "what we have in mind" in minds of other people. Words have meaning defined only by the objects they activate in minds. A symbolic name assigned to a combination of representation features increases stability of the mind object by adding a sharply defined feature. Many primitive features used by the human mind, such as kinesthetic, visual or auditory features, do not have symbolic names.

2.10. At any given moment of time t some of the features of representation $X_i(t)$ have well defined values, pointing to certain regions of the mind space. These features of representation $X_i(t), i = 1, 2...$, change with time. A collection of these features is called "mind state". An object corresponding to a given mind state is "activated" - the system recognizes this object and may respond to it. The process of activation of mind objects, or the evolution of mind states, has its dynamics. States in the regions of high M-function values slow the rate of changes of the mind state, "trapping" these states for some period of time. It makes sense to talk about energy and momentum of this dynamics. Changing from one state of mind to another requires energy. The system receives this energy from the environment. The external stimuli are driving changes in the features of representation $X_i(t)$ leading to the recognition and learning processes. The internal dynamics leads to activations of the entrained mind objects (Laughlin et. al. 1990) and includes a stochastic component influencing the momentum of changes of mind states. The dynamics of the whole system is a mixture of this internal and external dynamics. The balance between the two determines the level of intro/extroverticity of the system.

2.11. The probability of finding the system in a given mind state at a given time t depends on evolution of the mind state and on the value of mind function for that state. Some mind objects are more "attractive" than others, they hold the mind states for a longer time and are activated more frequently during the evolution of the mind state. Creation of new objects in the mind space requires time and energy. Frequent presentation of certain features of representation, i.e. frequently repeated states of mind, increases the value of the mind function in the corresponding region, creating new or stabilizing the existing objects in the mind space. New objects or memory traces have a tendency to decay if the same regions (the same states) of mind space are not activated many times and are not linked via some associations to other mind objects (i.e. are not overlapping in some dimensions with these objects). Objects are connected via their shared features (i.e. similar projections on some subspaces of the mind space), therefore an entrainment of objects occurs (Laughlin et. al. 1990). Transition probability $p(A- > B)$ from the mind object A to the mind object B may be expressed in agreement with the conditional expectancy hypothesis of Sommerhoff (1990): "The brain's internal representations of the world consist of linked sets of conditional expectancies of the what-leads-to-what kind, which are in the main based on the past what-leads-to-what experiences of the world". The mathematical formalism useful for the description of actual dynamics resembles quantum-mechanical formalism, with $p(A- > B) =< M_A|P|M_B >$ where M_A is a certain mathematical representation of the mind object A and P is the momentum of the mind state in a given moment of time. Simple recognition and learning processes activate only one object at a time. Once activated, an object is easily accessible due to the short-term memory. Therefore various objects in the mind space may be active, depending on the state of the input variables (sensory data and meta-node outputs). In this way complex objects, composed from many simpler ones, are analyzed in the recognition process and created in the learning process. The states of mind that lead to the strongest values of the mind function leave memory traces and are remembered as "an experience", enabling feedback (reflection).

2.12. Expressions such as "to have in mind, to keep in mind, to put in mind" and many others refer directly to the mind space. It is not an accident that popular "mind maps" (Buzan 1989) are effective in improving learning since they reflect, albeit only in a crippled, 2-dimensional way, real entrainments of objects that should be formed in the mind space in the learning process. In the mind maps method of learning one identifies keywords, while other objects, such as words, drawings, iconografic symbols or numbers, are linked to these keywords creating a kind of semiotic net. Multiple links partially reflect the complexity of the multidimensional mind space containing objects corresponding to these symbols. Mind should be regarded as an open system. The number of dimensions in the mind space may change with introduction of new features. The topology of the mind space is time dependent. New mathematical tools are needed to deal with such spaces and such functions.

2.13. Human mind space, a container of concepts, ideas and memories, is almost empty. Although millions of mind objects are stored in it, many sharing the same features, forming richly connected structures (entrainments), most of regions of the mind space are empty. Assuming only 100000 features of representation (axes, dimensions), each taking only two values (present-not present), the number of all possible distinct objects in the mind space (in this case a binary hypercube) is equal to 2^{100000} or about 10^{30103}, an unimaginably large number that has nothing to do with the number of objects stored or even recognizable by the cognitive system. Not all features are relevant for each object, but even assuming that a combination of no more than 5 features defines an object still the number of all possible objects is of the order of 10^{23}. The number of distinguishable objects that may be stored in the mind space is almost unlimited (in practice hardware realizations impose some limits). The number of thoughts, memory recalls and other mind objects that are activated during human life is much smaller. The duration of conscious human life is of the order of 10^9 seconds. Assuming one mental event every second gives around 1 billion events. Thus the mind space is almost empty since only a very small fraction of potentially distinguishable objects are realized. The number of concepts an average human uses is perhaps in the range of $10^4 - 10^5$. The number of other objects in the mind space is even larger, including many iconic memories.

2.14. The language introduced here allows to speak about various mind events without leading to paradoxes. The relation of this language to the "real" mental events is of course metaphorical. The model is useful for discussion of evolution or development of minds through unsupervised and supervised learning in terms of the mind function and of the topography of the mind space, discussion of recognition, recollection, association, dynamics and many other mental processes. This language is based on purely abstract, mathematical constructs, and does not refer to anything physical. We are free to build various models of cognitive systems but if they should have any similarity to real minds they should be based on real mind events. The view of the mind presented here is very different from conventional: it is a dynamical system with evolution of the mind state leading to a series of activations of various mind objects. Symbols and language are of secondary importance and logic can at best be used to approximate evolution of the mind state in some circumstances. Such system is purely subjective and reflects the nonalgorithmic nature of its environment. Before discussing the cognitive paradoxes some remarks about hardware realizations of the abstract concepts introduced here and about the relations to neurobiology are presented.

3.0 HARDWARE AND BIOLOGICAL REALIZATIONS OF MIND

3.1. In practice mind function $M(X_i(t))$ has to be computed by some hardware. It is natural to realize the mind function in a form of a modular neural network based on localized representation of the mind objects, each node processing a separate object. Other realizations, based on nonlocal (distributed) representations, are also possible. The model does not relay on distributed representations for generalizations and associations, it is sufficient that features are represented as fuzzy areas in the mind space. Massively parallel computers with analog inputs/outputs are most suitable for the hardware realization of the mind function.

3.2. As first approximation models of modular neural networks, such as GaRBF models (Poggio and Girosi 1990, Platt 1991), CALM (Murre 1992), ALCOVE (Krushke 1992), SONNET (Nigrin 1993) or FSM (Duch 1994; Duch and Diercksen 1994) may be adopted to model the mind function. Mind space objects are organized in a hierarchical way: simple objects are created in the subspaces connected to sensory features of representation. These primary objects have their linguistic labels and are formed from classes of combinations of invariant features of representation (given by low-level visual, auditory and somatory processing). Metaobjects are formed from abstractions of these primary objects and include measures, numbers, simple physical concepts such as "mass", "force" or "energy". At the meta-metaobject level more abstract concepts, such as variables, fields, wavefunctions and quantum objects are defined. They are not close to the primary objects and thus their meaning is hard to understand or interpret since there is no direct relation to experience. In mathematics even higher order metaobjects are created.

3.3. Feature Space Mapping (FSM) is a neural network model based on the separable processing functions of the network nodes. Such network may be trained using supervised and unsupervised learning procedures and is equivalent to an expert system that uses fuzzy logic (Duch 1994; Duch and Diercksen 1994). The mind function and the objects of the mind space are created using the unsupervised learning procedures and a growing network of processing nodes. Topology of the objects in the mind space may be constrained (genetic conditioning). Such networks are capable of natural language processing (cf. Miikkulainen 1993). FSM is a neurofuzzy system constructed from the mind space point of view. The systems has some features characteristic to the biological cognitive systems, although it was not designed to be the model of such systems. For example, humans use linear evaluation in many situations, using terms such as 'worse' or 'better' for comparison of frequently quite incompatible data or multidimensional data that cannot be linearly ordered. In the mind space this tendency may be linked to the measuring of the distance of different mind objects relatively to some point of view. Another aspect of this linearized thinking is expressed in the way problems are solved by focusing on one aspect of the problem at a time. The brain uses topographical maps for auditory, motoric, somatic and visual actions, probably also for more abstract reasoning, so mapping to the low-dimensional spaces is frequently done. Low-level processing and topographical mappings (Kohonen 1989), in particular semantic topographical mappings can explain some aspects of psychophysical relations among objects of mind. In the mind space model these mappings are related to dimensionality reduction allowing for data compression. Another interesting feature is the ability to focus on general rather than specific and return to details after general understanding has been reached. Such defocusing and focusing operations are used for classification in FSM (a dynamical version of the bumptree structures is used to speed up searches in multidimensional spaces). People can reach the same conclusion or express the same fact in many alternative ways. Mind space admits many pathways since there are very many dimensions and possibilities of associations.

3.4. Although in cognitive modeling neurobiological plausibility should not be as important as psychobiological plausibility a few remarks about relations with neurobiology are in order. The low level sensory data processing and formation of the feature detectors are described best using the attractor neural networks (Amit 1989). Assemblies of neurons may specialize in recognition of certain mind objects or representation of objects in some regions of the mind space. For the symbol grounding problem it is important to note that the forward cortical projections are accompanied by prominent projections back to the original sites. The signals in neuroanatomical networks may flow back and forth to sensory receptors and subcortical brain structures, making the activation of an object in the mind space by an internal dynamics almost indistinguishable from the external activation (Damasio 1989). Results of recent experiments on processing words and pseudowords (Pulvermueller et.al. 1994) support the hypothesis that transcortical cell assemblies are involved in recognition of mind objects. These cell assemblies are large groups of neurons, with strongly reciprocal internal connections, binding parts of the cortex in which different sensory modalities are processed. Transcortical cell assemblies are sufficient to create objects of the mind space, i.e. to bind different sensory modalities in one experience, without any central place in the cortex where all information is gathered. Interactions among various wave patterns in these cell assemblies are modeled in a probabilistic way at the mind space level. The state of mind may become fuzzy, many objects partially activated, many things "going on" in the mind – if there are too many the state of the mind becomes chaotic (formally a "mental temperature" global parameter controls the overall activation). Experiments with monkeys show that neural activity persist for as long as 16 seconds after the removal of visual stimulus. Such experiments may be analyzed in details using models based on attractor neural networks (Grianiasty et.al. 1993). From mentalistic point of view they may be described as creation of new objects (visual memories) in the abstract mind space with immediate access to most recently activated objects. In the experiments with monkeys trained to recognize visual patterns temporarily correlated reinforcement stimuli are changed into spatially correlated attractors (Grianiasty et.al. 1983); in the mind space temporal correlations are creating entrainments of objects.

3.5. The state of mind is constantly changing because of the incoming sensory stimuli, including the proprioreceptive stimuli (reptilians do not have such strong proprioreceptive stimuli and their minds dwell in one state for a long time). In some cases (sensory deprivation) one can observe the dynamics of mind state without sensory stimuli, driven by the internal noise of the system. Activation of a mind object is equivalent to a wave front of activations of hundreds of thousands of neurons. Assuming about 10^5 cells in each assembly and 10^{11} neurons in the whole brain the number of independent cell assemblies available for representation of mind objects would be of the order of one million; since many assemblies may share the same neurons it may be even larger. Sensory stimuli signifying potential danger requiring urgent attention demand computing power of a good part of the brain, integrated reaction of the whole organism. Storing such experiences in long-term memory and recollecting or reliving them has strong evolutionary advantage. This could have been one of the major factors in the development of consciousness. Biological solution is not necessarily the simplest realization of the mind function. Since cell assemblies specialize in recognition of different mind objects there is no need for more detailed modeling at the actual distributed neural network level.

3.6. Specific "mind landscape" is formed in the infant and developmental period primarily by the unsupervised learning process, in which many new synaptic connections are added, enabling new neuron assemblies to be formed and store new mind objects. In the childhood and later periods more supervised learning is involved. In adults mind space objects become more rigid, entrainments of these objects more stable and the mind states have stronger tendency to repeat themselves. New mind objects are created with greater and greater difficulty. Near the end of life no new objects are created (including memory traces) and the old, if not activated frequently enough, are forgotten - even if they are not completely decayed the entrainment leading to their activations may be lost (hence the tendency to repeat the same stories many times). To understand the complexity of developed, conscious mind one should understand the development process, animal minds, hominid minds before language was invented and the stages of personal, especially infant development. Transformations of consciousness (Wilber et al 1986) start from pre-personal, sensorimotoric level. In the first two years general features of the mind's space topography are formed. Most of the primary mind objects are formed between the second and seventh year of life and metaobjects start to form only later. The self-reflection stage is reached only between eleventh and fifteenth year. Modelling cognitive system of an intelligent human is certainly a very difficult task but good models of less developed minds (animal and handicapped people) should not be so hard.

3.7. Logical reasoning and problem solving is rarely used by people. Even medical doctors, after many years of studying, relay mostly on an intuitive knowledge acquired during their practice. In the model presented here intuition results from topography of objects in the mind space. In intuitive response there is no reasoning involved, just a look-up of associative data in the mind space. Reasoning requires access to various theoretical concepts and may be done only by small steps. Many people will not even try to answer a question if they cannot do it intuitively. Folk medicine was always based on observations with little theoretical justification. The knowledge stored in the mind space is almost static, changing slowly with observations or with the new training data coming in. Intuitive knowledge, hailed through centuries in many cultures, for example as the tao principle, may be identified with the quality of the inner representations of the environment formed in the process of unsupervised learning.

3.8. Complex objects that do not have short symbolic name require dynamic analysis. Translating from English to my mother's tongue single words or short idiomatic expressions come up in my mind immediately, they are ready associations, objects "in place". Longer expressions or sentences must be restructured according to the grammatical rules of the target language. Complex, temporary mind object has to be constructed in the short term memory from available simpler elements, i.e. known objects that have linguistic labels. This complex object is now labeled by an appropriate expression or a sentence in the target language. This linguistic "deep structure" is not reducible to purely symbolic objects and therefore linguists have failed in their search for it. Language does not have to be verbal, for example language of the movies is primarily visual. Although linguistic processes are very important for understanding of human cognition they are irrelevant in context of the fundamental problems of cognitive sciences discussed in this paper.

3.9. It is obvious that some conscious phenomena experienced by humans may be explained only by taking into account the structure of real brains. For example, conscious perception of reality is distorted by slow operation of neurons. One of the most interesting illusions is the color Phi phenomenon (cf. Dennett 1991): two lights, red and green, are placed close to each other and switched on and off in a sequence every 0.2 seconds, creating an illusion of a moving light. The color of this moving light changes right between the two lights. It looks as if the mind synthetising this illusion from the sensory data could predict future: how do we know that the green light will be turned on in 0.2 second so that the red light seems to move towards it? The neurons operate slowly and the brain needs time to put the mind object together from different features of representation identified by the low-level subsystems. The subject of conscious experience is not the reality itself but the picture of reality build from mind objects and combinations of primitive features. The visual cortex contains separate subsystems for the color and for the motion detection. Once a recognition by these systems is made the brain network structures stay excited for a few tenth of a second; blinking of the other light activates the motion subsystem and the combination of these two features, the color and the motion, gives the illusion of moving color light. The time frame of 0.1 second is the shortest quanta of time for processes consciously perceived because at least that much time is necessary to form a mind object from combination of different sensory features.

3.10. The evolution of the mind states leads in a natural way to the dreaming and day-dreaming. During the night dreaming a number of mind objects may be activated or created from various primitive objects. Since there is no overall guidance of the senses correcting badly formed objects in the short-term memory strange combinations of features and mind objects are possible. In sensory deprivation situations (for example in the "samadhi tanks") mind space is explored. If mental activity is suppressed in deep concentration certain granularity of experience should be expected, due to the wandering of the mind state through many dimensions of the mind space. Symbols, feelings, trains of thought and moments of attention arise, are noticed (by the reflective feedback mechanism) and vanish. This is exactly what is reported during intensive meditation and concentration practices (Laughlin et al 1990). Regression during hypnosis leads to very detailed description of events from the distant past. The details recalled seem to be frequently imagined rather than remembered (O'Connel et.al. 1970). This is what one should expect: there is a slow decay of memories and substitution of averaged values for forgotten values. If a few features of some mind object are recalled the state of mind points to a subspace of the mind space containing similar objects and the missing features are obtained from the similar (neighbor) objects completing the mind object recalled.

4.0 SOLUTION TO THE FUNDAMENTAL COGNITIVE PARADOXES

4.1. The mathematical language introduced in the previous sections tries to capture the essence of operation of the real mind. The mind function is defined in the mind space and created via process of unsupervised learning and genetic evolution. The natural hardware realization of this abstract model is in the form of modular neural network. Nodes of such network model activity of the transcortical neural cell assemblies in biological brains. Evolution of the mind state and activation of the mind objects are mental, nonphysical processes. Parallel changes in the supporting hardware are physical processes. Physical and mental are just two sides of the same phenomenon and the operation of the mind system may be viewed from two sides.

4.2. Since mind objects are reified experiences there is no mind body problem. How can a state of mind, such as a "low gas" observation, lead to an intentional, physical action? If the mind is in the state represented by the "low gas" mind object the next probable train of states (only probable, because many factors may push the next state of mind in another direction) is "car will stop" and "look for the gas station". These mind objects were created in the learning process and once they are in the mind space the motoric actions associated with these objects will follow. The brain processes (or other hardware processes) have to follow this particular entrainment of mind objects because the only stable patterns of neural excitations correspond to the objects that are entrained. These objects are close to each other in the mind space (i.e. transition probabilities among these objects are high) and at the hardware level corresponding attractors in the recurrent neural network (Amit 1989) are close to each other. The presence of a non-physical concept in the mind has thus direct influence on the hardware states. My belief, via the entrainment process, leads to a series of states of mind. Since each state is grounded in the kinestethic image and sensoro-motoric schemes it has direct influence on hardware actions - the “mind over matter” mechanism is quite simple. On the other hand any disturbance in the natural functioning of the neural hardware (especially at the level of neurotransmiters in the brain) will strongly influence the dynamics of the mind states and thus experiences of the system.

4.3. The symbol grounding problem (Harnad 1990) is solved in an straightforward way, together with the problem of qualia. Each mind object, such as a memory object, is created from a combination of many features of internal representation. An activation of the object, equivalent to some state of the mind, is done using a subset of these features. Since it brings the state of mind into a specific region of the mind space other qualities associated with this object are immediately accessible, and the back-projection paths to the sensors activated. The experience is repeated, with vividity dependent on the strength of the back-coupling and the level of activation of the object. What do I mean by “sweet”? Something sweet! The system, like an old Zen master hitting with his stick, points directly at the sensory experiences as the ultimate source of grounding the mind in reality. The problem arises only when the linguistic labels are separated from other qualities of the objects of mind and when someone insists that such artificially created subsystem should act as a cognitive system. We do not ground symbols in experiences since experience comes before symbols, we label experiences. The label “sweet” corresponds to a projection of all sensations, all objects that we have associated with it. The existence of qualia has observable consequences: the probability of the next mind state obviously depends on them. From the sensation “sweet” memories of things sweet spring up.

4.4. The problem of the mental content is a particular form of the qualia problem connected with the mental objects. Thoughts must be about something since they are activations of mind objects containing reified experiences, are non-decomposable mixtures of many features of representation. Cognitive systems must have subjective states which results from their past experiences. Chomsky’s “poverty of the stimulus” argument is also easily refuted if the mind space is taken seriously. A single sensory stimulus or a single word may put the state of mind into a region of the mind space where associations abound. Words, or abstracts symbols, are particularly effective in activation of mind objects because - in contrast with analog features of representation - they are more specific, they provide labels uniquely identifying the regions of the mind space where “chunks of our experiences” are stored.

4.5. The language of mind events allows also to understand from a new point of view the problem of free will. The discussion presented here agrees with Crick’s approach (1994), although is more specific. Suppose that the system “has two choices”, i.e. there are two different reactions possible in response to the data presented. This means that two objects in the mind space may become activated, each of them associated via some common features with motoric or other actions. The evolution of the mind state may be indeterministic even though it may be predictable. There are two sources of randomness, external and internal. The evolution is indeterministic if the environment, reflected in the topography of mind objects, is indeterministic. Complicated interactions with other objects in the mind space, among them with the representation of the self, depend on random events in the environment and have an influence on the final decision of the mind. Biological realization of the mind has also internal source of randomness: neuronal computations are subject to rather strong noise in the nervous system. Our ability to solve complex optimization problems is connected with the fact that some NP-hard algorithmic problems are greatly simplified if the search for the best solution is given up in favor of the search for the sufficiently good one. Randomized computing, with chaotic components, allows to solve problems of high complexity in suboptimal way. The decision may be predictable with high confidence if the topography of the mind space is known and the internal noise is low. Predicting decisions of some people is not hard, although usually the initial conditions for such predictions are not know precisely enough. From the mental point of view the mind has a free choice since the system has no direct access to its own hardware; from computational point of view decisions are made by the hardware (to some degree randomly, if the internal noise is taken into account) and are based on a non-algorithmic process (if the environment states are non-algorithmic). Each decision creates a new mind object that interacts through various associations with other objects leading to new states of mind that may lead to quite different decision.

4.6. Symbol processing systems cannot reach real understanding, even if they could pass the Turing test or solve the frame problem (I doubt that it is possible). Thermostats do not have qualia nor are qualia present in the Chinese Room example of Searle (Hofstadter and Dennet 1981). Object processing systems, grounded in sensory experiences, are not reducible to purely symbolic computations. In fact symbols may not be necessary at all for mental processes. Early hominids, before language was invented, had minds. Children that grew up in a jungle fed by animals also had minds, and there is no reason to suppose that infants or animals do not have minds, although sophistication of their minds is far from that of a mind of a philosopher.

4.7. In short, the root of the mind-body and related problems in cognitive science lies in the attempt to use a wrong language for description of mind events, language based on a separation of the linguistic labels from the real mind objects. There is no way of communication that would use mind objects directly. We are fooled by our use of language, of verbalization distorting the totality of our experience: words are like Platonic shadows on the wall, linearized descriptions that cannot do full justice to the multidimensional reality. We are inventing more words, increasing the number of linguistic dimensions, but still we deal only with the shadows. Poper (1972) calls the world of culture and concepts the C-world: it is based on the B-world, the world of psychological events. The mind space is the B-world while the collection of many mind spaces defines the C-world. These worlds require cognitive systems and their inner (mind) spaces. Information stored in the books and films has by itself no meaning - this meaning is in the mind spaces of cognitive systems.

5.0 TOWARDS A THEORY OF CONSCIOUSNESS

5.1. Consciousness seems to be a very elusive subject partially because most people have not really observed their own mental processes and relay on myths and illusions. The study of consciousness became an interesting subject of hard science only quite recently. Many institutes and organizations involved in such studies devote their energy in pursuit of mysterious properties of mind, such as the paranormal phenomena. Why should such phenomena have any bearing on the question of consciousness? They are interesting in their own right but it is very unlikely that they are necessary faculties of the conscious mind. We should examine necessary conditions to consider someone to be conscious. Are infants conscious? Observations of the development of infant's brains show close correlation between the density of neuronal connections and the ability to represent complex sensory data and form internal representation of the world. Kant was to a large degree right claiming that we see only those forms that our perception allows us to see. For each one of us the world is something different, something created by our own mind. Looking at the brain tissue of the developing mind one can see it quite clearly: we are born with many neurons that are only potentially available, while complexity of the environment and repetitive sensory patterns slowly "wire themselves" in the brain. If the feature detectors are not developed the mind does not perceive. For example, one can train the auditory system to recognize the phonemes of Vietnamese language, but without such training Vietnamese words will not be remembered nor recognized.

5.2. The brain constructs what we call "reality" using massive computational power. Even the brain of a fly makes 10^9 computations per second. Human brain performs on the order of $10^{16} - 10^{18}$ operations per second. This huge number of computations creates an illusion of continuous reality. In fact reality is reconstructed from discreet events, for example visual awareness is reconstructed from the rapid eye movements. Time resolution of the visual awareness is of the order of 0.1-0.2 seconds. If the mind state is trapped for a shorter time in a given area of the mind space short term memory traces are not formed and the experience does not become conscious. The brain performs many complex computations in parallel. Most of the actions and stimuli do not reach our awareness. What makes some processes conscious and other not? In the development of complex organisms the emerging mind must have had a center, a concept of self that should be preserved, influencing reactions of the whole organism in case of a danger. Such reactions were memorized and reflected upon. Peripheral computations were done in parallel, leading to automatic behavior that does not leave traces in the memory.

5.3. Why consciousness exists? Because our cognitive system is sophisticated enough to form a representation of itself and, as it is the case with all mind objects, it has qualia connected with this representation. The representation of "myself" is done by an unusually complex set of objects connected with very strong survival reactions. In the brain some of these self-related objects are realized by transcortical cell assemblies connected to subcortical brain structures controlling emotions. Therefore qualia related to these objects are unusually strong, with the mind state resonating between the "I" and all nonverbal qualia connected with it. Consciousness seems to be strange because it is impossible to verbalize such states of mind. It has to exist as a consequence of the fact that the mind space is composed of real experiences, not just their linguistic labels, and these mind objects are not decomposable into artificially separated components. Selective damage of the brain may lead to dissociation between the concepts and their labels, observed in some forms of aphasia. Since features of representations for different sensory modalities are determined by different, spatially separated parts of the cortex their integration by transcortical cell assemblies to form a total mind object is not always perfect. Short and long-term memory mechanisms contribute to the feeling of awareness. Perhaps the degree of being conscious should be measured by the degree of concentration. Focusing on something brings the subject to awareness only if we can hold to it for a while. This is a resonance process, mediated by the short-term memory, visual or other inputs and the long term memory, necessary for recognition of the input patterns. Sustaining this resonance for a longer time creates patterns of excitations in the brain, influencing subcortical brain structures responsible for bodily changes, hormone secretion, feelings. Conscious states are created when the activity of the brain leads to the mind states trapped in the objects of mind space for sufficiently long time (in case of humans 0.2-2 seconds). Consciousness emerged together with the growing sophistication of the mind space.

5.4. What is subconsciousness? Not all objects are activated strongly and long enough to become conscious, i.e. subject to reflection leaving memory traces. There are many low-level mental processes (for example, detecting features of sensory data, internal day-dreaming states) taking place at the same time. Many sensory experiences also form weak memory traces. The mind does not reflect on them, but since they are stored in memory they may be activated and reflected upon later. Such subconscious objects have nevertheless influence on the mind-state dynamics and thus on the qualia and the behavior. More interesting subconscious processes are connected with repressed desires and feelings. In the hierarchy of objects and metaobjects of the mind some higher order metaobjects are controlled by others that may prevent their full activation. In psychological terminology they are suppressed by the ego, are shadows of the persona. Mind states that activate objects close to some central objects - like the mind objects representing the ego - are controlled by these central objects. Transition from these mind objects may be so quick that their activation is never sufficiently long to leave memory traces and become conscious experience. Ego concepts are very hard to modify, because any such attempt is considered to be threatening and via connections to the subcortical structures other mind objects with strong fear component are activated, changing completely the state of mind. This mechanism was created by the basic survival instinct. Very similar mechanisms are used for brain washing. Central idea (a symbol, an object) is deeply implanted in the mind of a brainwashed victim and it becomes very important and attractive to all mind states in this region of the mind space. It controls the access to other mind objects connected via common features with this central idea mainly by coupling to fear subcortical centers.

5.5. Abhidharma, the early Buddhist psychology, is the most detailed analysis of consciousness that exists. It is not based on speculations but on logical analysis of mental observations. Introspection may reveal the true nature of consciousness. Experience in Zen and Vipassana meditation techniques has produced understanding of the mind expressed already more than 1600 years ago in the "Heart sutra", the holy text of the Mahayana Buddhism tradition, to this day repeated every day by millions of Buddhists: "Form does not differ from emptiness, emptiness does not differ from form. That which is form is emptiness, that which is emptiness form. The same is true of feelings, perceptions, impulses, consciousness." From the Western perspective translation of the Sanskrit word "sunjata" as "emptiness" is problematic: a better word (Wilber 1985) would be "unboundedness" or "inter-relatedness". The objects of mind, when reflected upon in details, dissolve into features and than emptiness or unboundedness and from this emptiness they are reconstructed. A good analogy is provided by the microscope: matter dissolves into atoms finally into emptiness under very high magnification. The final answer of the introspection masters repeatedly stated since ancient times is: there is noone who sees and noone who hears, the self is just the sounds, sights and thoughts. The meaning is found at the level of total integration of the mind and body - the features of the mind objects cannot be decomposed into the separate sensory/motoric and abstract thought subspaces.

5.6. Some scientists, notably the brain experts W. Penfield and J. Eccles (1994), came to the conclusion that the brain may be just a receiver, rather than creator, of consciousness. This is a fascinating possibility, but not far from the idea that everything happens as it does not because of the physical laws but because of the God's will. The idea that consciousness is the emergent property of the complex brains is the simplest and the most fruitful. It allows us to formulate scientific and engineering projects that in the end will either show that some mysterious element is missing or that consciousness results from the complexity and organization of the brain-like structures. Of course even creation of an artificial conscious system will not convince dualists that the world of spirit is a product of brain's activity: dualists will claim that a receiver has been built. Mind develops as a result of interaction with the environment. Although this is a trivial statement, it is very important and often forgotten. Disembodied minds may of course be imagined but they lead to many artificial philosophical problems. Psychological literature contains many descriptions of those unfortunate beings that were deprived of healthy interactions in the critical infant and childhood periods and as a result did not develop conceptual categories and abilities important in human life. We know very little about complex systems and their emergent properties. Why should an explanation of consciousness require non-material or non-physical elements? Cognitive science and neuropsychology can answer many precisely posed questions. The question about the nature of consciousness brings us very quickly to the question about the nature of the self. This is one of these questions that people avoid facing by all means, including creation of very elaborate theories. In essence it leads to genuine mysticism, although transpersonal psychology writers make it more acceptable to the Western mind (cf. Wilber 1985; Wilber at al 1986).

6.0 CONCLUSIONS

6.1. From the point of view of cognitive philosophy mind is of primary importance, realization of the mind in the form of a brain of secondary. Various physical realizations of mental processes are possible. Since mind states are described in purely mentalistic terms they are not only epiphenomenal or identical to some material (brain) processes. The structure of mind determines its function more than the supporting hardware does (provided that it allows for forming sufficiently complex structures in a stable way). An object in the mind space may have motoric components as well as purely symbolic components. In simple cases it is possible to find experimentally correlations between the activation of an object of mind (such as a visual or an auditory object) and coherent excitations of neurons assemblies necessary to support this activation (Griniasty et.al 1993, Pulvermueller et al 1994). In more complex inner representations many spatially separate regions of the neocortex cooperate and therefore such correlation will be much more difficult to find (Damasio 1989). It is more natural to talk about mental events in psychological terms rather than in a low level neurological terms. The mind-body problem is created by false identification with the mind only instead of the whole mind/body organism (Wilber 1985). Linguistic labels cannot be separated from other features (including motoric features) of the objects of mind, although many educated people, blinded by the power of language, strive to do so. Artificial intelligence based on symbolic systems does not lead to artificial minds (and probably also not to real intelligence).

6.2. Fundamental models in cognitive psychology should be based on psychological and biological facts and cannot be deduced from speculations on disembodied forms of mind. They are also hard to deduce from neurological data. Applications of models starting from first principles to really complex situations may not be fruitful at all. The reductionist program in biology and even in chemistry has not been very successful. Phenomenological concepts in chemistry are still widely used, concepts that cannot be deduced from quantum mechanics. The model of the mind presented in this paper is phenomenological. It allows to introduce concepts of self-organization of mind objects by supervised and unsupervised learning, and it enables direct modeling of objects in the mind space. Fundamental approach, i.e. trying to create a model of the mind starting from the neuronal level is much more difficult.

6.3. Cognitive modeling based on neural networks explains the details of many processes, such as distributed memory storage and associative recall of memories, resistance of the system to damage and noise, independence of the retrieval time on the number of facts, formation of cognitive topographical maps (such as somatory and tonotopic maps), various kinds of aphasia resulting from selective damages of the brain areas, formation of concepts in children, specific phenomena like the color Phi effect and lots of other processes. The solution to the cognitive science paradoxes presented in this paper indicates, that it should be possible to explain all phenomena using cognitive modeling. There is no need for quantum mechanical explanations on the cognitive level. Quantum mechanics is important at the neurotransmiter level, but we are not able to applied it with success even to a single protein molecule not to mention such complex systems like the brain of a snail. Why should consciousness emerge from some mysterious quantum mechanical principles only at certain level of complexity of the brain if there is no need for quantum mechanical explanations for simpler brains?

6.4. The details of the model presented here are not yet fully developed. The model has been already useful to create new, universal adaptive systems that can learn and reason (Duch 1994; Duch and Diercksen 1994), but the real challenge is to understand human minds. Not all features of internal representations are known, methods of elucidation of topography of the mind space objects should be found, detailed connections with neuropsychology worked out. As a first approximation stationary or almost stationary features should be considered. Some features of the semantic memory should be recovered in this way. Minds of very different types should be possible, depending on the way the mind space is formed and the objects constructed from experiences. One can imagine strange virtual minds that would be different from human minds in all respects and yet should deserve the name "mind" by virtue of having intentionality and genuine goals. In more distant future some coupling of human and artificial minds may even be possible, with exploration of the inner space objects created from the real sensory experiences replacing exploration of the physical space.

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