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Brain and the Composition of Conscious Experience

Of Deep and Surface Structure; Frames of Reference; Episode and Executive; Models and Monitors

Prologue

The resurgence of interest in 'consciousness' during the 1990s comes as somewhat of a surprise to one who in 1960 in *Plans and the Structure of Behavior* (Miller *et al*., 1960) declared for a 'subjective behaviourism' and in Sigmund Koch's *Psychology: A Study of a Science* developed the theme as to how the data on subjectivity, our awareness of conscious experience, could be related to the behavioural and brain sciences. The occasion for these reports was the observation of disjunction between patients' verbal reports of their introspections and their behaviour. Subjectivity could not be ignored by a science of psychology. The chapter in *Psychology, A Study of Science* (Pribram, 1962), begins with a quotation from C. Judson Herrick's, *The Evolution of Human Behavior*:

> It does no good to declare that consciousness is a negligible epiphenomenon in the face of the fact that the most significant things people do are consciously motivated and consciously directed. One does not solve a problem by leaving out the troublesome factors. . . .
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> Defeatism is an unhealthy scientific attitude; it is, in fact, radically unscientific, for science has a legitimate interest in everything of which we have veridical experience. We have ample scientific evidence that a man's mental processes — his thoughts and emotions — are tied in with his physical behavior in lawfully ordered ways. If we do not know just how this is done, the thing to do is to try to find out by skillfully designed experiments. The answer will never be found if the plain facts of common experience are ignored and the mental factors of behavior are left out of consideration (Herrick, 1956, pp. 234–6).

Using six experimentally obtained results, my chapter discussed the methods by which such results and the observations in the clinic can be related to each other and how empirically-derived models can form the basis for theory construction. A quota-

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tion presents the flaavour of my thinking. Discussing what constitutes the science of neuropsychology:

> The properties of a system are not given simply by summing the properties of the component subsystems. An understanding of the wetness of water or the fact that it floats when frozen is not derived solely from an understanding of the properties of its constituents, hydrogen and oxygen. The property, coalition, cannot be understood in terms of study of the behavior of the monodic or dyadic components of the group in which the coalition forms. The neural processes uncovered by neuropsychological analysis are thus expected, at best, to have properties that critically determine those of the behavioral system — never are the neural and the behavioral processes identical (Pribram, 1962, p. 122).[1]

> The problem of collating concepts derived from observed data [behavioral and neurological] with those introspectively derived is logically the obverse in the psychological and the physical sciences. An apparent handicap to the solution of the problem for psychology is that psychological concepts do not have the attribute of projection. Whereas a table appears to be 'out there,' my perception of it appears to be 'in here.' But this very attribute has been blamed for the difficulties encountered in the philosophy of the physical world. So perhaps psychological philosophy has the easier task at that (Pribram, 1962, p. 150).

Note that this statement turns the table on the argument that a science of consciousness, of subjective awareness, is 'the hard problem'. My stance is that subjectivity, conscious experience, exists as the starting point for *all* inquiry. Understanding (standing under) conscious experience is attained as is every other aspect of science by progressive objectification. Understanding qualia *is* understanding *how* we perceive the form of a table and the perspectives that place it 'out-there'; as well, understanding qualia takes into consideration *what* a table is constituted of, its molecular, atomic and quantum composition. In a discussion of this issue, a colleague exclaimed, 'and our awareness is *all* of that!' Only when we take a dualistic stance is the hard problem limited to conscious experience. Dualism, as I have indicated elsewhere (Pribram, 1986), is derived from the fact that we make propositional utterances, utterances that separate subject from object by way of predication. Language began with holophrases: 'Yahweh'[2] meant 'being' and was then converted to *a* being, a *subject* with a beard, who vindictively *threw* Adam and Eve, the *objects* of *His*

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[1] The statement that neural processes, 'at best, have properties that critically determine those of the behavioral system — never are the neural and the behavioral processes identical' needs comment and unpacking because, at one level, a homomorphic relationship can be identified. For the most part, the organism's biological processes are necessary but insufficient determinants of psychological processes that can be inferred from behavioural observation and analysis. However, we can specify that sensory information is processed in the primary sensory cortex by Gaborian wavelets, that such a process also characterizes telecommunication and thus describes the structure of both a neural and a psychological process. At this level of description, the *structure* of the psychological and the neurological process *are* identical. But, in addition, telecommunication is *about* something and even when we can characterize the neural processes critical to 'aboutness' (e.g. the determination of egocentric and allocentric frames of reference by processes located in the posterior convexity of the cerebral hemispheres), we still need to specify the contents of the aboutness, and these contents are specified by current or prior environmental (i.e. beyond the organism's biological) input. Note that such specification does not mean that the psychological process and/or its contents are, therefore, entities apart from their biological determinants. Quite the contrary, the biology is critically necessary (albeit insufficient), for their specification.

[2] 'Yahweh' is the usual transliteration of the sacred Hebrew יהוה (mistakenly rendered 'Jehovah' in the King James Version of the Bible).

wrath, out of the garden of Eden for disobedience. The consequences of such dualism are stated succinctly in another quotation from Herrick, which ends:

> In our own culture the cleavage of the 'spiritual' from the 'natural,' which is a survival from the most ancient mythologies, has fostered popular ideologies of religious fanaticism, class rivalries, and political antagonisms that are biologically unfit and even suicidal because they result in social disintegration. Our ultimate survival is endangered as long as ideological fantasies that are incompatible with things as they are control individual and national patterns of behavior. We must somehow manage to heal this artificial dismemberment of the human personality before we can hope for a permanent cure of the present disorder (Herrick, 1956, pp. 416–20).

Given the concerns of the 1950s with subjective (conscious) experience, which lifted psychology out of its behaviourist straightjacket and initiated what is currently called cognitive science, why the renewed interest? I believe that there are several important developments that account for the renewal. The first is the availability of brain imaging techniques that can directly address the relation of brain processing to conscious experience, such as effort, attention, intention and thought in human subjects. Previously, the relation of subjectivity to brain function had to be inferred from verbal reports provided by brain damaged subjects and from animal experiments. Now the line connecting subjectivity and brain functioning is somewhat more direct.

A second reason for resurgence is quantum, and to some extent relativity, theory. Physicists have become aware of the critical role of observation in their empirical endeavours. Observation is a psychological pursuit. Physicists are therefore lending their not inconsiderable talents to resolving the mind–brain issue and have by this interest enlisted mathematicians (who do mathematics, which is a totally thoughtful, logical and therefore cognitive, psychological enterprise) and engineers (such as signal processor and computer scientists) in their endeavour.

Finally, the advances in molecular biology are being applied to neuroscience with the result that practical advances are being made in further bridging the mind/brain gap for the lay public. This public which includes the media, has never bothered much with the distinction between mind and brain and reflects the current ascendancy of a materialistic science. But materialism leads to a culture that has been split along C.P. Snow's division between science and humanities, a division that, as noted in the quotation from Herrick, has created havoc in the affairs of humankind. An alternative is a neutral monism based on the concept of in-formation — a form-within, which negentropically *organizes* energy. But this is another topic which I have taken up fully elsewhere (Pribram, 1986; 1997).

In the context of this publication on blindsight, I want to address further the *brain* processes critically responsible for organizing our conscious experience. As in a previous related publication (Pribram, 1996), I am restricting myself to brain and conscious experience, not the fuller topic of 'consciousness' as this might be determined by genetic and environmental (e.g. social) factors, nor as it is defined in Eastern traditions and in esoteric Western religion and philosophy. For my thoughts on this broader topic the reader is referred to a recent publication (Pribram, 1997) prepared for the centennial celebration of Norbert Wiener's birth. That paper is entitled: 'What is Mind that the Brain May Order It?'

Three Scales of Inquiry

My theme begins with Weiskrantz's (1988) and with Petra Stoerig and Alan Cowey's (1993) distinction between reflexive, phenomenal and consciously accessible scales of processing. In 1971, I suggested that the difference between reflexive (automatic) and conscious processing entailed the difference between the operations taking place in neural circuitry and those occurring at another scale in the (synapto) dendritic processing web (Pribram, 1971). Stoerig and Cowey and also Weiskrantz have proposed an additional level of conscious awareness: monitoring of (or commenting on) phenomenal processing. This resonates with one of my own interests as developed in papers such as 'Feelings as monitors' (Pribram, 1970), but raises the issue as to how monitoring encompasses neural circuitry and the dendritic processing web.

Conscious experience thus has several dimensions that can be directly related to brain processes. These dimensions can be organized in a variety of ways; I have chosen one that I believe to be most generally accessible to the disciplines that have generated the variety. Thus, one can readily identify *states* of consciousness and there is abundant evidence that such states are coordinate with specifiable distributions of chemicals that directly influence the subneuronal (such as the synaptic, dendritic and microtubular) levels of processing in the brain. (For review, see Barchas *et al.*, 1977; Bloom *et al.*, 1985; and especially Pert, 1997).

Also one can specify the *contents* of consciousness. Contents, described as object-forms, as categories and as names are coordinate with frames of reference constructed in one or another brain system. These frames configure subneuronal processes and become accessible to consciousness when patterns of synaptic events arriving at post-synaptic dendritic sites are delayed in their transit to axonal departure to another processing site. Much of this essay concerns these contents of conscious experience.

Further, one can identify conscious *processes* that monitor states and contents: attention, intention and thought. Attention monitors sensory input; intention monitors action; and thought monitors memory (remembering). Such heedful processes connect states with contents and contents with states. They must therefore engage the subneuronal level of processing though they are configured by the neural circuitry within which the processing occurs. In order to influence conscious experience, they must operate to extend, stretch and hold (L. *tendere*), that is, delay the transmission of input patterns to output patterns within a circuit

Blindsight and Neglect

As this essay is written in response to the discovery of blindsight, I will begin with this and related phenomena in which, as in the earlier reports, there is a dissociation between instrumental behaviour and subjective awareness as expressed in verbal report.

Blindsight occurs as a result of an occipital lesion, almost always limited to one hemisphere and presumably to the primary sensory receiving area of that hemisphere. Subjects with blindsight respond correctly by guessing the location and configuration of a pattern presented visually, but they cannot 'see' such a pattern when it is located in the 'blind' hemifield.

As noted in the introduction, blindsight is not unique in such dissociations between patients' verbal reports of introspection and their behaviour. Another such dissociation occurs after parietal lobe lesions and provides a somewhat clearer view of what

patients experience when a still appropriately functioning limb contralateral to the lesion is excluded from awareness. Here is a case history presented by a student in my class who is experiencing such 'neglect'.

From Mrs. C:

> I was doing laundry about mid-morning when I had a migraine. I felt a sharp pain in my left temple and my left arm felt funny. I finished my laundry towards mid-afternoon and called my neurologist. He told me to go to the emergency room. I packed a few things and drove about 85 miles to the hospital where he is on staff (the nearest was 15 minutes away). In the E.R. the same thing happened again. And again, the next morning after I was hospitalized, only it was worse. The diagnosis of a stroke came as a complete surprise to me because I felt fine, and I didn't notice anything different about myself. I remember having no emotional response to the news. I felt annoyed and more concerned about getting home, because I was in the process of moving.
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> Not until several days later while I was in rehabilitation did I notice strange things happening to me. I was not frightened, angry or annoyed. I didn't feel anything — nothing at all. Fourteen days after I was admitted to the hospital, I became extremely dizzy, and I felt I was falling out of my wheelchair. The floor was tilting to my left and the wheelchair was sliding off the floor. Any stimulus on my left side or repetitive movement with my left arm caused a disturbance in my relationship with my environment. For instance, the room would tilt down to the left, and I felt my wheelchair sliding downhill of the floor, and I was falling out of my chair. I would become disoriented, could hardly speak, and my whole being seemed to enter a new dimension. When my left side was placed next to a wall or away from any stimuli, this disturbance would gradually disappear. During this period, the left hand would contract, and the arm would draw up next to my body. It didn't feel or look like it belonged to me. Harrison moved the left arm repeatedly with the same movement, and a similar behavior occurred, except I started crying. He asked me what was I feeling, and I said anger. In another test he started giving me a hard time until the same episode began to occur, and I began to cry. He asked me what I was feeling, and I said anger. Actually I didn't feel the anger inside but in my head when I began to cry. Not until I went back to school did I become aware of having no internal physical feelings.
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> I call that arm Alice (Alice doesn't live here anymore), — the arm I don't like. It doesn't look like my arm and doesn't feel like my arm. I think it's ugly, and I wish it would go away. Whenever things go wrong, I'll slap it and say, 'Bad Alice' or 'It's Alice's fault'. I never know what it's doing or where it is in space unless I am looking at it. I can use it, but I never do consciously because I'm unaware of having a left arm. I don't neglect my left side, just Alice. Whatever it does, it does on its own, and most of the time, I don't know it's doing it. I'll be doing homework and then I'll take a sip of coffee. The cup will be empty. I was drinking coffee with that hand and didn't know it. Yet I take classical guitar lessons. I don't feel the strings or frets. I don't know where my fingers are nor what they are doing, but still I play.
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> How do I live with an illness I'm not aware of having? How do I function when I'm not aware that I have deficits? How do I stay safe when I'm not aware of being in danger?

Mrs. C is obviously intelligent, attending lecture material, asking interesting questions. She is a widowed lady in her mid-fifties, enrolled in adult education, majoring in clinical psychology. She gets around splendidly despite Alice and despite a history of a temporary left hemi-paresis. The diagnosis was damage of the right temporal-parietal cortex confirmed by an abnormal EEG recorded from that location. The damage was not sufficiently extensive to show in a PET scan.

Placed in juxtaposition with blindsight, a simple conclusion can be reached: in humans, there are separate brain systems that organize allocentric (specifically, occulocentric) and egocentric (specifically, body centered) awareness. Damage to

these systems 'deletes' awareness but minimally impairs instrumental behaviour. When, however, additional brain damage occurs and 'denial' of the impairment in awareness is added, then behaviour can become severely maladaptive: a driver of an automobile will run into a telephone pole because he/she is unaware of his/her hemianopic loss of awareness; a patient will inadvertently mutilate his/her neglected limb because he/she is unaware of the neglect. Denial ordinarily occurs when the brain lesion is more anterior and medial to that which produces simple blindsight and neglect. More on this anon.

The Relation Between Allocentric and Egocentric Experience

Given a separate allocentric and egocentric awareness, how do these relate to each other? I once had a patient who, after an auto accident, experienced the onset of sudden dizzy spells during which his visual world would rotate and end upside down. After 10–15 minutes another spell and his world was right side up once more. During the spells, he would brace himself against a wall or hold onto something solid. While his visual world was upside down he could navigate, but cautiously. The spells were becoming fewer and his main complaint was his annoyance that when he saw girls walking upside down, their skirts remained up/down.

I had no chance to examine this patient while his visual world had turned. But recently two undergraduate students undertook to experiment with ocular prisms that inverted the visual world. Following the work of Stratton (1896) and Ivo Köhler (1964), we expected it would take a week or so for the visual world to appear right side up once more after continuous wearing of the prisms. One of the two students became the guide for the one wearing the prisms. As expected, in about eight days, the visual world was 'right side up' for both the students even though the prisms inverted the ocular image for one of them.

What I wanted to know is where did the prism wearer's feet appear to him: within his occulocentric, allocentric space or within his egocentric experience? The answer was forthright: in his egocentric body space. The same with his hands. I then inserted my hand to match his within his egocentric awareness. No problem. But when I held my hand in exactly the same way beyond his reach, it was now upside-down from how it had been for him when 'inside' his egocentric frame. At the border of his reach, things became confused and he simply 'couldn't tell'.

Mountcastle *et al.* (1975) have shown in monkeys that cells in the parietal lobe will become active (fire) when a piece of food is displayed within the reach of the monkey even when he is prevented from reaching. When the food is presented beyond reach, no activation is recorded.

To summarize: separate brain systems organize an occulocentric, that is, allocentric 'space' and another, a body centered, egocentric 'space'. These two 'spaces' meet at the boundary of the person's reach. Injury to these systems allows a patient to behave appropriately to environmental circumstance, despite loss of awareness. Additional brain damage can, however, impair behaviour. The damage is usually forward and medial to that which impairs awareness. In humans, such damage results in a denial of loss of awareness. In animals, instrumental behaviour guided by allocentric or egocentric cues becomes impaired. It is this 'paradox' — the fact that animals' and humans' instrumental *behaviour remains intact despite damage to the 'primary'*

sensory receiving systems and, further, that *behaviour is disturbed by more forward lesions* — that led many eighteenth century neuroscientists to mislocate these primary systems (see the disputes between Ferrier, Goltz, Munk; reviewed by Ferrier, 1876).

Object Centered Frames of Reference

Allocentric and egocentric 'spaces' constitute frames of reference within which behaviour becomes organized. These two are not the only frames for which separately localized brain systems can be identified. Another set of systems deals with the perception of entities. In vision these are, e.g., objects and colour; in audition they are, e.g., phonemes and tones. It is characteristic of entities that they remain invariant over transformations. For example, object constancy derives from operations that can be described in terms of mathematical group theory (Hoffman, 1978; Pribram, 1991). Colour constancy derives from operations on double opponens processing (DeValois & DeValois, 1993; Zeki, 1993).

I did not realize the devastating effect on conscious experience that damage to a constancy system would produce until I read 'The Case of the Colorblind Painter' presented by Oliver Sacks in *An Anthropologist on Mars* (1995), The painter, whose colour constancy system was selectively damaged, was not left with just a colourless black/white visual world; he was left with a muddy, hazy experience. Should the damage be to *object* constancy, what might the visual world appear to be?

When we performed an experiment on size constancy, Ungerleider, Ganz and I (1977) showed that monkeys who had their peri- and prestriate cortical systems removed responded to the retinal image size of a pattern (a square), and failed to take the distance of the pattern into account. Extrapolating to object constancy, one would expect that a person would fail to recognize an object when its perspective changed. Turnbull (Turnbull & McCarthy, 1996; Turnbull, 1997; Turnbull *et al.*, 1997), describe just such a patient. For this patient, every perspective of an entity entailed its own 'meaning': its separate potential usefulness and relationship to other perspectives.

Other Reference Frames and the Relations Between Them

Taken a step further, other frames of reference can be identified. A categorical and a propositional frame are the most obvious. Just as perspectives are grouped to construct invariances that are identified as entities, so entities can become grouped into categories. Eleanor Rosch (1975), has performed a series of experiments showing how categories are constructed around a kernel, a prototype. And Martha Wilson (1987) has shown, using monkeys, that with respect to visual entities, the inferotemporal cortex is critical to the formation of prototypes. Furthermore, she has provided a model for the operation of this prototype system (see also the review by Pribram, 1991, Lecture 7).

Edelman (1989), has constructed his theory of consciousness around the operations that produce categories. Others (e.g. Freud, 1895; Eccles, 1958) have invoked propositional utterances as the basis of conscious experience. A propositional frame of reference uses entities and categories to construct proposals, naming entities and categories and predicating their relationship to one another.

At this propositional level of experience we can go back and identify the distinction between allocentric and egocentric frames and suggest that this distinction

underlies Brentano's (1973) conceptualization of 'intentional inexistence' or, as it is usually called, 'intentionality'. Intentionality is the experiencing of 'aboutness' — experiencing the distinction between self and other, where *both* experiences are about entities, an egocentric 'me' and an allocentric 'other'. Note that when operating in the propositional frame, the ego and allocentric frames are embedded — but note also that the embedding is reciprocal and interpenetrating, not just hierarchical.

This reciprocal embedding can be accounted for by a multidimensional model where dimensions are extended into a more encompassing domain. Hertz named such operations holonomic (*holos*, whole; *nomos*, lawful). What I have in mind is a shift much as occurs from a representation in Euclidian geometry to Rimanian, or from viewing a scene in two-dimensions to viewing it in three. Essays into such hyper-spaces are being explored (see e.g. *Hyperspace*, by Michio Kaku, 1994) in physics, but as yet have not been applied to understanding the variety of frames of reference in our conscious perceptual experience and their relation to one another. I believe this to be a most fruitful direction to pursue in consciousness research and wish I had the mathematical and intellectual tools to do so myself. However, this much appears to be necessary: in a massively parallel system, each of the variables (dimensions) can be encoded in its own synaptodendritic domain (or segment of the network), and the entire ensemble scanned simultaneously. Any significant change in any one or in several of the dimensions would change the profile of the ensemble and thus the output to the scanner which determines the frame of reference.

Earlier I noted that, with deeper brain damage, a failure in awareness of a loss of awareness results. Such denials can become complex in that they are often situation dependent. Ramachandran (1995) has described in detail such complexities. These context (situation) dependent second-order impairments of conscious experience are dispositions that lead to meta-consciousnesses. At the same time, when unimpaired, such dispositions operate outside of awareness and therefore partake of unconscious processing. For that matter, the *processing* that allows us to experience entities and frames — e.g., allo- or egocentrically, categorically, or propositionally — is always unconscious. We experience only the result of processing as the contents of consciousness. And even these escape intentionality, aboutness, under most circumstances when processing has become automatic. Only when a situation is new, as when we are learning to drive, or when automaticity is disrupted, do we need to 'pay' attention and become consciously aware that we are processing the contents of consciousness.

The Surface and Deep Structure of Experience

How then, are we to conceptualize the unconscious–conscious distinction? The easiest way, for me, derives from a distinction made by Chomsky regarding a deep *vs.* a surface structure of language. Take a person who is fluent in several languages. While speaking, say, French, he/she is totally caught up in the 'French frame of reference'. He/she utilizes this frame to address a deep structure that 'contains' all he/she needs to know in order to cope. Now he/she shifts to Chinese. Once again the 'Chinese frame' allows him/her to address that *same* deep structure in order to cope.

From all we know about memory storage, this deep structure is more or less distributed over some extent within each brain system. It is composed of patches within a

synaptodendritic processing web — patches that are organized by experience (see Alkon *et al.*, 1996, for review). What follows is from *Languages of the Brain* (Pribram, 1971), pp. 104–5**:**

> Any model we make of perceptual processes must thus take into account both the impor-tance of . . . subjective experience, and the fact that there are influences on behavior of which we are not aware. Instrumental behavior and awareness are often opposed — the more efficient a performance, the less aware we become. Sherrington noted this antago-nism in a succinct statement: 'Between reflex action and mind there seems to be actual opposition. Reflex action and mind seem almost mutually exclusive — the more reflex the reflex, the less does mind accompany it.'
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> The reciprocal relationship between awareness and behavior is perhaps best illumi-nated by the psychological processes of habit and habituation. If an organism is repeat-edly exposed to the same situation, is placed in an invariant environment, two things happen. If he consistently has to perform a similar task in that environment, the task becomes fairly automatic, i.e., he becomes more efficient. The organism has learned to perform the task; he has formed *habits* regarding it. At the same time the subject habitu-ates: he no longer produces an orienting reaction; he no longer notices the events constant to this particular task in this environment. His verbal reports of introspection, his failure to move his head and eyes in the direction of the stimulus, and electrophysiological meas-ures such as galvanic skin response, plethysmography and EEG, all attest to the disap-pearance of orienting when an unvarying situation is repeated. . . . However, habituation is not an indication of some loss of sensitivity on the part of the nervous system but rather the development of a neural model of the environment, a representation, an expectancy, a type of memory mechanism against which inputs are constantly matched [Sokolov, 1960; Pribram, 1971; Thompson, 1986; Grandstaff & Pribram, 1972]. The nervous sys-tem is thus continually tuned *by* inputs to process further inputs.
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> The habitual performance of the organism also results [of course] from neural activity. . . . So the question is: What is the difference between the two kinds of neural activity that make awareness inversely related to habit and habituation?

Nerve impulses and graded potential changes (hyper- and depolarization) occur-ring within a dendritic web are two kinds of processes that could function recipro-cally. A simple hypothesis would state that the more quickly the patterns of signals arriving at synapses are transduced into patterns departing from the web via axons, the shorter the duration of the design occupying the processing web. Once habit and habituation have occurred and a throughput has been established within the process-ing web, behaviour becomes 'reflex'. By contrast, the more persistent designs of graded polarizations are coordinate with awareness. The hypothesis carries a corol-lary: nerve impulse patterns *per se* and the behaviour they generate are unavailable to immediate awareness. Thus, even the production of speech is 'unconscious' at the moment the words are spoken.

The distinction between neural circuits composed essentially of axons when a rapid throughput has been established in the web and processing in the web is impor-tant and not ordinarily acknowledged.

Neurons are ordinarily conceived to be the computational units of the brain. Thus the majority of processing theories since the seminal contribution of McCulloch and Pitts (1943) have taken the axonal discharge of the neuron, the nerve impulse, as the currency of computation.

However, there is more to processing than these models indicate. Not only are axonal-dendritic synapses that connect neurons subject to local influences in these

networks, but innumerable dendro-dendritic synapses provide an initially un-constrained high connectivity needed to account for the spatial and temporal richness of experience (Bishop, 1956; Pribram, 1960; 1971; Schmitt *et al.*, 1976). Presynaptic dendrites are found in many locations in the sensory and central nervous system (see Table, p. 9, in Shepherd, 1988), As summarized by Szentagothai (1985, p. 40):

> The simple laws of histodynamically polarized neurons . . . indicating the direction of flow of excitation . . . came to an end when unfamiliar types of synapses between den-drites, cell bodies and dendrites, serial synapses, etc. were found in infinite variety . . .

Junctions (axodendritic and dendo-dendritic), between neurons in the form of chemi-cal synapses, electrical ephapses, and tight junctions occur within overlapping den-dritic arborizations.

These junctions provide the possibility for processing within each neuronal circuit as opposed to the mere transmission of signals. The term neurotransmitters applied to chemcials acting at junctions is, therefore, somewhat misleading. Terms such as neuro-regulator and neuromodulator convey more of the meaning of what actually tran-spires at synapses.

One of the most striking facts regarding neurons is that, when stimulated, neurons produce more RNA than any other tissue in the body (Hydén, 1961). And after stimu-lation stops and RNA production diminishes in the neuron, large concentrations of molecularly similar RNA begin to appear in the adjacent glia (Hydén, 1969).

RNA production is thus somehow involved when nerves are stimulated physio-logically and also when the organism performs a task. However, the story is not simple. Within 24 to 48 hours after cessation of stimulation the effects on RNA con-centration are no longer discernible — even in glia. The suggestion has been made, therefore, that RNA functions only as an intermediary between DNA and proteins which form the basis of a more permanent record. RNA determinations are nonethe-less useful in indicating that the memory process has become active.

Nerve impulse conduction therefore leads to a variety of junctional dendritic microprocesses. When a nerve impulse courses down an axon it becomes attentuated both in amplitude and speed of conduction as the axon branches into teledendrons. This is because the amplitude and speed of conduction are proportional to fibre size diameter. Thus, when the nerve impulses arrive at synapses, presynaptic polarizations result. These are never solitary but, as noted, constitute arrival patterns. The patterns are constituted of sinusoidally fluctuating hyper- and depolarizations which are insufficiently large to immediately incite nerve impulse discharge. It is this delay that affords opportunity for computational complexity.

Neurons are thresholding devices that sample the results of the dendritic micro-process and form discrete packets of nerve impulses for communication and control of other levels of processing. These packets are more resistant to degradation and interference than the graded microprocess. They constitute the channels of communi-cation not the processing element. The following quotations from *Brain and Percep-tion* (Pribram, 1991) and from Thatcher & John (1977) summarize what appears to be occurring:

> The sub- and superneuronal aspect of the dendritic microprocess, its potential to extend beyond the single neuron, provides explanatory power for both older and recently accumulating evidence that brain processes coordinate with perception [and memory] are *distributed* (Pribram, 1991, p. 10).

> The spatiotemporal patterning of these cooperative processes . . . [involve] ionic shifts . . . with extrusion of potassium ions and ionic binding on extracellular mucopolysaccharide filaments. If we focus our attention not on the membranes of single neurons, but upon charge density distributions in the tissue matrix of neurons, glial cells, and mucopolysaccharide processes, we can envisage a complex, three-dimensional volume of isopotential contours, topologically comprised of portions of cellular membranes and extracellular binding sites and constantly changing over time (Thatcher & John, 1977, pp. 305–6).

There is more. Dendrites are fitted with spines that resemble little cilia, or hairs, protruding perpendicularly from the dendritic fibre. These spines have bulbs at their endings, knoblike heads that make contact with teledendrons, the branches of axons and with other dendrites to form synapses. Activity in teledendrons and in dendrites such as those stemming from axonless neurons produce depolarizations and hyperpolarizations in the dendritic spines. The postsynaptic effects are ordinarily invoked chemically and can be modified by other chemicals that act as regulators and modulators (see Pert, 1997, and Jibu *et al.*, 1996), The following paragraphs to the end of this section are adapted from *Brain and Perception* (Pribram, 1991, pp. 85–7).

   Shepherd, Rall, Perkel and their colleagues (see, e.g., Coss & Perkel, 1985; Perkel, 1982, 1983; Perkel & Perkel, 1985; Shepherd *et al.*, 1985) modelled the process whereby these postsynaptic events occurring in spine heads interact. The issue is this: the stalks of the spines are narrow and therefore impose a high resistance to conduction (active or passive) toward the dendritic branch. Spine head depolarizations (as well as hyperpolarizations) must therefore interact with one another if they are to influence the action potentials generated at the axon hillock of the parent cell of the dendrite. The interactions (dromic and antidromic) among dendritic potentials (by means of which the signal becomes effective at the next stage of processing) thus depend on the simultaneous activation of both pre- and postsynaptic sites. According to Shepherd and colleagues (1985), several advantages accrue from this form of activation:

> First the relative efficacy of distal dendritic inputs would be greatly enhanced. Second . . . the transients within the model spines and dendrite are rapid and do not have the slow, low amplitude time course of synaptic potentials recorded experimentally at a distance from the cell body. Within the distal dendrite, information might thus be processed through precise timing of specific inputs to different neighboring spines. . . . These precise interactions would greatly increase the complexity of information processing that can take place in distal dendrites (p. 2194).

The activation of interacting polarizations occurs in parallel, is distributed and discontinuous: 'Thus, the active propagation. . . was discontinuous and resembled in this respect the saltatory conduction that takes place from node-to-node in myelinated nerve' (Shepherd *et al.*, 1985, p. 2193).

   A prime virtue of this enhanced complexity is the potential for selectivity allowed by such a process:

> . . . it has been shown that [post]synaptic polarization in a spine head can spread passively with only modest decrement into a neighboring spine head. If the neighboring spine is presynaptic, transmitter release could be evoked (p. 2192).

Thus effects on the presynaptic neuron can occur, effects critical to selectivity in learning (see e.g., Freud, 1895; Hebb, 1949; Stent, 1973).

Active spines appear to provide a basis not only for multiply contingent processing of synaptic inputs as outlined above but also for storage of information. The spine stem resistance as a parameter for varying the effectiveness of spine input to parent dendrite has been recognized as a locus for plasticity underlying learning and memory (Shepherd *et al.*, 1985, p. 2193).

And the spine stems have actually been seen to change their length and thickness under different processing conditions (Perkel & Perkel, 1985).

It is this processing web that is conceived to compose the deep store which becomes addressed by neuronal circuits that represent the surface organizations of various frames of reference. And it is the substrate — the connectivity of this deep distributed store — that has evolved so dramatically in the human brain cortex:

Type of animal	Neuron density
Mouse	142.5
Rat	105.0
Guinea Pig	52.5
Rabbit	43.8
Cat	30.8
Dog	24.5
Monkey	21.5
Human	10.5
Elephant	6.9
Whale	6.8

Density of Neurons in the Cortex of Animals

Neuronal densities in the motor cortex in various animals, based upon Tower and Elliot (1952) and Tower (1954). In Abeles (1991), p. 50. *Note:* Neuronal densities are inversely proportional to the amount of connectivity (see Diamond, 1990),

A Content-Addressable System

Propositional, categorical, object, allo- and egocentric frames access this deep store somewhat like a computer program addresses the memory store on a hard disk of a computer. However, in the brain the process appears to be content- rather than location addressable. The following example of how a content-addressable system can work relates hippocampal to isocortical function.

The current formulation was instigated by another presented by J. McClelland and Bruce McNaughton (McClelland, 1996), The McClelland-McNaughton model takes into account the latter's finding of a representation in hippocampal neurons of a path in space. Thus their model directly matches hippocampal activity with the activity of the cortical convexity (as would be expected of a comparator). On the input side such a model is plausible. However, their model also demands such a comparative process on the output side. This is implausible in view of results obtained by Paul MacLean and myself (Maclean & Pribram, 1953; Pribram & Maclean, 1953), when mapping cortical connectivity by strychnine neuronography. While we were able to readily show multiple inputs to the hippocampal formation, we were totally unable to acti-

vate *any* isocortical region by stimulating the hippocampal cortex. The finding was so striking that MacLean (1990) developed the theme of a schizophysiology of cortical function.

On the other hand outputs are plentiful to the amygdala, to the *n. accumbens septi* and to other subcortical structures via the fornix. Confirmation of the difference between input (encoding) and output (decoding) operations involving the hippocampal formation has recently come from studies in humans using fMRI (Gabrieli *et al.*, 1997), Encoding into memory was found to activate the para-hippocampal cortex (including the entorhinal cortex which receives input from the remainder of the isocortex), whereas decoding (retrieval) was found to activate the subiculum which - provides the major *subcortical* output of the hippocampal region via the fornix' (p. 265).

The subcortical nuclei do not have the laminar structure of cortex and so are poor candidates for the point to point match a computer would ordinarily be conceived to implement. On the other hand, a match could readily be achieved if the comparison would involve a distributed stage, much as when a holographic memory is used to store and retrieve information (for instance with holofishe). It is the evidence that a distributed store is, in fact, built up in the hippocampal formation during learning that makes this sort of model plausible.

Landfield (1976), and O'Keefe (1986), have developed this sort of model. O'Keefe reviews the evidence and describes the model as follows:

> Attempts to gain an idea of the way in which an environment is represented in the hippocampus strongly suggest the absence of any topographic isomorphism between the map and the environment. Furthermore, it appears that a small cluster of neighboring pyramidal cells would map, albeit crudely, the entire environment. This observation, taken together with the ease that many experimenters have had in finding place cells with arbitrarily located electrodes in the hippocampus, suggests that each environment is represented many times over in the hippocampus, in a manner similar to a holographic plate. In both representation systems the effect of increasing the area of the storage which is activated is to increase the definition of the representation.
>
> A second major similarity between the way in which information can be stored on a holographic plate and the way environments can be represented in the hippocampus is that the same hippocampal cells can participate in the representation of several environments (O'Keefe & Conway, 1978; Kubie & Ranck, 1983). In the Kubie and Ranck study the same place cell was recorded from the hippocampus of female rats in three different environments: All of the 28 non-theta cells had a place field in at least one of the environments, and 12 had a field in all three environments. There was no systematic relationship amongst the fields of the same neurone in the different environments. One can conclude that each hippocampal place cell can enter into the representation of a large number of environments, and conversely, that the representation of any given environment is dependent on the activity of a reasonably large group of place neurones.
>
> The third major similarity between the holographic recording technique and the construction of environmental maps in the hippocampus is the use of interference patterns between sinusoidal waves to determine the pattern of activity in the recording substrate (see Landfield, 1976). In optical holography this is done by splitting a beam of monochromatic light into two, reflecting one beam off the scene to be encoded and then interacting the two beams at the plane of the substrate. In the hippocampus something similar might be happening. . . . The beams are formed by the activity in the fibers projecting to the hippocampus from the medial septal nucleus (MS), and the nucleus of the diagonal band of Broca (DBB).
>
> Pioneering work by Petsche, Stumpf and their colleagues (Stumpf, 1965) showed that

the function of the MS and DBB nuclei was to translate the amount of activity ascending from various brainstem nuclei into a frequency moduled code. Neurons in the MS/DBB complex fire in bursts, with a burst frequency which varies from 4–12 Hz. Increases in the strength of brainstem stimulation produce increases in the frequency of the bursts but not necessarily in the number of spikes within each burst (Petsche, Gogolak and van Zweiten, 1965). It is now widely accepted that this bursting activity in the MS/DBB is responsible for the synchronization of the hippocampal theta rhythm (O'Keefe, 1986, pp. 82–4).

The November 1995 issue of *Scientific American* shows how such a holographic matching process could work. Of course, in this quotation, the matching process works by way of illuminating crystals, while the neural substitutes for this would be surface distributions of dendritic polarizations in somatosensory cortex (King *et al.*, 1994; Pribram, 1995):

> Given a hologram, either one of the two beams that interfered to create it can be used to reconstruct the other. What this means, in a holographic memory, is that it is possible not only to orient a reference beam into the crystal at a certain angle to select an individual holographic page but also to accomplish the reverse, *illuminating a crystal with one of the stored images gives rise to an approximation of the associated reference beam, repro-duced as a plane wave emanating from the crystal at the appropriate angle.*
>
> A lens can focus this wave to a small spot whose lateral position is determined by the angle and therefore reveals the identity of the input image. If the crystal is illuminated with a hologram that is not among the stored patterns, *multiple reference beams — and therefore multiple focused spots, are the result. The brightness of each spot is propor-tional to the degree of similarity between the input image and each of the stored patterns.* In other words, *the array of spots [weights in a layer of a PDP network] is an encoding of the input image, in terms of its similarity with the stored database of images* (Psaltis & Mok, 1995, p. 76).

Putting this together with the McClelland-McNaughton model, which is based on data which do show a representation of the *path* taken by an animal down an alley maze, encoding in the hippocampus may be both holographic-like *and* patterned in space and time. The hypothesis is that as multiple paths become represented in the hippocampal formation, a transformation into holographic-like surface distribution in the spectral domain is effected. When subsequently a particular path is sought, the buffer operates much as does the holographic memory described above. Initially, actual paths construct the holographic memory and during retrieval, scan paths activate the comparator to access a particularly appropriate actual path. Essentially, the process implements a shift in coordinates from space–time (configurational) to spectral and back to configurational.

The shift of coordinates is suggested to take place by way of scanning, that is, constructing a particular scan path. Computational models such as those proposed by Harth, Unnikrishnan and Pandya (1987), and by Yasue, Jibu and Pribram (Pribram, 1991), have been developed for vision to account for the selection of coordinates as a result of internal scanning. The shift from spectral to the configuration coordinates has been demonstrated in the visual system both at the thalamic and cortical level (Spinelli & Pribram, 1967; Pribram *et al.*, 1981), Electrical stimulation of temporal or frontal lobe cortex enhances or diminishes the extent of the inhibitory surrounds and flanks of dendritic receptive fields in thalamus and cortex so that the sensory channels can either become multiplexed or fused. As the dendritic fields can be described in

terms of a spacetime constraint on a sinusoid — such as the Gabor elementary func-
tion, the constraint is embodied in the inhibitory surround of the field. Enhancing the
surround enhances processing in configuration coordinates; diminishing the surround
enhances the sinusoidal (spectral domain) aspects of processing. Thus, the develop-
ment of scanpaths operates on the inhibitory process that characterize the fluctuations
of the polarizations of the dendritic connection web.

The frame of reference in this model is the *path* through the maze that is to be
instantiated. Extrapolating from this example, frames of reference are not to be con-
sidered to be static — rather they are dynamic processes optimizing a fit to ongoing
sensory and central (brain) activity. With regard to object-centred reference frames,
Palmer (1983) describes the process as follows.

> The reference frame hypothesis makes use of the underlying transformation group in a
> somewhat different way. Rather than ignoring properties that vary over the transforma-
> tions of the group, it assumes that the effects of transformations are neutralized by impos-
> ing an 'intrinsic frame of reference' that effectively 'factors out' the transformation,
> thereby achieving shape constancy. The 'intrinsicness' of the frame simply means that
> the frame is chosen to correspond optimally with the structure of the figure rather than
> being imposed arbitrarily (pp. 275–6).

More generally, Smolensky describes the relationship between surface (memory
retrieval in his example) and deep (storage) structure as follows:

> The concept of memory retrieval is reformalized in terms of the continuous evolution of a
> dynamical system towards a point attractor whose position in the state space is the mem-
> ory; you naturally get dynamics of the system so that its attractors are located where the
> memories are supposed to be; thus the principles of memory storage are even more unlike
> their symbolic counterparts than those of memory retrieval (Smolensky, 1988, p. 12).

To summarize: using language as an example, we are rarely if ever aware of how
we speak or write or read. Rather it is the contents that derive from the process that
constitute our experience. That experience is formed at least at two levels: a semi-
automatic perceptual (and motor) skill that allows us to cope readily with circum-
stance; and an awareness of that coping which intrudes whenever fluidity in process-
ing becomes jeopardized. Both levels operate within a set of mutually embedded
reference frames. Experienced conscious awareness emphasizes one frame to the
temporary exclusion of the others much as when a fluent multilingual speaker uses
one language at a time. Reference frames, like languages, are surface structures that
address a deeper distributed process. The surface structures, the reference frames, are
conceived to be embodied in brain circuits; the deep structure in the synaptodendritic
web within these circuits. Embedding of frames indicates that the same neural ele-
ments can partake of several circuits (Hebb, 1949/61); it is the pattern of connectivity
that determines the reference frame. The synaptodendritic web is composed of
patches that are modified by experience. Modification is determined not only by the
processes and contents of experience *per se* but also by another form of processing
which is organized by brain systems different from those that organize reference
frames.

Episodic Experience

These other systems are located, in a sense, at the opposite 'end' of the brain. The sys-
tems include the anterior poles of the frontal and temporal lobes and the limbic forma-

tions on the medial part of the cerebral hemispheres that connect the two poles (Kaada *et al.*, 1949; Pribram, 1961). Whereas the posterior convexal systems organize our experience within a complex of reference frames, these frontolimbic systems organize our experience into a 'narrative' composed of episodes and events that occur within these episodes. Again a case history highlights the issues:

TK [an eight-year old boy] had an agenesis of the corpus callosum with a midline cyst at birth. During the first six months of his life, two surgical procedures were carried out to drain the cyst. Recently performed Magnetic Resonance Imaging (MRI), showed considerable enlargement of the frontal horns of the lateral ventricle — somewhat more pronounced on the right. The orbital part of the frontal lobes appeared shrunken as did the medial surface of the temporal poles.

TK appears to have no ability for quantifying the passage of time [what Bergson (1922/65), called durée] and no experiential appreciation of the meaning of time units. For example, a few minutes after tutoring begins, he cannot say — even remotely — how long it has been since the session started. He is as apt to answer this question in years as in minutes. He does always use one of seven terms of time quantification (seconds, minutes, hours, days, weeks, months or years), when asked to estimate the duration of an episode but uses them randomly. He can put these terms in order, but does not have any sense of their meaning or their numerical relationships to one another.

When TK returned from a trip to the Bahamas he did recall that he had been on the trip; however, the details he could recount about the trip numbered fewer than five. His estimates of how long it had been since his trip, were typical in that they were inaccurate and wildly inconsistent on repeated trials. Also, the first five times back at tutoring he stated that he had not been at tutoring since his trip. It appears that he is unable to place in sequence those few past events that he can recall. Nonetheless, he can answer questions correctly based on his application of general knowledge about development, e.g., he knows he was a baby before he could talk because 'everyone starts as a baby'. But, one day he asked his tutor if he knew him when he was a kid, indicating, I think, his incomprehension of the duration of each of these developmental periods and his unawareness of what events constituted such a period for him.

TK is aware that he has a past, that events have happened to him but he cannot recollect those events. He also spontaneously speaks of events in his future such as driving an automobile and dating and growing a beard. He has play-acted on separate occasions his own old age and death. TK is capable of excitement about the immediate future. On the very day that he was going to the Bahamas he was very excited as he exclaimed repeatedly: 'I'm going to the Bahamas.' But when his tutor asked him when, he said blankly: 'I don't know'. He also displayed keen anticipation when one day he saw a helicopter preparing to take off from the hospital. The helicopter engines revved approximately 13 minutes before it took off and TK become increasingly more vocal and motorically active, laughing as he repeated 'When's it going to take off?' He also anticipates future punishment when he is 'bad'. He is aware, on some level, of the immediate future in his constant question 'what's next' which he asks his mother at the end of each activity.

There are a variety of other occasions on which he demonstrated this capacity regarding tempo (as opposed to evaluating the duration of an experience). There have been several breaks in his usual thrice weekly tutoring schedule. Each of four times this schedule has been interrupted, he has run to meet his tutor when he approached rather than waiting inside as he usually does. Also, on these occasions he has typically asked if his tutor missed him. However he states he does not know how long it has been since his last session, and there was no evidence that he knew it had been longer than usual.

TK compares who walks faster or who draws faster. He has at least a basic sense of sequencing as when he says, 'I'll take a turn and then you take a turn.' He also uses terms like 'soon' and 'quick' correctly in conversation. For example, when he wanted to do a

drawing at the beginning of a session, and his tutor said that we needed to begin to work and he countered 'this will be quick'. Unsurprisingly, he finished his drawing at his normal pace. He somehow seems to use such terms correctly without any experiential appreciation of them. (Modified from Letter written by Richard Ahern on 19 March 1995, addressed to Karl H. Pribram. For a complete description, see Ahern *et al.*, 1998).

Note that TK has no difficulty whatsoever in processing entities or allocentric and egocentric space. His categorical and propositional skills are so well developed that he can use these 'semantic' processes to veil his deficit in 'episodic' processing to some extent.

Episodic processing organizes experience not according to invariant frames (as defined above), but according to covariations among events. Covariations are 'parsed' into episodes, (de)marked at both ends by a 'stop' constituted of an orienting response. Orienting is ordinarily accompanied by visceroautonomic arousal, arousal which fails to occur after amygdalectomy (Pribram *et al.*, 1979; Pribram, 1991, Lecture 8). In the absence of this visceroautonomic arousal, habituation of the orienting response fails to occur and the organism (monkey or human) continues orienting to a repetition of the event. There is no closure; experience is ever novel and never familiar.

Seizures originating around the amygdala produce experiences such as *déjà vue* (a feeling of familiarity in a strange place) and *jamais vue* (a feeling of estrangement in what should be a familiar place). When the seizures are prolonged, an entire experienced episode fails to become encoded into the person's retrievable life story. As an example, one Friday I was accompanied by a young psychologist to my car after having lectured at Napa State Hospital in California. I wished her a happy weekend, and she said that she looked forward to it because of a party the group was having. The following week, she and others of the group were again accompanying me to my car, and I asked how this young lady had enjoyed the party. She answered that she had become overly tired and had fallen asleep and not gone to the party. The others in the group turned to her in surprise — they had all seen her, seemingly enjoying her attendance, 'a bit spaced-out because, perhaps she had had a bit much to drink'. On examination it turned out that the young lady had psychomotor seizures due to an epileptic focus in the region of her medial temporal lobe. In extreme instances, when this part of the brain is not just temporarily out of commission, but is permanently injured as in TK, experience simply never engenders the feeling of familiarity. What remains is an encoding of experience in reference frames. *Inter*personally the impaired transaction feels strange (estranged).

As to how a 'stop' process that marks an episode might operate, I have for years suggested to my laboratory colleagues that the marking could work somewhat like pagination in a computer program, or setting a bandwidth in a content-addressable holographic-like memory. This would account for the effect of priming and the intrusive retrieval of material by a subject with 'memory loss' due to excessive alcoholism, as in Korsakoff's syndrome, or in HM, who has had both amygdala and hippocampus bilaterally removed (Weiskrantz *et al.*, 1974). The suggestions need to be modelled in a PDP type program to understand more fully the observations.

The Frontal Executive System

Nonetheless, as a temporary 'model' of the function of a simple marker designating the beginning and end of an episode, when combined with the model of hippocampal function presented earlier, current understanding goes a long way toward specifying the brain process involved in episodic experience. To this understanding must be added what we know about the role of the anterior frontal cortex in organizing executive working memory (reviewed by Pribram, 1991, Lecture 10; and 1997), This part of the frontal lobe is anatomically intimately related to the amygdala via the uncinate fasciculus and to the hippocampal formation by way of the adjacent cingulate cortex (Papez circuit: hippocampus → septal region [*n. accumbeus septi*] → mammillary bodies of the posterior hypothalamus → tract of VicDazir → anterior thalamic nuclei → cingulate cortex → hippocampus). Essentially, the executive working memory, in conjunction with these limbic structures provides flexibility in processing experienced events. This is accomplished by connections with the rest of the brain to allow monitoring of what is going on — by inducing the delay in processing necessary for the signals in a circuit to engage extended parts of the synaptodendritic web.

   An experiment by Fuster (1997) demonstrates this delay function. Using the delayed matching from sample technique, Fuster recorded from neurons in the inferotemporal cortex (part of the reference frame system critically involved in making visual choices (see Pribram, 1991, Lecture 7 for review). He found neurons to be active at all stages of the task — different neurons for different stages. He then temporarily deactivated the frontal cortex by cooling it. Now he found *no* cells active during the delay — only during the initial (sample) and final (matching) stages. Monitoring is thus achieved by virtue of the operations of the anterior frontal cortex but not within it. Rather the anterior frontal cortex apparently actively *facilitates delay* within the circuits that are critical to the performance of a task, making it possible for alterations in that circuitry to occur. In computer language, the executive routine influences (e.g. sets up delays within) ongoing programs and the relations (such as priorities) between them.

   In 1966 I described a process by which such delays and priorities become assigned under the heading 'The Temporal Hold' (which is in the same paper in which I suggested the holographic metaphor). The paper was entitled 'Some Dimensions of Remembering: Steps Toward a Neuropsychological Model of Memory' pp. 179–88:

> This 'temporal hold' is assumed to be accomplished through an operation similar to that which gives rise to a temporary dominant focus in the experiments of Ukhtomski (1926), Rusinov (1956) and Morrell (1961). Without regulation by such a hold mechanism, the organism fluctuates inordinately among possible temporal codes and thus produces only a jumble of arrival patterns. In such circumstances even temporary combinations, i.e., moiré effects necessary to the registration of interference patterns as holograms cannot be achieved. Support for some sort of temporal hold process emanating from the fronto-limbic portions of the brain comes from electrical recordings made in man. These are decribed as follows by Grey Walter:
>
> > When conditional and imperative stimuli are presented in this way a remarkable change appears in the frontal brain response; a negative potential appears immediately after the conditional response and endures until the imperative response, when it declines rapidly to zero or becomes positive. This has been described as the 'Contingent-Negative Variation' or Expectancy Wave (Walter *et al*., 1964). In conditions such as those described, the E-wave is the most constant and stable of all electrocerebral phenomena in

normal adults. It does not depend on the character of the intrinsic normal rhythms and is as large and extensive with the eyes open as shut. In children, however, and in mentally disturbed patients, the E-wave is often elusive and variable; above all, it is extremely sensitive to social influences.

As already mentioned the E-wave arises always and only during sensory-motor association, but both the sensation and the motion may be of quite a subtle nature. In the simplest case the presentation of a conditional stimulus in any modality, followed by an imperative stimulus in another modality, evokes an E-wave following the primary conditional responses and lasting until the moment when the imperative response would have occurred.

The striking feature of the E-wave is that it appears, as it were, to submerge the imperative response, and terminates very abruptly at the instant when the latter would have subsided. The typical sawtooth waveform of this phenomenon is remarkably like that of the time-base of an oscilloscope, rising steadily toward a maximum value over a time determined by the established stimulus interval, and dropping suddenly to zero. The duration of the E-wave as studied systematically so far is several seconds, but in some subjects the potential difference seems to be sustained much longer during 'extinction' trials when there is no imperative stimulus to act as a 'fly-back' trigger. Sometimes there is even a suggestion of a staircase or 'Treppen' effect when conditional stimuli are presented at intervals of a few seconds without reinforcement to subjects with a very slow rate of extinction. Since the E-wave presumably represents depolarization of the apical dendritic plexus, the possibility of 'recruitment' in such a mechanism would be interesting to study in more detail. The subjects who have shown signs of this effect are highly suggestible and easily hypnotized (Black and Walter, 1963),; the capacity to maintain a high and even cumulative level of expectancy may be typical of this disposition, and may depend on some idiosyncrasy of the electro-chemical relations in the superficial cortical levels (Walter, 1964, pp. 310–13).

Episodic processing and its working memory component (especially when considered as short term memory) have often been considered to precede semantic processing (what has been discussed here as processing involving reference frames). The clinical evidence presented indicates, however, that episodic and semantic (referential) processing can effectively proceed independently of one another although the brain systems that organize these processes do, of course, ordinarily interact. Thus ordinarily, episodic awareness uses referential systems and referential systems become modifiable by virtue of input from the episodic systems.

Summary

Weiskrantz's, Stoerig's and Cowey's distinction between reflexive, phenomenal and consciously accessible processing becomes, according to the analyses presented here, a distinction between automatic, referential (semantic) and episodic executive processing. Automatic, reflexive, processing occurs whenever a neural circuit has become thoroughly established with a minimal synapto-dendritic delay. Referential, phenomenal, processing is semi-automatic but easily accessible to monitoring when shifts among reference frames are initiated within circuits, either 'spontaneously' or by some more organized sensory or central input.

Executive monitoring comes about when frontolimbic processes become addressed, thus producing delays that allow shifts among reference frames in the systems of the posterior convexity. Ordinarily such shifts are included within episodes marked with a beginning and an end (a function of the amygdala), and by re-

organizing the frames' serial position (a function of the anterior frontal cortex; see review by Pribram, 1991, Lecture 10). An experiment by Tucker (Tucker *et al.*, 1995) provides support for this view. Using a dense electrode array to record event-related changes in brain electrical activity, Tucker showed that a response to visual stimulation evoked in the occipital cortex is followed in about 100 msec. by a response (also visual event related) in the anterior frontal cortex only to 'reprise' back to the occipital cortex within another 100 msec. Interaction between the referential and executive systems and between the executive and referential systems (the Fuster experiments) has thus been shown to occur. I wonder how the occipital–frontal–occipital reprise might change in blindsight patients. Might there still be a back to front to back event-related response? Or would the frontal system have nothing to work with — thus, accounting for the blind part of blindsight? The experiment would be well worth doing.

Conclusion

The high points of this essay can be summarized as follows. The analysis relating brain to conscious experience made by Weiskrantz, Stoerig and Cowey, based on their extensive experimentation with blind-sighted humans and monkeys, has been supplemented by a synthesis based on my own experimental analyses as reviewed in *Brain and Perception* (Pribram, 1991) and clinical experience. This synthesis takes off from Weiskrantz, Stoerig and Cowey's three levels of 'minding': (1) reflexive, automatic; (2) phenomenal, referential; and (3) conscious, executive. I have reviewed evidence indicating that automatic processing involves interpenetrating frames of reference; that when reference frames shift, a delay is introduced in the processing circuitry. Such a delay may be introduced by the executive processor or the shift may be induced by sensory or central (e.g. drive stimulus) input and engage the executive secondarily. The episodic system organizes and in turn is fine tuned by the executive system.

Conscious experience is dependent on the delay introduced between synaptic arrival patterns and axonal departure patterns. The delay occurs within modifiable dendritic patches (Pribram, 1971; Alkon *et al.*, 1996), When such a delay occurs the opportunity arises for shifts in referential framing and in monitoring such shifts.

This evidence and especially the clinical case histories presented have indicated that the human brain organizes both a Cartesian Theatre composed of reference frames and a Narrative Consciousness composed of episodically parsed events (Pribram, 1997).

Epilogue

In the prologue I suggested that the so-called hard problem is common to all epistemological endeavour. Scientific and other types of knowledge always *begin* with our conscious experience. We can no more ontologically 'know' a quark or a table than we ontologically 'know' a colour or a pain. We relate our experiences to one another and match these communications to our own experiences. It really isn't any easier or harder to 'know' a quark than to 'know' another's pain. The knowing is different (Pribram, 1965) — in the case of a quark it comes from analysing in a downward direction in a compositional hierarchy; in the case of another's pain it is working in an upward direction in a relational hierarchy (through consensual validation).

Neither process is easy but we have attributed a misplaced concreteness (and therefore labelled them the easy problems) to the downward process and have been suspicious of relativistically (relationally) reached conclusions. Nonetheless, science needs both types of knowing: concepts such as feedback (homeostasis) in biology and relativity in cosmology are indispensable (see Granit, 1970, for their indispensability in understanding the motor systems of the brain).

I believe the misplaced concreteness of downward analysis comes from the faith we have in deductive reasoning. Such reasoning is logically tight and solid. But, of course, it depends for its 'truth' on the axioms from which the reasoning takes off. Inductive, synthetic reasoning is relativistic, loose, in the sense that complementary schemes (frames of reference) can organize the experiences. Abductive reasoning (Peirce, 1934), has the virtue of helping to choose among frames by comparing one inductive scheme with another derived from outside the experiences from which the first derives. Induction and abduction thus overcome the Gödelian constraint imposed by deductive systems. Reductive systems can only formalize what we have *chosen* to be 'true'. (I have always been intrigued by viewing the concept 'formalizing' as dipping our ideas into formalin to harden them much as we do brains, so we can slice them up more readily).

My trials in essaying these 'explanations' of conscious experience end much as did my previous paper relating to this topic (Pribram, 1996): the dictionary holds that to experience means to try; conscious experience occurs when I try and in this endeavour, my trying has indeed been tried.

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