

# Introduction: Brain and Consciousness A Wealth of Data

KARL H. PRIBRAM

## Introduction

The explicit purpose of this conference was, in the words of E. Roy John, to discuss the evidence available for understanding "the physiological basis of subjective experience, the material origin of human self-awareness." I attended the presentations and discussions and have devoted many hours to studying the written contributions that evolved from the conference. The presentations and contributions were and are impressive and I am honored to be invited to write an introduction to the resulting publication. What I hope to do in this introduction is examine some of the assembled contributions most relevant to the explicit purpose of the conference within the framework of systematizations I have achieved of my own observations and experimental results.

## Quantum Theory

Walter Freeman poses the challenge in chapter 2: "On the fallacy of assigning an origin to consciousness." According to this challenge the title of our symposium is misleading. There is no *the* mind and therefore there can be no "machinery" of mind in the sense of Newtonian mechanistic explanation. According to Freeman, mind (derived from *mind*ing as pointed out by Gilbert Ryle, 1949) is process, actually a set of processes coordinating the functions of our material body with the panoply of environmental events. Of course, the brain has a special relation to organizing these processes and Freeman presents evidence on how some of these organizations develop and become replaced with others. He makes the further point that certain activities (usually cyclic) initiate the organizing process.

A great beginning. I can clearly hear some of my philosopher friends, however, shaking their heads, grumbling: "But where does this leave us with regard to our

conscious experience of a more or less unitary self, the progenitor and executive of the minding process?" I counsel patience. In chapter 1, Robert Doty, in fact, takes the next step in addressing the issue of "the unity of mind." Doty furthers the idea that Newtonian mechanics fails to describe the role of brain in organizing minding. Doty is forthright in proposing that brain processes are nonlocal cooperatives such as those that describe interactions in quantum physics.

In chapter 3, E. Roy John comprehensively reviews his own considerable amount of evidence that ensembles of distributed neural events cooperate to produce recognizable brain patterns that correlate with recognizable behavioral patterns. John points out that ensemble cooperation is best described in the spectral domain, though spatiotemporal factors operate to constrain the patterns of cooperation. John, however, does not clearly distinguish temporal from spectral organization, a distinction necessary for understanding the possibility enunciated by Doty that in the brain cortex ensemble cooperativity is akin to processes described in quantum microphysics.

The distinction between spectral and temporal organization (as well as between spectral and spatial organization) is mathematical. Spectra are measured in terms of frequencies, which in mathematics are Fourier transforms of patterns of time and space). Spectral analyses of the EEG determine power in various bandwidths of frequency. The time of occurrence of any particular frequency becomes enfolded into the totality of the bandwidth measurement.

In 1946, Dennis Gabor devised a scheme to measure the efficiency with which telephone communication (via Atlantic cable) could proceed. Following Hartley (1928), Gabor pointed out that there is a tradeoff between frequency and time (and therefore space on the cable) taken for transmission. He suggested that the frequency and duration of a signal be plotted simultaneously. The resultant plot within which the signal was described is a phase space—and Gabor used Hilbert's mathematics to develop the plot. In such a phase space the duration of a signal must cover at least a half wavelength or else the frequency of the signal is indeterminate. This minimum is mathematically identical with that described by Heisenberg to describe a quantum in microphysics. Gabor therefore called his minimum a "quantum of information."

During the 1970s it became clear that this Gabor elementary function, as the quantum of information is now called, is the best descriptor of a receptive field of a neuron in the visual cortex submitted to harmonic analysis (see review by DeValois and DeValois, 1988; Pribram and Carlton, 1986). Whether this means that dendritic processing as reflected in receptive field organization, is a microphysical quantum process remains an open question, van der Tweel in chapter 8 marks that though such an hypothesis can not be disproved, he remains unconvinced. Unfortunately, he provides no explanation for this stance. In view of the overwhelming mass of data in favor of Gabor-like processing in both the visual and auditory systems, it remains tenable that the laws that were formulated to describe quantum physics apply as well to sensory psychophysics (Licklider, 1951) and to the neurophysiology of sensory processing. (For detailed review see Pribram, 1990a and 1990b, Lectures 1, 2 and 4.)

To summarize: The contributions of Doty, Freeman, and John, that make up Part I of this book, point us toward an explanation of the role of brain organization in mental processing as obeying laws akin to those developed to describe quantum rather than mechanistic (Newtonian) physics. Evidence is available that, indeed, processing is distributed among ensembles of neural (dendritic) events but constrained by the temporal and spatial "initial conditions" describing the anatomic connectivity and functional properties of the neural network.

The fact that these considerations are reached by use of harmonic analysis based on spread functions such as the Fourier or Fourier-like transformations indicated that, by means of convolutions and inverse transforms, correlations among patterns can be readily achieved. Such procedures are the essence of image processing in computerized tomography. In processing sensory inputs, such correlations can be accomplished through movements that allow the extraction of invariant properties, constancies, to produce symmetry groups, which when inverse transformed are, (at least computationally) coordinate with the perception of objects. (For detailed reviews, see Pribram, 1990b, Lecture 5 and Appendix B.)

According to such a computational scheme, over any wide range of movements the only "object" that remains invariant is the mover, the corporeal self. (For the precise neural processes involved in the perception of a corporeal self, see Pribram 1990, Lecture 6). The challenge initiated by Freeman and posed by philosophers is, at least as an initial possibility, met by following through the proposals (based on their data) made by Doty and John.

## Chaos Theory

Harmonic analysis undertaken along the lines indicated by Gabor yield linear, invertible, computational transformations. Much more popular at the moment are closely related nonlinear procedures such as those used in Synergetics (see Haken, chapter 7, and Haken and Stadler, 1990) and in the applications of so-called chaos theory to the analysis of brain electrical activity. Freeman introduces this type of analysis in chapter 2 and Parts II and III of this book are filled with carefully executed studies using these techniques.

The quantum of information is an elementary function that changes (e.g., its frequency and therefore minimum duration) as conditions change. Further, neurologically, these quanta describe receptive field nodes in ensembles of cooperative dendritic events. Due to spontaneous neural activity and inputs from sensory and chemical receptors and from other neural networks, the activity in these ensembles is continuously changing. When the trajectories of these changes lead to temporary, i.e., quasistable, patterns within the ever-changing "enchanted loom" as Sherrington (1911/1947) once described brain electrical activity, these quasistabilities are called "attractors." When such patterns cannot be identified, the system is said to be chaotic. I believe this terminology is misleading: a holographic encoding of the nodes of interference patterns—Fourier coeffi-

clients—looks to be “random” or “chaotic” but in fact is a distributed domain that contains all of the information (by Gabor’s definition) necessary to display, when inverse transformed, images of objects.

The reason for applying these nonlinear techniques is that simple Fourier transformations do not supply sufficiently rich computational power to describe either neuroelectric or psychophysical phenomena *per se*, much less the relationships between them. To the extent that one can stay linear, as in quantum physical description, to that extent computation is simplified. When, however, nonlinearities must be introduced, as when irreversible choices or trajectories need to be described, they can be conceived either as basic—or as critical variables that affect a basically linear process. Bazar, in chapter 5, and Haken, chapter 7, take the latter route and their analyses and models are readily compatible with what I have described so far. For instance, in Bazar’s contribution, the “strange attractor” is a fractal (i.e., a noninteger) and fractals derive from the Fourier transformation, which allows not only translational but dilational invariance, the essence of fractal geometry (see Pribram, 1990b, Lecture 5 for details). Could it be that the trajectory leading from what appears to be chaos to what is described as the “strange attractor” is simply one manifestation of a Fourier-like process? In such a process, constraints reflect nonlinear rather than linear couplings of neural resonators, as indicated by the contribution of Alvarez Amador, Pascual-Margui, and Valdés-Sosa (chapter 4). Evidence produced with microelectrodes by Singer (1989) indicates that such resonances among dendritic processes within a cortical column in the visual cortex do, in fact, occur and can account for the conjoining of features in visual processing.

Chaos theory is distinguished from other binding techniques using non-linear dynamics, such as that of Thatcher in chapter 20 of this volume, in specifying attractors, tendencies toward which ensembles of momentary configurations (maps) of neural microprocesses converge. The principles of chaos theory take a step further the optimization principles of: 1) paths of least action in macrophysics (Hamiltonians that describe the tendency of systems to converge on least energy expenditure); 2) the action integral path in quantum mechanics (Feynman, 1985) in which Hamiltonians become vectors in phase space and therefore make possible stabilities above energy minima; to 3) attractors which describe (Prigogine and Stengers, 1984) temporary stabilities far from equilibrium (i.e., far from points of minimum energy). The binding problem, the fact that imaging is experienced as a unitary flow while the brain functions in terms of discrete microstates, is addressed by Lehmann in chapter 10.

Lehmann notes that the apparently continuous “flow” that characterizes conscious experience is found neurologically to be composed of discrete “moments.” Lehmann describes momentary microstates displayed as EEG maps, each map lasting about 10 msec. The metaphors of cinematography and television bring this issue into everyday experience: discrete frames or scans are experienced as continuous flows of images. Philosophers have discussed this issue as a part of the “grain problem” that deals with the fact that the grain or scale of our descriptions

(and measurements) of physical events is often different from the scale of description of consciously perceived events. We perceive tables and chairs, not molecules, atoms, or quarks. In the case of discrete neural events such as those describing momentary microstates, the issue is posed as to how such moments become bound into larger and larger units until continuity is achieved. Lehmann's data identify the initial steps as reflected in the neuroelectric record. His data suggest that "even though the individual functional microstates are very short, their reoccurrence over a certain period of time would permit the brain to reenter into a given global condition." Lehmann's description is reminiscent of that used by Gerald Edelman (1987, 1989). Edelman tackles the binding problem by describing putative reentrant processes that accomplish correlations and integrations between the activities of "multiple reentrantly connected" cortical systems. In older engineering terminology, feedbacks and feedforwards were described to accomplish integration (see, e.g., Pribram, 1971) and currently, "backwards processing" is the backbone of neural network (PDP) approaches to the problem (Rumelhart and McClelland, 1986, Vols 1 and 2). E.R. John and various collaborators in this volume (see Pritchep et al., chapter 23) utilize cross-spectral coherence as well as factor analytic methods to determine groupings of processes. Each of these techniques addresses the issue of binding from a slightly different perspective. What the techniques have in common with each other and with chaos theory is their expression in mathematical language that can be exploited computationally.

## Conscious Sensation

To grasp fully the importance of the processes described by these mathematical techniques it is necessary to first explore the relation between experience and the input that triggers the experience. The question can be framed as to what it is that is "added" to conscious experience by the transformational processes that lead from sense organ to brain. The issue is clearly illustrated at the sensory receptor and primary sensory projection system for the experience of color.

Radiant energy is diffracted by reflection and the optical structure into a continuous spectrum. This spectrum is convolved with three photochemical receptor systems (as suggested by Helmholtz 1909/1924 and identified by Wald, 1964) to form three output functions from the retinal cone system. The tuning curves of these functions center on maxima that do not correspond to what we know to be primary colors from ordinary mixing experiments. Rather, the cone receptor outputs are in turn convolved with lateral inhibitory networks of the horizontal and especially the amacrine layers of the retina to produce, by subtraction, outputs from the ganglion cells that correspond to opponens pairs (Hering, 1964; Hurvitch and Jameson, 1957). DeValois (1988) has shown that the receptive fields of units at the lateral geniculate nucleus demonstrate such opponens processing: e.g., red will excite, while green will inhibit one cell's response, and the opposite may be true of another.

Two opponens pairs have been identified: red-green and blue-yellow. These interact with an achromatic dimension to form color "images" in a three-dimensional Cartesian color space.

An additional dimension comes into play when the excitatory region of the receptive field and its inhibitory flank respond in an opposite manner to a particular color and still another opposition with its opponent (Zeki, 1980; DeValois and DeValois, 1988). To achieve color constancy depends on utilizing the double opponens processing capabilities for the three sets of color pairs. Hurlbert and Poggio (1988) used computational techniques to simulate color constancy in color spaces composed of Mondrians of different reflectances. Their implementation utilized parallel processing in simple analog networks composed of the linear units devised by Poggio (see Pribram, 1990b, Lecture 1). One of these implementations uses a "gradient descent" method that, over iterations, minimizes the least mean square of the error between actual and desired output (as determined by psychophysical experiment). This method is similar to that employed in Occam and the thermodynamic models (for review, see Pribram, 1990h, Lecture 2). As Hurlbert and Poggio pointed out, this procedure is closely related to optimal Bayesian estimation. In their computations, they used vectors to represent sample input sequences of Gaussian stochastic processes with zero mean (similar to the difference of Gaussians, reviewed in Pribram, 1990h, Lecture 4). The property (e.g., Blue) is then fully specified by a computation similar to a regression equation.

It is necessary that the operator in this computation be space invariant, that is, it must not change with a change in location. This is accomplished by computing in the spectral domain (Fourier transforming). The computation thus becomes "equivalent to the formation of an optimal [matched] filter" (p. 239). The computation utilizes the power spectrum (amplitude-modulated frequencies) of the inputs. From an ensemble of such inputs, the cross power spectrum is computed. These computations carried out by processes in the primary visual systems (Pribram, 1991) are all critical to our conscious *experience* of color. Are other sensory experiences equally dependent on transformations of sensory input by neural operations?

## Epicritic and Protocritic Sensory Processes

An excellent candidate for attempting to answer this question is provided by the chapter on recovery from brain damage by Bach-y-Rita (chapter 18). Central to his theme is the conscious experiencing of pain. Pain is the foundation of one category of hedonic experience. As such it is critical to the issue of defining consciousness. There is a deep implicit relation between hedonic valuation and conscious experience: in fact, in the French language "conscience" (to know together) means both consciousness and conscience. The deep meaning of this relationship cannot be deciphered from observations of behavior alone: An operational behavioral definition such as "pain is that which produces withdrawal or agonistic responding" fails to describe the full spectrum of the phenomenon: aches and suffering

cannot always be handled by simple responding; and, masochistic behavior actually seeks what in other contexts would be described as pain-inducing stimulation.

The neural side of the hoped for equation brings its own puzzles. Any free nerve ending, which under ordinary circumstances mediates sensations of deformation, can, when stimulated excessively, serve as a pain receptor. Two separate paths to the central nervous system carry signals that become interpreted as "pain": A system of "A" delta fibers that transmits relatively rapidly and a system of "C" fibers that transmits signals slowly. In the spinal cord, the pain-transmitting fibers are inexorably intertwined with those that determine the sensation of temperature as well as those entering the cord via the B fiber viscerotonic afferent system (Precht and Powley, 1990). At the brain stem level the paths become peculiarly complex: endpoints are reached in the periaqueductal grey and in the thalamic grey matter surrounding the third ventricle but other tracts carry signals back downward into the spinal cord! Finally, at the cerebral level somatosensory thalamocortical pathways such as those involved in the transmission of pain are traced to the parietal lobe but parietal lobectomy is useless in ameliorating intractable pain, whereas frontal lobectomy or leukotomy serve well. Add to all this the observation that, on the whole, brain tissue is insensitive to manipulation and that no single brain neuron or groups of neurons can be identified to respond solely to signals that ordinarily result in pain and we have on our hands what appears to be an insurmountable task of explanation.

But the matter is far from hopeless. The presence of pathways descending from the brain stem to spinal cord has suggested that the sensation of pain may be subject to a gating procedure (Melzack and Wall, 1965). Tracing these fibers to layer V of the substantia gelatinosa of the dorsal horn of the cord, the origin of the spinothalamic pain and temperature tract gives anatomical support to the gate theory.

The discovery that electrical stimulation of the periaqueductal grey (the terminus of a large number of the "C" fiber system of the spinal pain and temperature system) can, depending on the frequency of the stimulus, not only lower but also raise the threshold of withdrawal from ordinarily noxious stimulation has provided specific evidence for gating (Liebeskind, Guilbaud, Besson, and Oliveras, 1973; Liebeskind, Mayer, and Akil, 1974).

When it was discovered that the periaqueductal grey is the site of preference for the absorption of opiates another important lead to explanation was opened. Soon it became apparent that a set of chemicals secreted by the pituitary and within the nervous system were also absorbed selectively by the periaqueductal grey system and showed the pain-protecting properties of opiates. These enkephalins, endorphins (endogenous "morphines"), and dynorphins are all derived from a protein molecule that is also the origin of the adrenocorticotrophic (ACTH) hormone secreted by the adrenal cortex in situations producing chronic stress, i.e., discomfort.

At the brain stem and cerebral level electrical stimulation of these same systems of neurons has produced both deterrence and reinforcement of behavior. These

systems of neurons extend from the periaqueductal grey to the limbic forebrain (Olds and Milner, 1954; Olds, 1955). Here, as in the case of pain and temperature tracts in the spinal cord, the deterrence and reinforcement systems are to a large extent indistinguishably intertwined.

Pain and temperature, though an apparently odd couple, continue their close relationship into the amygdala of the limbic forebrain and the closely related cortex of the temporal pole and orbital surface of the frontal lobe. As in the case of pain, and, in contrast to other somatosensory submodalities, the discrimination of temperature is hardly affected by parietal lobectomy or stimulation. Temperature discrimination, as is avoidance of pain, is, on the other hand, severely disrupted by lesions or stimulations of the amygdala and related cortical systems (Pribram, 1977).

There is more evidence that the pain and temperature senses are in some way intimately related. During frontal leukotomy, marked warming of extremities is experienced and observed when the final quadrant of fibers is transected. Electrical stimulation in humans of sites that produce endorphin secretion are often accompanied by feelings of chilliness (Richardson and Akil, 1974). And the production of endorphins has been directly implicated in the raising of the threshold of the production of chills and thrills.

With one assumption, based on physiological experiment and evidence obtained in arctic research, a neural model for the pain (and temperature) process can be constructed. The assumption is that in mammals metabolism is anchored in maintaining a stable basal temperature. The evidence for this assumption has been reviewed in detail by Brobeck (1963). In addition, it is the maintenance of a stable basal temperature that is perceived as comfort.

Pain and temperature sensations, therefore, serve as initiators of experiences of suffering and comfort. It is well known that maintaining basal temperature and metabolic stability entails homeostatic (or better, homeorhetic, because their set point is resettable) processes. What can now be added is that pain and suffering are also regulated homeorhetically.

The homeorhetic nature of pain and suffering explains phenomena such as the insensitivity to pain during competitive sports and other strenuous activity. Administration of Naloxin, as endorphin antagonist, during a "runners high" collapses the euphoric feeling.

Masochism is also explained. The appetitive phase of discomfort is ordinarily experienced as itch, the consummatory phase as pain. During skillful sadomasochistic interaction, the masochist's threshold for pain (endorphin level?) is raised more or less gradually so that what would ordinarily be experienced as pain is a phenomenon akin to an itch.

Essentially, the homeorhetic processing of pain and discomfort is the result of a dual "gating" mechanism: (1) top-down connections from the frontolimbic forebrain to the thalamic and periaqueductal grey (Fulton, et al. 1949), which, in turn, connect with the dorsal horn cells of the substantia gelatinosa of the spinal cord; (2) the threshold-raising endorphins, which are controlled by these top-down neural systems.

The fact is, therefore, that together with other homeorhetic processes, such as those regulating eating, drinking, and sexual behaviors, the pain and temperature senses are processed to a large extent by a frontolimbic rather than by a parietal forebrain system. This fact can be conceptualized in terms of experiments in which peripheral nerves are sectioned. During the initial stages only fine fibers of the C type compose the regenerating nerve. During this stage only diffuse relatively uncomfortable and difficult to localize (in time and space) sensations are experienced. Once the normal fiber size spectrum has been attained, sensations are once again experienced as normal, i.e., they demonstrate what neurologists call local sign. Henry Head (1920) distinguished these normal sensation as *epicritic* and the system of spinal cord and brain stem fibers involved has been traced to parietal lobe cortical terminations.

By contrast, as reviewed here, the fiber systems involved in the sensations that Head called *protopathic*, and which are initially mediated by the small nerve fiber system, terminate frontolimbically. Because this system operates not only in pathological circumstances but also normally in the intact organisms, the term *protocritic* is more appropriate.

In summary: a protocritic set of systems based on sensations perceived as pain and temperature has been identified. These protocritic systems are homeorhetic and join other homeorhetic brain stem and frontolimbic systems that regulate the well-being of the organism. A major characteristic of these systems is their top-down control over receptor processing.

## Forms of Conscious and Unconscious Processing

Mitchell Valdés-Sosa and Maria Bobes in their chapter 13 review the issues concerning implicit (unconscious) and explicit (conscious) processing. These issues are ordinarily discussed in terms of mechanisms of memory. These mechanisms concern primarily the coding and retrieval operations of remembering rather than those of memory storage. The question asked by Valdés-Sosa and Bobes is whether coding and retrieval are unitary or modular. Their evidence added to those of others clearly support modularity, i.e., separate systems can be identified to process different remembrances.

Their analysis raises additional questions. Are implicit, unconscious, processes all of a kind? Furthermore, if explicit conscious processes are modular, to what does modularity apply: states, contents or only the processes that relate the states and the contents of consciousness?

Shvyrkov in chapter 17 on animal experience addresses the organization of what in humans would be called implicit processing. Human subjectivity is in many respects a meta-consciousness, i.e., a subjective awareness of awareness. For example, bilateral resections of the medial portions of the temporal lobe produce a profound disturbance of subjective memory in humans without loss of skill memory. In monkeys with such resections I have observed retention of a visual discrimination at the 90-98% level after 2 years (with controls performing

in the low 80% range). The lesioned monkeys were sufficiently conscious to perform the task, and there was no adequate test of meta-consciousness for monkeys to determine whether a loss similar to that sustained by humans had occurred.

Inspired by P.K. Anokhin, what Shvyrkov did find out was that the skills he was testing were organized according to the behavior acts, their objective environmental consequences and not the "functions" of the body parts implementing these behaviors. Shvyrkov's findings support those of Bernstein (1967) and my own which have demonstrated that the classical precentral motor cortex encodes the environmental consequences, the environmental loads placed on the motor system, and not the metric contractions or movements of muscles (Malis, Pribram, and Kruger, 1953; Pribram, 1971; Pribram, Sharafat, and Beekman, 1984; Pribram, 1984; Pribram, 1991).

The conclusion can be reached that objective awareness of the contents of consciousness is shared with animals. This leaves open the question of shared subjectivity and of the nature of unconscious processing. These questions are related: Sherrington (1911/1947) noted that to the extent that behavior is "reflex" to that extent "mind" does not enter the process. As noted, the term "mind" derives from "minding", i.e., "paying" attention.

The contributions of Steven Hillyard et al., (chapter 9), Joaquin Fuster (chapter 15), Thalia Harmony et al., (chapter 19), Robert Thatcher (chapter 20), Gerd Pfurtscheller (chapter 12), et al., in this volume address the extensive set of data obtained from studying the relation of attention and para-attentional processing by means of recorded electrical brain activity. Two overlapping classes of electrical brain activity have been identified (John, Herrington, and Sutton, 1967): those (extrinsic) which closely reflect sensory processing and those which depend more intimately on the contributions of brain processing (intrinsic). The extrinsic components have been shown to reflect more or less objective, content oriented automatic para-attentional processes while the intrinsic components are identified with more subjectively controlled, conscious attention (see, for example, Hillyard and Picton, 1979; Näätänen, 1990; and Pribram and McGuinness, 1991 for comprehensive reviews).

William James once stated that he was just about ready to jettison the concept "consciousness" in favor of thinking only in terms of "attention". If we accept the definition of attention (and para-attentional processes) derived from brain electrical recording as determined by a set of control operations on sensory processing, we can next ask: What brain processes can be shown to provide these controls?

## The Orienting Reaction: Key to Conscious Experience

Control over sensory input constitutes attention. Control is exercised not only over protoceritic sensory processing but over epicritic as well. The pathways by which such control is exercised have been documented by studies utilizing the orienting reaction. Sokolov (1963) in a classical series of experiments demonstrated that

orienting occurs not only in response to extraordinary sensory stimulation but to any stimulus that mismatches a neuronal model representing the prior experience of the organism. This demonstration was accomplished by presenting tones or light flashes in a regular series and then omitting an "expected" stimulus; or by presenting tones or light flashes in a regular series and then omitting an "unexpected" stimulus; or by presenting tones or flashes of a certain intensity and then presenting one of lower intensity. In each instance a strong orienting reaction was obtained on the unfamiliar occasion.

Sokolov used viscerautonomic indicators such as heart and respiratory rate and galvanic skin conduction as well as behavioral (turning of head and eyes) indicators of orienting in his experiments. In my laboratory, an additional series of studies showed that in both monkeys and humans the viscerautonomic responses could be dissociated from the behavioral indicators by resections of the amygdala and temporal pole and by lesions of the orbital portions of the frontal lobe (Bagshaw and Benzie, 1968; Bagshaw and Coppock, 1968; Bagshaw et al., 1965; Bagshaw et al., 1965, 1970a, b, 1972; Bagshaw and Pribram, 1968; and Luria et al., 1964).

Ordinarily the orienting reaction habituates in a few (three or five to ten) trials indicating familiarity with the situation. After amygdala/temporal pole or orbitofrontal damage, however, the viscerautonomic components of the orienting reaction do not occur and the behavioral components fail to habituate. Familiarization apparently entails viscerautonomic arousal.

The fact that behavioral orienting continues after amygdalotomy indicates that another processing system is involved in the total orienting reaction. This other system centers on the striatum of the basal ganglia (caudate and putamen) and a lateral strip of frontoparietal cortex surrounding the Rolandic somatic sensory-motor projection systems. Behavioral orienting ceases when this strip of cortex and/or the related basal ganglia are damaged; in fact, total neglect of the stimulating event is produced when damage is severe (Heilman and Valenstein, 1972). In a sense, this system, when activated, readies, i.e., prepares, the organism's orienting process. Readiness entails maintaining attention.

As noted, the process whereby attention is maintained has been studied using the late, intrinsic, components of event-related brain electrical potential changes (ERPs). Beginning at around 300 msec, after a relevant but unexpected stimulus, a process is initiated that "updates" the neuronal model (Donchin, 1981). Updating is signalled by a late (ca 400 msec) negativity.

The updating process involves a circuit in which the thalamic reticular nucleus plays a critical part. Activation of this nucleus inhibits activity in the thalamo-cortical sensory projection pathways. In turn, activity in the reticular nucleus is controlled by an extralaminar tecto-legmental brain stem system that itself is influenced by input from the brain stem reticular formation and collaterals from the laminar sensory projection pathways. An additional input to the reticular nucleus of the thalamus originates in the orbitofrontal-amygdala system. This input is antagonistic to the input from the tecto-legmental system: whereas the tecto-legmental input activates the thalamic reticular nucleus, and therefore in-

hibits—gates sensory projection activity, orbitofrontal-amygdala input inhibits the activity of the thalamic reticular nucleus and thus enhances activation of the lemniscal sensory projection systems, allowing behavioral orienting to occur. In turn, this orbitofrontal-amygdala system is controlled by the basal ganglia via the intralaminar and central nuclei of the thalamus.

The question arises as to the order in which activation and gating occur. Utilizing depth recordings in humans, Velasco and Velasco (1979; Velasco et al., 1973) showed that the late components of the ERP recorded from thalamic electrodes precede those recorded from brain stem sites: Updating is a top-down process. The orienting stimulus acts as a trigger, releasing attentive readiness to alter the neuronal model on the basis of just experienced consequences.

According to the model of attentional controls proposed by Pribram and McGuinness (1976; 1990) a third system is involved in mediating, when necessary, between familiarization and the maintenance of readiness. This mediating system is centered on the hippocampal formation. Excitation of the hippocampal system makes innovation possible (see Pribram, 1988, for review). The system, when idling, reflects comfortable, unstressed exploratory behavior. When engaged, the system makes it possible for attention to be *paid* and effort to be expended in the updating process. The hippocampal system exerts its influence on arousal by way of frontocorticothalamic connections and on the maintenance of readiness posteriorly by way of brain stem connectivities (see Pribram, 1991) for review.

## Subjective, Objective, and Intentional Consciousness

These controls on attention add a dimension to consciousness that goes beyond awareness of sensory-driven perceptions. The additional dimension is referred to as reflective self-awareness or intentionality (Brentano, 1960; von Uexkll, 1926). Intentionality combines subjective and objective awareness. Subjective awareness, as noted, devolves on the arousal systems centered on the amygdala to provide familiarity. Dysfunction of these systems produce the clinical syndromes of *déjà* and *jamis vu*. These syndromes entail a feeling of familiarity in strange situations (*déjà*) and a feeling of unfamiliarity in situations that have been encountered repeatedly (*jamis*) in which case habituation has failed to take place. In the extreme, during a psychomotor seizure which most likely spreads to the hippocampal formation, the events experienced fail to become part of "the remembered present" (as Edelman has aptly called the coding process by which current experience remains accessible, 1989).

Disturbances of the hippocampally centered systems do not interfere with experiencing objective consciousness. A patient with such lesions responds and experiences himself and the contents of his perceptions normally until a distracting event occurs that does not allow the updating process to come to completion. Experienced events are apparently stored haphazardly and can be retrieved only with special probing techniques (see Weiskrantz, 1986, for review). Each ex-

perienced episode is self contained, never to become integrated into the stream of consciousness. Thus, it is the hippocampal system that completes the "stream of consciousness" that constructs subjectivity.

Disturbances of the systems entailing the maintenance of readiness can lead to neglect syndromes, as has already been described. These systems make possible the awareness of excitations of the corporeal self as distinct from the primary sensory projection systems that make possible responding *per se* to sensory contents. Cases such as those of blind sight occur when the primary sensory thalamocortical projection pathways are damaged (Weiskrantz, 1986). Cases of neglect demonstrate disturbances of self-reference. Acting together, normal functioning of these systems makes possible the intentional distinction between the conscious experience of being a perceiver and the sensed contents of that experience. It is these systems, therefore, that are critically concerned in the production of intentional consciousness.

## The Brain Consciousness Connection

According to the data reviewed here, a great deal is known about the relations, in general, between brain processes and conscious experience. What remains to be explored in most instances are the specifics of the brain processes entailed in the systems relations that have been uncovered. It is to these explorations that the contributions in the current volume are addressed. These contributions have as their basic assumption some form of identity between brain processing and conscious experience. I have suggested elsewhere (Pribram, 1986) that this identity can best be understood in terms of the metaphor of computer programming: I use English in addressing my word processor. The word processing system, the operating system, the ASCII assembler, and hexadecimal codes are all stages in the transformation of English to binary, which is the language used by the computer. In a similar fashion, subjective experience is transformed in steps to the language(s), codes, used by the brain. Many of the transformational steps are performed by the wetware of the sensory and neural processes reviewed in this volume; some others by the relations among changes in the environment, as for instance those produced by movement (see Gibson, 1977, 1979, for review).

What becomes clear from these considerations is that some sort of order remains invariant across all of the processing steps involved in the procedure that constitutes the transformations from English to binary and those from conscious experience to dendritic processing. We usually call this order "in-formation"—the form within. Measures of the amount of information are mathematically related to the amount of ordering of energy, that is the amount of entropy. Entropy reflects the efficiency with which a system operates. Relations between measures of entropy and measures of synergy; and the amount of organization of ensembles of Gabor quanta of information; and of "chaotic" attractors have been developed (see for example Pribram 1990, 1991).

These contributions may be only a first step toward understanding, but one that promises to break down the brain/consciousness barrier once and for all.

## References

- Bagshaw, M. H., Benzie, S. (1968). Multiple measures of the orienting reaction and their dissociation after amygdalotomy in monkeys. *Exp. Neurol.* 20, 175-187
- Bagshaw, M. H., Coppock, H. W. (1968). Galvanic skin response conditioning deficit in amygdalotomy monkeys. *Exp. Neurol.* 20, 188-196
- Bagshaw, M. H., Kimble, D. P., Pribram, K. H. (1965). The GSR of monkeys during orienting and habituation and after ablation of the amygdala, hippocampus and inferotemporal cortex. *Neuropsychologia* 3, 111-119
- Bagshaw, M. H., Mackworth, N. H., Pribram, K. H. (1970a). Method for recording and analyzing visual fixations in the unrestrained monkey. *Percept. Mot. Skills* 31, 219-222
- Bagshaw, M. H., Mackworth, N. H., Pribram, K. H. (1970b). The effect of inferotemporal cortex ablations on eye movements of monkeys during discrimination training. *Int. J. Neurosci.* 1, 153-158
- Bagshaw, M. H., Mackworth, N. H., Pribram, K. H. (1972). The effect of resections of the inferotemporal cortex or the amygdala on visual orienting and habituation. *Neuropsychologia* 10, 153-162
- Bagshaw, M. H., Pribram, K. H. (1968). Effect of amygdalotomy on stimulus threshold of the monkey. *Exp. Neurol.* 20, 197-202
- Bernstein, N. (1967). *The co-ordination and regulation of movements*. New York: Pergamon Press
- Brentano, F. (1961/1967). The distinction between mental and physical phenomena. In: *Realism and the background of phenomenology*, Chisholm, R. M. (ed.). New York: Free Press, 39-61
- Brobeck, J. R. (1963). Review and synthesis. In: *Brain and behavior* vol. 2. Brazier, M.A.B. (ed.). Washington, D.C.: American Institute of Biological Sciences, 389-409
- DeValois, R. L., DeValois, K. K. (1988). *Spatial vision* (Oxford psychology series, No. 14). New York: Oxford University Press
- Donchin, E. (1981). Surprise—Surprise? *Psychophysiology* 18, 493-513
- Edelman, G. M. (1987). *NeuroDarwinism: The theory of neuronal group selections*. New York: Basic Books
- Edelman, G. M. (1989). *The Remembered present: A biological theory of consciousness*. New York: Basic Books
- Feynman, R. P. (1985). *QED*. Princeton, NJ: Princeton University Press
- Fulton, J. F., Pribram, K. H., Stevenson, J. A. F., Wall, P. (1949). Interrelations between orbital gyrus, insula, temporal tip and anterior cingulate gyrus. *Trans. Am. Neurol. Assoc.* 175-179
- Gabor, D. (1946). Theory of communication. *J. Inst. Electrical Engineers* 93, 429-441
- Gibson, J. J. (1977). On the analysis of change in the optic array in contemporary research in visual space and motion perception. *Scand. J. Psychol.* 18, 161-163
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin
- Haken, H., Stadler, M. (1990). *Synergetics of Cognition*. Berlin: Springer-Verlag
- Hartley, R. V. L. (1928). Transmission of information. *Bell. System. Tech. J.* 7, 535
- Head, H. (1920). *Studies in neurology* (Vol. 1 and 2). London: Oxford University Press
- Heilman, K. M., Valenstein, E. (1972). Frontal lobe neglect. *Neurology* 22, 229-232

- Helmholtz, H. von (1909/1924). *Handbook of physiological optics*, (3rd ed.). Rochester, NJ: Optical Society of America
- Hering, E. (1964). *Outlines of a theory of the light sense*. Cambridge, MA: Harvard University Press (original work published in 1878)
- Hillyard, S. A., Picton, T. W. (1979). Event-related brain potentials and selective information processing in man. In: *Cognitive Components in Cerebral Event-Related Potentials and Selective Attention* Desmedt, J. E. (ed.)
- Hurlbert, A., Poggio, T. (1988). Synthesizing a color algorithm from examples. *Science* 239, 482-485
- Hurvich, L., Jameson, D. (1957). An opponent-process theory of color vision. *Psychol. Rev.* 64, 384-404
- John, E., Herrington, R., Sutton, S. (1967). Effects of visual form on the evoked response. *Science* 155, 1439-1442
- Licklider, J. C. R. (1951). Basic correlates of the auditory stimulus. In: *Handbook of experimental psychology*. Stevens, S. S. (ed.). New York: John Wiley and Sons, 985-1039
- Liebeskind, J. C., Guillemand, G., Besson, J. M., Oliveras, J. L. (1973). Analgesia from electrical stimulation of the periaqueductal gray matter in the cat: Behavioral observations and inhibitory effects on spinal cord interneurons. *Brain Res.* 50, 441-446
- Liebeskind, J. C., Mayer, D. J., Akil, H. (1974). Central mechanisms of pain inhibition: Studies of analgesia from focal brain stimulation. In: *Advances in neurology, Vol. 4, Pain* J. J. Bonica (ed.). New York: Raven Press
- Luria, A. R., Pribram, K. H., Homskaya, E. D. (1964). An experimental analysis of the behavioral disturbance produced by a left frontal arachnoidal endothelioma (meningioma). *Neuropsychologia* 2, 257-280
- Malis, L. I., Pribram, K. H., Kruger, L. (1953). Action potential in "motor" cortex evoked by peripheral nerve stimulation. *J. Neurophysiol.* 16, 161-167
- Melzack, R., Wall, P. D. (1965). Pain mechanisms: A new theory. *Science* 150, 971-979
- Näätänen, R. (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral Brain Sci.* 13, 201-288
- Olds, J. (1955). Physiological mechanisms of reward. In: *Nebraska Symposium on Motivation*. Jones, R. R. (ed.). Lincoln, NE: University of Nebraska Press, 73-138
- Olds, J., Milner, P. (1954). Positive reinforcement produced by electrical stimulation of septal area and other regions of rat brain. *J. Comp. Physiol. Psychol.* 47, 419-427
- Precht, J. C., Powley, T. L. (1990). B-Afferents: A fundamental division of the nervous system mediating homeostasis? *Behavioral Brain Sci.* 13, 289-331
- Pribram, K. H. (1971). *Languages of the brain: Experimental paradoxes and principles in neuropsychology*. Englewood Cliffs, NJ: Prentice-Hall
- Pribram, K. H. (1986). The cognitive revolution and the mind/brain issues. *Am. Psychol.* 41, 507-520
- Pribram, K. H. (1988). Brain systems involved in attention and para-attentional processing. In: *Attention, cognitive and brain processes and clinical applications*, Sheer, D., Pribram, K. H. (eds.). New York: Academic Press
- Pribram, K. H. (1990). Frontal cortex—Luria/Pribram rapprochement. In: *Contemporary neuropsychology and the legacy of Luria*, Goldberg, E. (ed.). Hillsdale, NJ: Lawrence Erlbaum Associates
- Pribram, K. H. (1991). *Brain and perception: holonomy and structure in figural processing*. Hillsdale, NJ: Lawrence Erlbaum Associates

- Pribram, K. H., and Carlton, E. H. (1986). Holonomic brain theory in imaging and object perception. *Acta Psychol.* 63, 175-210
- Pribram, K. H., McGuinness, D. (1976). Arousal, activation and effort in the control of attention. *Psychol. Rev.* 82, 116-149
- Pribram, K. H., McGuinness, D. (1991). Attention and para-attentional processing: Event-related brain potentials as tests of a model. *New York Academy of Science*
- Pribram, K. H., Sharafat, A., Beckman, G. J. (1984). Frequency encoding in motor systems. In: *Human motor actions: Bernstein reassessed*, pp. 121-156. Whiting, H. T. A. (ed.). North-Holland: Elsevier
- Prigogine, I., Stengers (1984). *Order out of chaos*. New York: Bantam Books
- Richardson, D. E., Akil, H. (1974). Chronic self-administration of brain stimulation for pain relief in human patients. *Proceedings American Association of Neurological Surgeons*, St. Louis, MO.
- Rumelhart, D. E., McClelland, J. L., (PDP Research Group) (1986). *Parallel distributed processing, Vol. I and II*. Cambridge, MA: MIT Press
- Ryle, G. (1949). *The concept of mind*. London: Hutchinson. (Republished by University of Chicago Press, 1984)
- Sierington, C. (1911/1947). *The integrative action of the nervous system*. New Haven, CT: Yale University Press
- Singer, W. (1989). Search for coherence: A basic principle of cortical self-organization. *Concepts in Neuroscience* 1(1), 1-25.
- Sokolov, E. N. (1963). *Perception and the conditioned reflex*. New York: MacMillan Publishing
- Uexkull, J. von (1926). *Theoretical biology*. San Diego, CA: Harcourt Bruce Jovanovich
- Velasco, F., Velasco, N. (1979). A reticulo-thalamic system mediating proprioceptive attention and tremor in man. *Neurosurgery* 4, 30-36
- Velasco, N., Velasco, F., Machado, J., Olvera, A. (1973). Effects of novelty, habituation, attention, and distraction on the amplitudes of the various components of the somatic evoked responses. *International Journal Neuroscience* 5, 3-13
- Wald, G. (1964). The receptors of human color vision. *Science*, 145, 1007-1017
- Weiskrantz, L. (1986). *Blindsight: A case study and implications*. Oxford: Clarendon Press
- Zeki, S. M. (1980). The representation of colours in the cerebral cortex. *Nature*, 284, 412-418

# Part I

## Integrative Processes