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Evolution

Evolution of consciousness

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ABSTRACT The hypothesis of the origin of consciousness is built upon the unique properties of the mammalian neocortex. The apical dendrites of the pyramidal cells bundle together as they ascend to lamina I to form neural receptor units of ≈100 apical dendrites plus branches receiving hundreds of thousands of excitatory synapses, the collective assemblage being called a dendron. It is proposed that the whole world of consciousness, the mental world, is microgranular, with mental units called psychons, and that in mind–brain interaction one psychon is linked to one dendron through quantum physics. The hypothesis is that in mammalian evolution dendrons evolved for more effective integration of the increased complexity of sensory inputs. These evolved dendrons had the capacity for interacting with psychons that came to exist, so forming the mental world and giving the mammal conscious experiences. In Darwinian evolution, consciousness would have occurred initially some 200 million years ago in relation to the primitive cerebral cortices of evolving mammals. It would give global experiences of a surrounding world for guiding behavior beyond what is given by the unconscious operation of sensory cortical areas *per se*. So conscious experiences would give mammals evolutionary advantage over the reptiles, which lack a neocortex giving consciousness. The Wulst of the avian brain needs further investigation to discover how it could give birds the consciousness that they seem to have.

In the past decade or so there has been a general recognition of the centrality of consciousness in human experiences (1–9). The mental word consciousness is now an "in" word, being used shamelessly even by strong materialists!

An introductory statement for the evolution of consciousness is that one cannot expect that consciousness came to higher animals as a sudden illumination. Rather, as with life originating in a prebiotic world, it would be anticipated that consciousness came secretly and surreptitiously into a hitherto mindless world. Moreover, as we attempt to discover evidence for consciousness from the study of animal brains and behavior, we can only assess probability. We search for manifestations of consciousness in mammals because we recognize it as central to the ongoing human experiences, the qualia, that fill our waking life like a rich tapestry replete with feelings, thoughts, memories, imaginings, and sufferings. Our experience is uniquely ours, but we are rescued from solipsism by communication with other human beings by language and other subtle creations, such as music and gesture, and by sharing our immersion in a rich inherited culture.

Mammalian Cerebral Cortex

Mammals have a cerebral cortex qualitatively similar to ours, though, with rare exceptions, much smaller. Some exhibit intelligence and a learned behavior and are moved by feelings and moods, even with emotional attachment and understanding. So we must give them some feelings and qualia such as we human beings experience even though it cannot be rationally established in the way that is possible by interhuman communication (10).

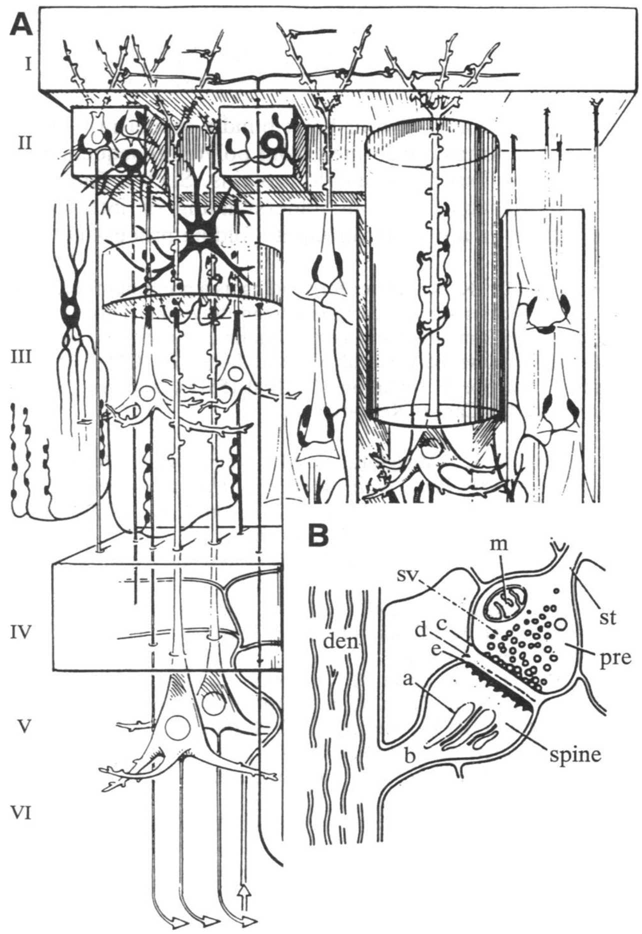

FIG. 1. (*A*) Three-dimensional construct by Szentágothai showing cortical neurons of various types. There are two pyramidal cells in lamina V and three in lamina III, with one shown in detail on the right (12). (*B*) Detailed structure of a spine synapse on a dendrite (den). st, Axon terminating in synaptic bouton or presynaptic terminal (pre); sv, synaptic vesicles; c, presynaptic vesicular grid; d, synaptic cleft; e, postsynaptic membrane; a, spine apparatus; b, spine stalk; m, mitochondrion (13).

I am presenting a biological basis for an evolutionary origin of consciousness. It derives from a hypothesis of mind–brain interaction that has already been published (10, 11) and that is based on the special anatomical and functional properties of the mammalian cerebral cortex. The microproperties of neural communication in the cerebral cortex (Fig. 1*A*) are in classical physics and are not of immediate concern in mind–brain interaction. Rather, our concern is in the ultramicroproperties (Fig. 2*B*), where quantum physics may be expected to play a key role (10, 11, 16–17) (F. Beck and J.C.E., unpublished data).

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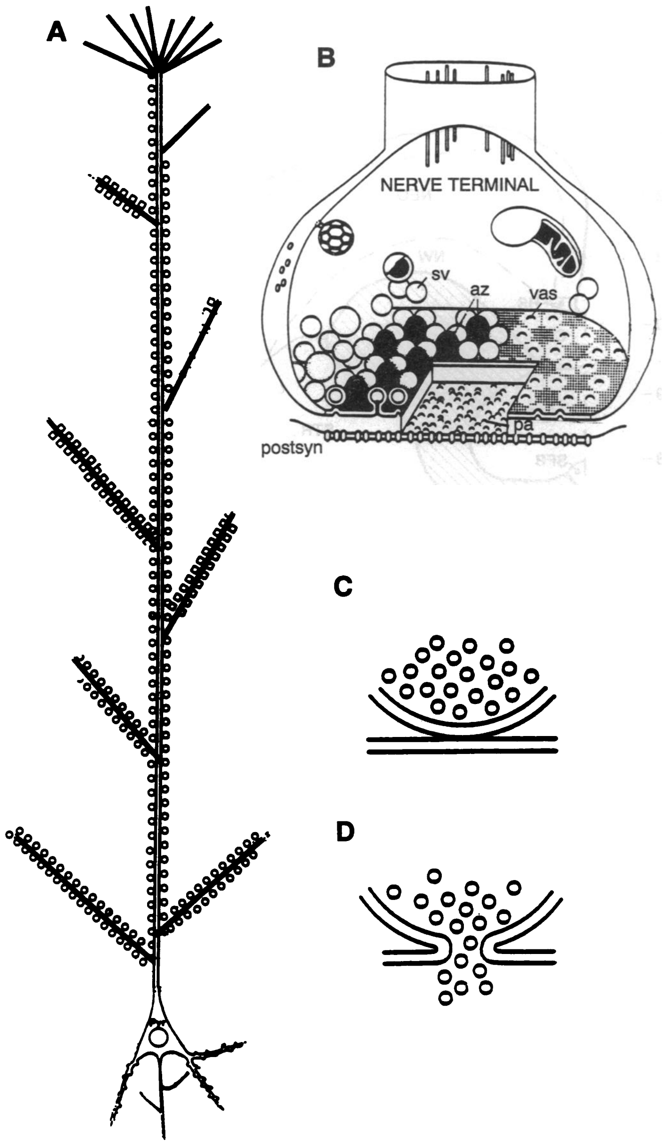

FIG. 2. (A) Drawing of a lamina V pyramidal cell (Pyr), with its apical dendrite showing the side branches and the terminal tuft all studded with spine synapses, boutons (not all shown). The soma with its basal dendrites has an axon with axon collaterals before leaving the cortex. (B) Schema of a mammalian central synapse. The active zone (az) is formed by presynaptic dense projections spacing synaptic vesicles (sv). pa, Particle aggregations of postsynaptic membrane (postsyn). Note synaptic vesicles in hexagonal array and the vesicle attachment sites (vas) on the right (14). (C and D) Stages of a synaptic exocytosis: vesicle with release of transmitter molecules into the synaptic cleft (15).

A pyramidal cell of the mammalian cerebral cortex (Fig. 1A) has on its apical dendrite thousands of excitatory spine synapses (Figs. 1B and 2A). Each of these synapses (Fig. 2B) operates through a presynaptic vesicular grid (14) of 30–50 synaptic vesicles filled with molecules of the synaptic transmitter substance (Fig. 2B). Each vesicle is poised on the presynaptic membrane (14) for emission of its transmitter molecules in exocytosis (Fig. 2 B–D).

Exocytosis is the basic unitary activity of the cerebral cortex. Each all-or-nothing exocytosis results in a brief excitatory postsynaptic depolarization, the excitatory postsynaptic potential (EPSP). Summation of many hundreds of these micro-EPSPs is required for an EPSP large enough to generate the discharge of an impulse by the pyramidal cell. This impulse will travel along its axon (Fig. 2A) to make effective excitation at its many synapses (Fig. 1A). This is the conventional macrooperation of the neural component of the neocortex (Fig. 1) and it can be satisfactorily described by classical physics even in the most complex designs of network theory (19) and neuronal group selection (5).

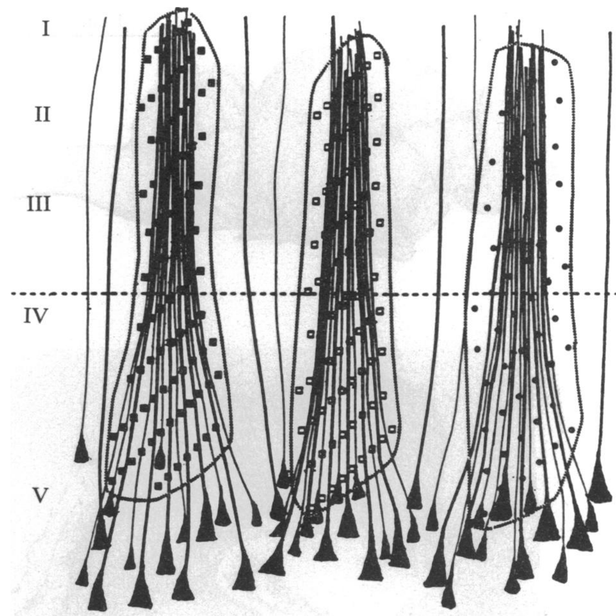

FIG. 3. Drawings of three dendrons showing manner in which apical dendrites of large and medium pyramidal cells in lamina V bunch together in lamina IV and more superficially, thus forming a neural unit. A small proportion of apical dendrites do not join the bunches. Apical dendrites are shown terminating in lamina I. This termination is in tufts (see Fig. 2A) that are not shown. The other feature of the diagram is the superposition on each neural unit or dendron of a mental unit or psychon that has a characteristic marking (solid squares, open squares, solid circles). Each dendron is linked with a psychon, giving its own characteristic unitary experience.

A quite different theory is necessary for describing the manner in which mental events could generate neural events of the neocortex. Mental activity of the neocortex results in an increased metabolism that causes local increases in cerebral blood flow, as shown by radioXenon mapping by Ingvar (20) and Roland *et al.* (21), or by the more accurate positron-emission tomography (PET) scanning technique of Raichle and associates (22) for the activity of the human brain in response, for example, to the mental demand to generate words.

These mental actions can be attributed to an increase in exocytoses. A presynaptic impulse propagating into a bouton (Fig. 2B) and causing an influx of Ca^{2+} ions generates an exocytosis not on every occasion but with a wide range of probability, often 1 in 3 or 1 in 4, and never more than one exocytosis (23–28). This controlling effect probably is due to the vesicles being embedded in the paracrystalline presynaptic vesicular grid (Fig. 2B) and thus being subject to quantum physics (F. Beck and J.C.E., unpublished data).

Dendrons and Psychons

The apical dendrites of the pyramidal cells in laminae V, III, and II bundle together as they ascend to lamina I (29, 30), so neural receptor units of the cerebral cortex are formed composed of ≈100 apical dendrites plus their branches (Fig. 2A); they are called dendrons, three of which are drawn in Fig. 3 (11) for apical dendrites of lamina V pyramidal cells.

In the hypothesis of mind–brain interaction (10, 11, 16) (F. Beck and J.C.E., unpublished data), it is proposed that the whole mental world is microgranular, with the mental units being called psychons. Ideally, there would be one psychon

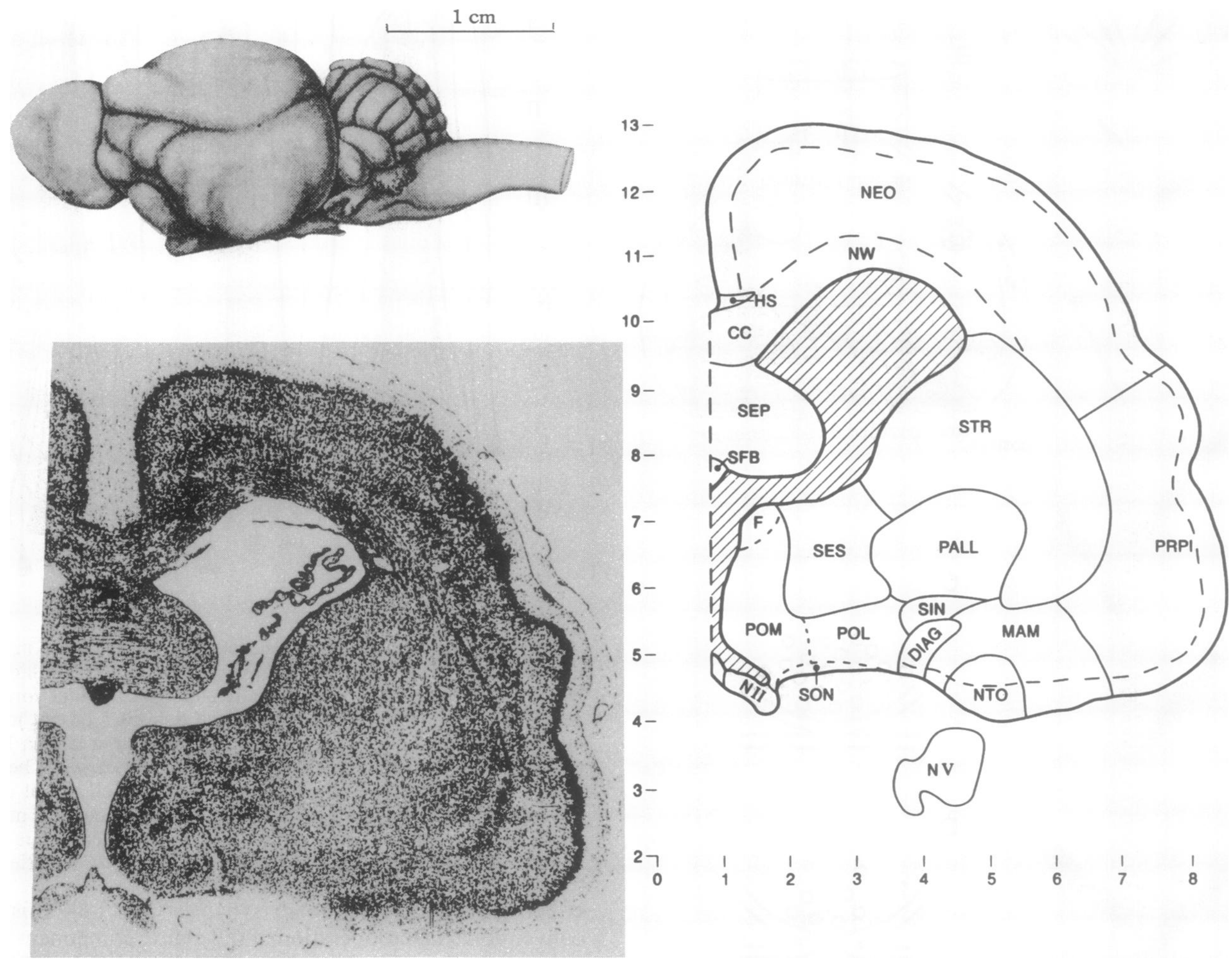

FIG. 4. (*Upper Left*) Brain of an insectivore neocortex above the prepyriform cortex. (*Lower Left*) Transverse section of the brain of an insectivore (hedgehog). (*Right*) Diagram of transverse section (*Lower Left*) showing the following: CC, corpus callosum; DIAG, diagonal band of Broca; F, fimbria—fornix complex; HS, hipp. supracommissuralis; MAM, medial amygdaloid division; NEO, neocortex; NTO, nucleus of the lateral olfactory tract; NW, neocortical white matter; N II, optic nerve; N V, trigeminal nerve; PALL, pallidum, globus pallidus; POL, lateral preoptic area; POM, medial preoptic area; PRPI, prepyriform region; SEP, telencephalic septum; SES, stria terminalis nuclei; SFB, subfornical body; SON, supraoptic nucleus; STR, striatum. Scale numbers are mm (31).

for each dendron, as shown in Fig. 3 by the ensheathing of each of the three dendrons by the superposed patterns of solid squares, open squares, and dots. It is further proposed that mind–brain interaction occurs for each psychon–dendron unit and that it can be accounted for by quantum physics, as has been described above (10, 11) (F. Beck and J.C.E., unpublished data).

There is an immense input to a dendron by thousands of synapses on the apical dendrites plus side branches of each pyramidal cell (Fig. 2*A*), which gives tens of thousands of synaptic vesicles on the presynaptic vesicular grids of one pyramidal cell (Fig. 2 *A* and *B*) that are poised for exocytosis. Thus, there are millions of poised synaptic vesicles on a dendron, which consequently is a tremendously sensitive receptor for psychon inputs. And so, consciousness is experienced (10, 11) (F. Beck and J.C.E., unpublished data).

Cerebral Evolution and Consciousness: The Hypothesis

In all mammals so far examined, there is the same composition of apical dendrites of pyramidal cells arranged in dendrons (Fig. 3). There may be as many as 40 million dendrons for the human cerebral cortex (11), but there are probably no more than 200,000 for the cerebral cortices of the most primitive mammals, the basal insectivores, if they have dendron assemblages characteristic of higher mammals. This estimate is based on measurements by Stephan *et al.* (31) of the neocortices of >50 species of insectivores, including 4 basal insectivores. As illustrated in Fig. 4, in the neocortex the pyramidal cells appear to have a vertical orientation. A dendron structure is being looked for.

The cerebral cortex with the synaptic machinery of its dendrons can be regarded as a functionally effective neural design that evolved in natural selection as a purely material structure for efficient performance of the cerebral cortex in integrating the increased complexity of neural inputs that resulted from the evolutionary advances in receptors for special senses—light, sound, touch, movement, and olfaction. The hypothesis is that biological evolution induced in the neocortex the design of apical dendrites that is recognized as a dendron (Fig. 3) and that had as a side effect the capacity for interacting with the world of the mind. And so, psychons came to exist. Thus, it is sufficient for the emergence of consciousness. It will be noted that the hypothesis is restricted to the role of the cerebral cortex in providing an explanation of how in evolution the cerebral cortex came to interact with the "mind world." The actual experiences, qualia, provided by the mind world psychons—light, color, sound, touch, taste, smell, pain, intentions, feelings, and memories—in all of their uniqueness are not explained. The most we can say is that the dendron–psychon linkage is related to the types of qualia experienced, since the hypoth-

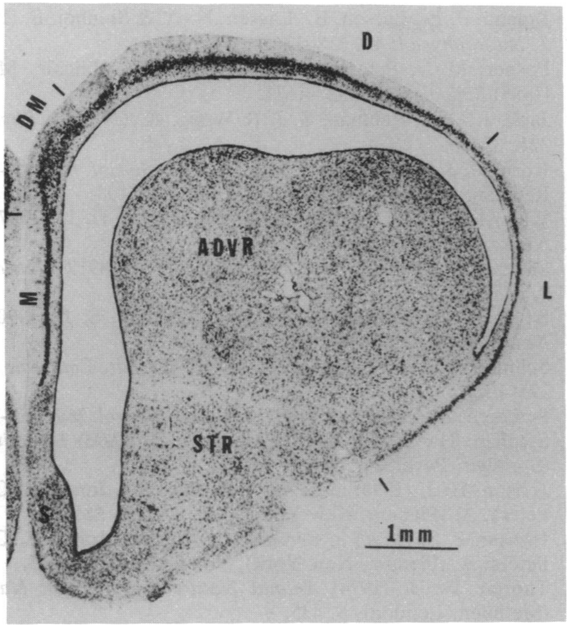

FIG. 5. Nissl section from encephalon of the alligator *Alligator mississippiensis*. Cortex is divided into medial cortex (M), dorsomedial cortex (DM), dorsal cortex (D), and lateral cortex (L). ADVR, anterior dorsal ventricular ridge; S, septum; STR, striatum (33).

esis is that each psychon is a unitary experience in consciousness. We may ask if the mind world existed before it could be experienced by the evolving cerebral cortices of primitive mammals. The answer should be that the mind world came to exist when the evolving cerebral cortex had the microsites with synaptic vesicles poised in the presynaptic vesicular grids (Figs. 1*B* and 2*B*). This microstructure emerged with the evolving dendrons that could interact with psychons as described above.

How far down our evolutionary origin can we recognize some evidence for consciousness? If all mammals experience consciousness, its evolutionary origin can be as early as 200 million years before present (32).

Now comes the question about the reptilian origin of mammals (32, 33). The forebrain of reptiles (Fig. 5) shows an undeveloped cerebral cortex, which is in great contrast to the most primitive mammalian cortex (Fig. 4). Clearly, the reptilian cerebral cortex has far to evolve before it can play a significant role in cerebral activity and in mind–brain interaction based on dendrons. But we have to recognize that the primitive reptilian cerebral cortex (Fig. 5) did, in time, evolve into a primitive mammalian cortex (Fig. 4).

There seems to be no good evidence that reptiles experience consciousness. Thorpe (34) reports on the behavior of amphibia and reptiles but does not mention consciousness. All actions can be regarded as instinctive and learned, and this has to be assumed also for still lower vertebrates—the fish. So consciousness appears to have come into the mindless world of biological evolution with the origin of mammals. Animals would not experience "gleams" of consciousness (feelings) until the mammalian cerebral cortex with its microsites of neuronal structures (dendrons) had evolved with the propensity for relating to a world other than the matter–energy world. So psychons, with their conscious experiences, entered the hitherto mindless world.

The hypothesis that consciousness gives an animal behavior (9) that is of great significance in natural selection can be tested by comparative studies on reptiles and mammals in the same environment.

The reptilian–avian transition is difficult to follow (35). The medial, dorsomedial, and lateral components of the reptilian cortex (Fig. 5) continued in a relatively reduced form in birds. However, birds have a unique development in the forebrain, called the Wulst, that is concerned with vision. I would follow Thorpe (36) in agreeing that many birds exhibit "insightful" behavior, particularly at feeding time, and that is evidence for conscious experiences. So there is the problem of identifying the ultramicrosites in the bird pallium that could be involved in mind–brain interaction, giving birds gleams of conscious experiences.

Hitherto the matter–energy world had been globally sufficient in a mindless universe. Now we have an evolutionary explanation for the phylogenetic origin of mammalian consciousness. It would occur initially in the primitive cerebral cortices of evolving mammals, such as the basal insectivores of today. The evolution of a neurally efficient cerebral cortex had as an "unintended" consequence a unique property—that of interacting by quantum physics with the mind–world (F. Beck and J.C.E., unpublished data). It is a superb example of what I have called anticipatory evolution (10).

Conclusions

It should be pointed out that the present hypothesis of the evolutionary origin of consciousness has four great attractions: (*i*) that it is neuroanatomical, (*ii*) that it is in accord with biological evolution, (*iii*) that it utilizes the most highly evolved structures of the cerebral cortex with their ultramicrosite operation, and (*iv*) that it is based on quantum physics.

The quantum physicist Stapp (17) has maintained that classical physics provides an unacceptable basis for the hypotheses of brain–mind interaction, which instead requires quantum physics. So Stapp (17) rejects such theories as neuronal network (19) and neuronal group selection (5) and proposes a theory based on quantum physics. This theory needs a secure basis in ultramicrosite neuroscience of the cerebral cortex where quantum physics could be effective. This has now been done by F. Beck and J.C.E. (unpublished data).

As has been described (10, 11), consciousness gives a global experience (9) from moment to moment of the diverse complexities of cerebral performances—e.g., it would give a mammal global experiences of a visual world for guiding its behavior far beyond what is given by the robotic operation of the visual cortical areas *per se*.

There has recently been much attention to the neuronal mechanisms that cause interactions between widely separated cortical areas, and that has been named the binding problem (7, 37, *). It is suggested that global conscious experiences given by psychons in their interactions could play an important role in the binding problem.

Thus, conscious experiences would give evolutionary advantage. This simple consciousness need not be an enduring entity but may merely exist from moment to moment according to the activities of the cerebral cortex. The brain would provide an enduring memory that gives the animal a continuity of behavior and of feeling of existence. Nevertheless, the conscious experiences can be assumed to include quite complicated qualia of devoted attachment and enjoyment as well as pain.

This is a formulation of a Darwinist hypothesis for the origin of consciousness in the most primitive mammals. This hypothesis for the origin of consciousness does not account, however, for the highest levels of consciousness in *Homo sapiens sapiens* (10, 11, 18)—self-consciousness—which is the unique experience of each human self (10, 11).

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