TRANSCENDING THE MIND/BRAIN PROBLEM

by Karl H. Pribram

Ever since René Descartes enunciated his dictum, Cogito ergo sum, philosophers have debated the relationship of mental phenomena to the material universe. Those of us in the laboratory trying to understand the relationship of brain anatomy and physiology to behavior and to subjective experience continually come up against this issue. The very words we use to describe our work—brain and experience—embody the problem. I believe the time has come to look at this problem once more but with the wisdom that ought to come from recent discoveries in the physical, biological, and behavioral sciences. The time does seem ripe. There has been a surge of publications on the topic.[1] However, there appears to be little in the way of wisdom or often even acquaintance with those scientific discoveries that bear directly on the issue.

Ontology and Scientific Discovery

A major deterrent to wisdom has been the pronouncement by certain philosophers that scientific discoveries can have no bearing on the question.[2] The issue, we are told, is a philosophical one that must be resolved through reasoning and not by experiment. It is claimed to be ontological, not scientific, in nature.

My theme throughout this paper will be that there is some merit to most of the philosophical arguments but that in essence they can be transcended. And so I agree that ontology is at the root of the mind/brain issue. However, it is incorrect to argue that therefore scientific research has no relevance. My claim here is that the very assumptions that have given rise to the problem have been shaken by the results of research.

The Dematerialization of Matter

The fundamental assumption that has given rise to the mind/brain problem is that mental phenomena and the material universe are in

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some essential fashion different from each other. In the ordinary domain of appearances, at the Euclidean, Newtonian level of analysis, this assumption is certainly tenable. A phenomenal-material dualism describes the situation clearly and will be discussed fully below. What remains to be discovered in this domain is the relationship between mental and material, and, as we shall see, the answer to this question lies in an abandonment of the mental-material dichotomy.

Modern physics has concentrated on levels of analysis—of the macro- and microphysical universes—where the simple dualism between mental and material does not hold. Niels Bohr's and Werner Heisenberg's principle of uncertainty emphasize the importance of the observer in any understanding of what presumably is observed.[3] Eugene P. Wigner states the issue succinctly: Modern microphysics and macrophysics no longer deal with "relations among observables but only with relationships among observations."[4]

An objection can be entered that such difficulties of distinguishing observables from observations encountered by physicists today are temporary, superficial, and of no concern to philosophers interested in the eternal verities. But that is not the message these thoughtful Nobel laureates in physics are attempting to convey. They have been exploring universes where the everyday distinction between material and mental becomes disturbingly untenable at a very fundamental level. As we proceed I shall tender some explanations that may help account for their views.

The dematerialization of matter can be traced in some sense to earlier formulations. For instance, physics was conceptually understandable in James Clerk Maxwell's day when light waves were propagated in the "ether." But then physicists did away with the "ether." Still they did not rid themselves of Maxwell's wave equations or the more recent ones of Erwin Schroedinger or Louis Victor prince de Broglie.[5] One readily can conceptualize waves traveling in a medium, such as when sound waves travel in air, but what can be the meaning of light waves or electromagnetic waves "traveling" in a vacuum? Currently physicists are beginning to fill that vacuum with dense concentrations of energy, potential for doing work when interfaced with matter.

Is Information Material or Mental?

Further, when forces are postulated to exist between material bodies the forces still can be conceptualized as "material" even though they themselves are not constituted of matter. When matter and energy are related by the equation $E = mc^2$, energy is shown to be "material"

(and neural excitation, the brain's "energy," falls readily under this rubric). But energy is measured by the amount of work that can be accomplished by using it and the efficiency of its use depends on its organization as measured by its entropy. The invention of the vacuum tube and subsequent devices has shown that minute amounts of energy can control large expenditures and that these minute organizations provide "information," that is, they inform and organize energy. Measures of information and entropy thus were seen as related.[6] Computers were constructed to process information, and programs were written to organize the operations of computers. Is the information contained in a program "material" or "mental"? If it is either, what then of the information in a book? Or the entropy that describes the behavior of a heat engine or of a warm-blooded mammal? Clearly we have come to the limit of usefulness of a distinction between the material and the mental.

Research on "mind" using behavioral techniques also blurs a distinction which seems so clear when only the ordinary Euclidean, Newtonian domain of appearances is considered. As noted above, the organization of the behavior of organisms can be comprehended best by recourse to concepts such as "information" and "programs" or "plans" which serve equally well in understanding the operations of machines.[7] Once again the question arises: Is information processing to be conceived as mental or material?

Philosophers and psychologists of a nonbehaviorist persuasion immediately will counter that behavior is not mind and therefore any argument about mental phenomena derived from behavior is spurious. They would rather begin with "the phenomenon itself existentially experienced." But there is little that can be done with such experiences except to attempt to describe them (behaviorally) and to organize the descriptions (structurally). Thus Maurice Merleau-Ponty, an existentialist philosopher, has authored a book entitled *The Structure of Behavior* (1963), which in both spirit and content shows remarkable resemblances to our own *Plans and the Structure of Behavior* (1960), which tackles the issues from a behavioral and information-processing vantage.[8] I do not mean to convey here that there is no distinction between a behavioristic and an existential-phenomenalistic approach to mind. Elsewhere I detail this distinction in terms of a search for causes by behaviorists and a search for informational structure reasonably (meaningfully) composed by phenomenologists.[9] What I do want to emphasize here is that both approaches lead to conceptualizations that cannot be classified readily as either mental or material. Behaviorists in their search for causes rely on drives, incen-

tives, reinforcers, and other "force"-like concepts that deliberately have a Newtonian ring. Existentialists in their quest for understanding "mind" come up with structure much as anthropologists and linguists when tackling other complex organizations. And structural concepts are akin to those of modern physics where particles arise from the interactions and relationships among processes. In neither case can this resultant of inquiry be characterized as mental or material unless one wishes simply to state a bias in favor of one or the other as being more meaningful to oneself.

I have belabored these findings of scientific research to indicate that perhaps they do have relevance to ontology. If the mind/brain problem arises from a distinction between the mental and the material and we find that at a certain level of analysis we no longer can make such a separation clearly, then the very assumptions upon which the issue is joined may be found wanting.

With these considerations in mind let us now look at some specific proposals that have been forwarded recently and place them within a perspective which states that the material-mental dichotomy holds only for the ordinary Euclidean-Newtonian world of appearances.

Do Experiences Matter or Does Matter Become Experienced?

In this world of appearances there is no question but that human mental experience can be distinguished sharply from that which is experienced. The issue has been labelled "intentionality" (or intentional inexistence) by Franz Clemens Brentano and has given rise to inferences about the nature of reality.[10] The question is often phrased: Are my perceptions (my phenomenal experiences) the really "real," or does the content of those perceptions make up the "real" world? My phenomenal experiences are mental; the world as it appears to me is material. I can give primacy to my experience and become a phenomenologist, or I can give primacy to the contents of the experience and become a materialist. But I can also give primacy to neither and attest to the dual nature of reality.

Materialism and phenomenology run into difficulty only when each attempts to deny the other. As long as only primacy is at stake, either view can be made consistent. After all, our experiences are primary, and empiricism is not inimical to a real material world. And we do appear to be experiencing something(s), so our experiences may well become organized by those real somethings.

However, by accepting such a moderate position with regard to mind and matter we immediately come up against a set of dualistic problems. Are the contents of perception "really" organized by the

experience of the perceiver? Is that experience in turn organized by brain function, sensory input, and the energies impinging on the senses? Would a complete description of brain function of an organism also be a description of the experience of that organism? If so, are not the material descriptions of brain, senses, and energies sufficient? Or at least do the descriptions of experience add anything to the material descriptions? Cannot the inverse be equally true—what do the descriptions of brain, senses, and energies materially add to what we so richly experience?

Transcending Dualisms without Denying Them

I believe that today there are answers to these questions where only a few years ago there were none. These answers come from "unpacking" conceptual confusions and demonstrating where each conceptualization captures a part of a truthful whole.

A semantic analysis shows that descriptors of brain, senses, and energy sources are derived from an analysis of experience into components. The components are organismic and environmental (biological and physical or social), and each component can be subdivided further into subcomponents until the quantum and nuclear levels of analysis are reached. This procedure of analysis downward in a hierarchy of systems is the ordinary way of descriptive science. Within systems, causes and effects are traced. When discrepancies are found statistical principles are adduced and probabilities invoked. Scientists have become adept and comfortable with such procedures.

Mental language stems from different considerations. As in the case of descriptive science, mental terms take their origin in experience. Now, however, experience is validated consensually. Experience in one sensory mode is compared with that obtained in another. Then validation proceeds by comparison of one's experience with that of another. A little girl points to a horse. Up to now mother has allowed her to say "cow" whenever any animal is pointed to. But the time has come to be more precise, and the experience of horse becomes validly different from that of cow. Mental language is derived from such upward validations in a hierarchy of systems.

Elsewhere I detail the differences in scientific approach which this upward—or outward—look entails.[11] It is certainly not limited to psychology. When Albert Einstein enunciated his special and general theories of relativity he was looking upward in the set of hierarchically arranged physical systems. The resultant relativistic views are as applicable to mental conceptualizations as they are to physical. It is these relativisms which existentialists and phenomenologists con-

stantly struggle to formulate into some coherent principles. My own belief is that they will be successful only to the extent that they develop the techniques of structural analysis. But structural analyses often depend on enactment to clarify the complexities involved. Abhorrent as the computer and other engineering devices may be to philosophers and psychologists of the existential-phenomenal persuasion, these tools may turn out to be of great service to their mode of inquiry.

If the above analysis is correct, then a dualism of sorts can be entertained as valid. First a caution, however. This form of dualism is concerned with the everyday domain of appearances—of ordinary experiences. Commencing with such ordinary experiences two modes of conceptualization have developed. One mode operates downward in a hierarchy of systems, analyzing experience into components and establishing hierarchical and cause-effect relationships between these components. The other operates upward toward other organisms to attain consensual validation of experiences by comparing and sharing them.

Thus two mirror images—two optical isomers, as it were—are constructed from experience. One we call material and the other mental. Just as optical isomers in chemistry have differing biological properties though they have identical components and arrangements, so the mental and material conceptualizations have different properties even though they initially arise from the self-same experiences.

I suggest that this is the origin of dualism and accounts for it. The duality expressed is of conceptual procedures, not of any basic duality in nature. As we shall see below, there are other dualities that are more basic, but these are not the ones that have become the staple of those arguing for dualism.

Constructional Realism: A Pluralistic Monism

Before I proceed with a critique of current dualisms, it may be helpful to describe alternative views. Most of these fall under the rubric of "monism," which states simply that the truly basic components of the universe are neither material nor mental but neutral. The dematerialization of matter at the level of analysis that concerns modern physics—reviewed above—supports such a "neutral monism."[12] Critical philosophers (e.g., Herbert Feigl) steeped in linguistic analysis developed this monistic view by suggesting that the "mental" and "material" are simply different ways of talking about the same processes. Thus "mind" and "brain" come to stand for separate linguistic systems, covering different aspects of a basic commonality. The prob-

lem has been to find a neutral language to describe the commonality without being either mental or material in its connotations.

I take this "dual aspects" view a step further by proposing that each aspect not only is characterized linguistically but in fact is a separate "realization" or "embodiment."[13] Further, I have proposed that what becomes embodied is informational "structure." Thus in essence I have stood the critical philosopher's approach on its head: The enduring "neutral" component of the universe is characterized as linguistic—or mathematical, musical, cultural, etc.—and is essentially structural. The dual aspects are dual realizations—which in fact may be multiple—of the fundamental informational structure. Thus a symphony can be realized in the playing at a concert, in the musical score, on a record or on a tape, and thence through a high-fidelity audio system at home.

"Mind" and "brain" stand for two such classes of realization, each achieved, as described above, by proceeding in a different direction in the hierarchy of conceptual and realized systems. Both mental phenomena and material objects are realizations and therefore realities. Both classes of reality are constructions from underlying "structures," which it is the task of science to specify in as neutral a language as possible (neutral, i.e., with respect to connotations that would suggest that the "structures" belong in one or the other class). I note elsewhere the relationship of such a constructional realism to critical realism, pragmatism, and neo-Kantian rationalism.[14]

Mind as Emergent and as Actor

The views expressed thus far have provided a coherent theory which accounts for dualistic views but transcends them by showing them to arise from procedural differences which separately realize a common structure. That structure is neutrally described in mathematical and information-processing (or similar) terms—terms which cannot readily be characterized as either material or mental.

This theory is considerably different from more classical dualistic views which hold to a fundamental separation between mental and material. I believe that there is considerable merit to these views in that they pose questions which are not addressed by the constructional realism proposed above. I do not agree with the dualistic solution (or rather nonsolutions) given by unreconstructed dualists, however, and will detail an alternative in the last section of this paper. But let us examine one recent document which states the case for one form of classical dualism in comprehensive fashion: *The Self and Its Brain* by Karl R. Popper and John C. Eccles.[15]

The Self and Its Brain embodies in its format the views of its authors. The book is divided into two major portions: Popper deals with the philosophy of mind; Eccles describes the neurophysiology of brain. In keeping with the interactionist tone of the volume there is a third section made up of discourse between Popper and Eccles—a sort of question and answer period. The interaction is somewhat stilted and one sided; the discourse deals much more often with mind than with brain. But even this defect is, I feel, in keeping with the authors' philosophy. In their system, mind gently—"with a cognitive caress," as Eccles once put it to me—influences and biases brain function. Popper is not quite so gentle as Eccles, however, and I tend to agree with him. After all, "the pen is mightier than the sword"; there is nothing gentle about the way I am moved by music, a spouse's anger, etc. Perhaps this basic disagreement between Eccles and Popper and their attempt to deal with it "gently" has led to the somewhat artificial tone of the interchange. I am sorry about this because I feel that the format of two views and an interchange between them is potentially powerful. (I suggested it once to Arthur Koestler, but he chose to go it alone and produced *The Ghost in the Machine*.)

What does bring power to the format of *The Self and Its Brain* is the book itself. Popper's interactionism depends on the products of mind, its contents, becoming manifest in the physical world. The physical world in turn influences the brain through the senses. Books are prime examples, and *The Self and Its Brain* is a prime example of a book (a medium) being in format what its contents are meant to convey.

But here we experience in reality the dissonance expressed in the dialogue between Popper and Eccles. Popper's books and other contents of mind constitute his World 3. World 3 interacts with the brain (which is part of the physical world—World 1) through the senses.[16] The interaction is clear-cut. By contrast, Eccles has mind selecting from the sensory input, organizing the functions of the association cortex especially that of the dominant, speech-producing hemisphere: "In these further stages the different sensory modalities project to common areas in the polymodal areas. In these areas . . . wide-ranging information is processed. How is it selected . . . and put together? . . . It is proposed that the self-conscious mind plays through the whole (polymodal) liaison brain in a selective and unifying manner . . . somewhat like a searchlight. Or better, a multiple scanning and probing device that reads out from the selects. . . ."[17]

Thus mind operates on brain directly for Eccles and indirectly through World 3 for Popper. For Popper mind is an emergent, and

the problem is how emergents can interact with their substrate.[18] He worries about "downward causation of the higher level acting on the lower level" and comes to the conclusion that "the emergence of hierarchical levels or layers, and of an interaction between them, depends upon a fundamental indeterminism of the physical universe. Each level is open to causal influences coming from lower *and* higher levels."[19] For Eccles mind is a given entity that organizes brain function and is organized in turn by World 3 acting through the senses; mind pre- and postdates brain but needs cortex of a special sort in order to make a liaison.

To me Popper's position is the easier starting point. As we shall see, however, there is some merit to Eccles's view as well. What Popper has done is split what ordinarily is called "mental" into two worlds—World 2 and World 3. World 2 is the mental state; World 3 is composed of the contents of that state. Both World 2 and World 3 are emergents of complex brain organization. World 3 is a product of World 2. World 2 is completely mental, but World 3 can be, in the part at least, material (e.g., the book).

I believe this division and the resultant attempts at interactionism to be unnecessarily awkward. I prefer to begin with the idea that mental states are the result of an interaction between an organism and its environment, in particular between an organism's brain and its social environment. This position is derived from behaviorism but goes beyond it in that it admits the ghosts in the machine, admits them to be as real as the machine itself.[20] Images, experiences, intentions, plans, expectations, joys, and sorrows are not excised from the "real" world but are prime manifestations of that world.[21] They are not necessarily the primary or only manifestations, however, as the phenomenologists or even the empiricists would have them. Eccles and Popper, as dualists, rightly decry such overemphases on the primacy of the subjective but often come up with confusing statements regarding causation from the interactionist stance. Thus Popper talks of illusions which have a mental origin as in wish fulfillment.[22] However, Sigmund Freud, in the "Project" (1895), suggests that wish fulfillment and its illusions come about by very specific brain processes, more in keeping with Popper's overall, emergent property position.[23]

The proofs of the existence of a reality beyond our senses are reviewed clearly by Popper, and I hold with him and with psychologists such as James Jerome Gibson that there are invariants in the relationship between organism and environment that provide strong proofs of stable organizations in that environment.[24] Note that the interaction I espouse is between organism and its environment.

Note also that such interaction does not deny the emergence of mental properties. However, the emergence can stem either from biological evolution which has produced novel brain organizations that result in linguistic capacities or from cultural evolution which can produce new linguistic modes such as writing and printing.[25]

Popper by contrast addresses the interaction between mental and material. And although he reviews the problems faced by materialism because of the insights obtained from the new physics, he fails to see that these insights apply as well to a dualism which still holds dear the separation of mind and matter. I repeat: Are forces "material"? Are light "waves" waving in vacuo "material"? Are quarks with their charm and flavors "material"? As noted, Wigner states that modern physics is based on "relationships between observations not relationships between observables."[26] But is not this the self-same definition which characterizes modern scientific psychology?

I do not of course deny the distinction between observation and observable—the problem of intentionality (see, e.g., John R. Searle). What I do claim is that the distinction no longer distinguishes what we call the physical from what we call the psychological sciences. I do not deny reality to an appearance of the material world as in Newtonian mechanics or in Gibsonian perceptual psychology. Nor do I deny that one can distinguish between these appearances and other realities or between physical reality and psychological reality. But for me realities are constructed, often painfully and painstakingly. Appearances are one such reality, the perceptual reality, beyond which lie others.

I am sitting quietly writing this commentary. I am moving in a complex trajectory around the earth's axis, the sun, and within our galaxy. Both statements reflect a reality—the one my perceptual reality, the reality of appearance; the other, my physical reality based on the observations and calculations of innumerable scientists. Which reality is "objective" and which "subjective"? Which is based solely on the interaction of material observables, and which is based on mental operations such as calculation and observation?

Popper's invention of World 3 attempts to cope with these questions, but I believe the invention does not go far enough. The issue is not material versus mental but how we construct a material reality and how we construct one that is apparently mental.

Elsewhere I argue that the way Popper—and Eccles—describe the interaction of mind and brain is akin to a colloquial use of the concept "force."[27] We say that gravity pulls us to the earth. However, the concept "gravity" was derived from studying the interactions of masses in motion. Gravity is by definition an interaction term; gravity

would not "exist" were there no "us" to be attracted to the earth. We then reify gravity and have it pull us; and appearances certainly confirm this way of conceiving forces—that they are being "produced" by one body and operating on another. Popper develops his thesis of World 3 being "produced" by World 2 in this spirit.

What I see as helpful in the World 2–World 3 division is the attempt to portray the same issue that I have in mind when I discuss structure and its realization. In a sense what I call "structure" is what Popper and Eccles call "mind." The difficulty is, however, that my "structures," like all other concepts, are derived from the interaction of organism and environment. "Structure" therefore can be inherent in environment and in material, physical environments (such as the structure of a symphony being embodied in a printed score or a magnetic tape). This would make my formulation akin to Alfred North Whitehead's and Wigner's—a form of panpsychism. But in agreement with Eccles I am not wholly willing to go that far at the moment. Rather I prefer to hold the line by stating that structures transcend both the physical and mental realities in which they become realized.

There is thus an important difference between a constructional realism such as I propose and the dualist (triadic) interactionism espoused by Eccles and Popper. In a constructional scheme the precise place of brain mechanisms can be specified. The sensory and brain perceptual mechanisms that are used to construct the Newtonian reality of appearances; the cognitive, "intrinsic" (my term for Eccles's "liaison") brain mechanisms that are necessary to the formulation of quantum and nuclear physics; the connative, motor brain mechanisms that organize intention and plan; the emergence of feelings from the neurochemical organizations of the brain—all can be fitted into their precise and proper place in the scheme.[28] There is no global "mind" that has to make mysterious contact with global "brain." Many mysteries are still there—to name only one, for example, how emergents do come about and how they are so utterly different from their substrate. But issues become scientific and manageable within the broader context of philosophic inquiry.

The Brain as a Wave-Form Analyzer

One example is in the order of such manageability and the precision with which the problems can be stated. I take this example from my own work because Eccles reviews it and criticizes it in his part of the book. The problem relates to both perception and memory. The issue

is how sensory input becomes encoded in the brain cortex. Eccles puts the problem in the following way:

> What neural events are in liaison with the self-conscious mind both for giving and receiving.... We reject the hypothesis that the agent is the field potential generated by the neural events. The original postulate of the gestalt school was based on finding that a massive visual input such as a large illuminated circle resulted in some topologically equivalent potential field in the visual cortex, even a closed loop! This crude hypothesis need not be further considered. However a more refined version has recently been proposed by Pribram (1971) in his postulate of micro-potential fields. It is assumed that these fields provide a more subtle cortical response than the impulse generation by neurones. However, this field potential theory involves a tremendous loss of information because hundreds of thousands of neurones would be contributing to a micro-potential field across a small zone of the cerebral cortex. All the finer grain of neuronal activity would be lost in this most inefficient task of generating a minute electrical potential by current flow in the ohmic resistance provided by the extracellular medium. In addition we have the further problem that there would have to be some homunculus to read out the potentials in all their patterned array! The assumed feedback from micro-potential fields onto the firing frequencies of neurones would be of negligible influence because the currents would be extremely small.
>
> We must believe that there is an essential functional meaning in all the discrete neuronal interactions in spatiotemporal patterns, otherwise there would be a great loss of information. In this context, we must consider the organization of the cortical neurones in the anatomical and physiological entity that is called a module.... In the first place it is inconceivable that the self-conscious mind is in liaison with single nerve cells or single nerve fibers. These neuronal units as individuals are far too unreliable and ineffective. In our present understanding of the mode of operation of neural machinery we emphasize ensembles of neurones (many hundreds) acting in some collusive patterned array. Only in such assemblages can there be reliability and effectiveness.... the modules of the cerebral cortex... are such ensembles of neurones. The module has to some degree a collective life of its own with as many as 10,000 neurones of diverse types and with a functional arrangement of feed-forward and feedback excitation and inhibition. As yet we have little knowledge of the inner dynamic life of a module, but we may conjecture that, with its complexly organized and intensely active properties, it could be a component of the physical world (World 1) that is open to the self-conscious mind (World 2) both for receiving from and for giving to. We can further propose that not all modules in the cerebral cortex have this transcendent property of being "open" to World 2, and thus being the World 1 components of the interface. By definition there would be restriction to the modules of the liaison brain, and only then when they are in the correct level of activity. Each module may be likened to a radio transmitter-receiver unit.... the module may be thought of as an integrated microcircuit of electronics, only vastly more complicated.[29]

Although Eccles quotes my *Languages of the Brain*, he ignores in the above account whole sections (e.g., pp. 126-31 and pp. 324-27) devoted to what I label there as "logic modules."[30] The structure of

such modules is presented in much greater detail than Eccles has done in *The Self and Its Brain* or anywhere else. Furthermore, the precise operation of the modules has been simulated by computer on several occasions in my laboratory.[31]

But there is more. Eccles criticizes me in the first paragraph quoted above: "The assumed feedback from micro-potential fields onto the firing frequencies of neurones would be of negligible influence because the currents would be extremely small." In the second paragraph he uses these same currents (which, as clearly defined in *Languages of the Brain*, are the depolarizations and especially the hyperpolarizations that occur at synapses and within dendritic fields) to "emphasize ensembles of neurones (many hundreds) acting in some collusive patterned array . . . with as many as 10,000 neurones of diverse types and with a functional arrangement of feed-forward and feedback excitation and inhibition." Excitation and inhibition for the most part are carried out in axonless (Golgi type 2) "local circuit" neurons which depend on the very micropotentials that Eccles criticized in the first paragraph.[32] It is becoming clearer that processing in the brain—processing within local neuronal circuits—is proceeding by way of local electrotonic and chemical communications that characterize dendrodendritic interactions rather than via the action potential mode so characteristic of long sensory and motor pathways.[33]

G. M. Shepherd and W. Rall have presented voluminous neurophysiological evidence on the functional organization of these local microcircuits—evidence on which I based my proposal of microstructures.[34] What then is the actual difference between Eccles's microcircuits and my microstructures except that I clearly specify the graded response characteristics of the patterning of electrical potentials that produces the functional arrangements within microstructures (or microcircuits) while Eccles fails to do so and take umbrage in "the self and its mind" operating a "radio transmitter or receiver" (the brain modules).

So much for the neurophysiology. The question is of course: What does this neurophysiology gain us with respect to the mind-body problem? I have suggested that the neuronal microstructure, the microcircuitry, is encoding periodic activity, that sensory transduction of environmental energy results in patterns of neural activation in the wave-form domain. Eccles is not averse to this when he suggests that microcircuits act much as radio transmitters-receivers. Radios operate on periodic information; they are tuned to transmit and receive wave forms.

The initial evidence for neural encoding in the wave-form domain was presented in *Languages of the Brain*.[35] Since its publication, evidence continues to pour in. G. S. Ohm and Hermann von Helmholtz originally suggested that the auditory system operates as a wave-form analyzer.[36] Georg von Bekesy showed that the skin and the somatosensory mechanism behave in a similar fashion.[37] But the most dramatic evidence concerns the visual system. More and more evidence is accumulating to show that visual spatial processing is accomplished in the wave-form domain—the eye analyzes the periodic fluctuations of the intensity of light over space.[38]

In the engineering sciences such processing in the wave-form domain is called optical information processing (if done with lens systems) or image processing (if performed with computers) or holography (if storage on photographic film is employed). It is holography that first called my attention to the attributes of the wave-form domain and their relevance for understanding the mind/brain.[39] In a hologram (the photographic film that stores the microstructure of periodic changes of light and dark over space) the information about forms in space becomes distributed. This sheds light on one of the most difficult problems of neuroscience, namely, how to explain the fact that local lesions in the brain do not selectively impair one or another memory trace. In a hologram restricted damage does not disrupt the stored information because it has become distributed.

In essence the information becomes blurred over the entire extent of the holographic film but in such a precise fashion that it can be deblurred by performing the inverse procedure. Thus image reconstruction (or construction) from the stored wave-form domain is simple; applying the same transform that produced the store will also decode it into an image. In short, contrary to what Eccles states to be a problem with my theory, the evidence that the brain encodes information in the wave-form domain indicates that no "homunculus" is needed to read out the memory trace. Either an input from the senses or from some central source (such as Popper's suggestion that the pain-pleasure expectation and attention mechanisms might be responsible) will activate the wave-form encoded memory trace to produce an image.[40] No "self-conscious mind" is sitting there, biasing the functions of the association cortex, as Eccles suggests. Rather, as Popper claims, self-conscious mind is conceived best as an emergent property of a specifiable brain organization.

For the mind/brain problem this mechanism has direct relevance. Note that storage takes place in the wave-form domain. Images as such are not stored, nor are they "localized" in the brain. Rather by virtue

of the operation of the local brain circuitry, usually with the aid of sensory input from the environment, images and mental events emerge and are constructed. The images are the ghosts resulting from the operations of the machine (brain).

A similar mechanism involving the motor mechanisms of the brain can account for intentional, planned behavior. The evidence that such a mechanism exists is presented in *Languages of the Brain* and elsewhere.[41] Much of my laboratory research has been involved demonstrating that brain function is active, not passive, in its interactions with environment and elucidating the processes operative in this active aspect of mind. This research has shown that the intrinsic cortex and limbic formations of the forebrain actively organize sensory input, etc.

Suffice it here to say that I believe the discovery that certain operations of the brain can be understood best in terms of processing in the wave-form domain is as important to the mind/brain problem as the discovery in quantum and nuclear physics that ultimately the appearances of matter may be immaterial.

A New Duality: The World of Appearances versus the Wave-Form Domain

The point was made earlier in this paper that the dualism of mental versus material holds only for the ordinary world of appearances—the world described by Euclidean geometry and Newtonian mechanics. An explanation of dualism was given in terms of procedural differences in approaching the hierarchy of systems that can be discerned in this world of appearances. This explanation was developed into a theory, a constructional realism. But it was also stated that certain questions raised by a more classical dualistic position were left unanswered by the explanations given in terms of a constructional realism.

What are these questions? Recall that Popper and Eccles propose entirely different—and, in a fundamental sense, opposite—views of how mind and brain interact. Popper has mind an emergent from brain functioning; Eccles has mind operating on the intrinsic "liaison" formations of brain cortex. Still these authors managed to publish a book together. Each must have felt some affinity for the other's views. What is it that they may have sensed to be in common, what deep feeling did they fail to articulate adequately in their book?

I believe that the analysis provided earlier in this paper may help "unpack" this issue. Note that, when one looks downward in the hierarchy of systems that compose the ordinary world of appearances,

essentially reductive analyses are engaged. To take account of new properties that arise when components become organized into higher-order, more complex structures, "emergence" is proposed; the proposal is essentially descriptive of what is observed. The upward look in the hierarchy, as in the phenomenal and existential approaches, simply takes these "emergents" as the fundamental achievements of observations. Constructional realism is compatible with such views of emergence, and, as noted above, I believe Popper is attempting to achieve a similar end by his construction of a World 3.

Eccles by contrast is holding out for a very different sort of formulation. He insists that mind transcends brain function in that mind operates upon brain, not because mind emerges from the functioning of the brain. As noted above, articulated in this fashion, Eccles's formulation makes no scientific sense.

But consider now the brain as a wave-form analyzer and the general characteristics of the wave-form domain. These characteristics have been appreciated fully only recently. The recording of patterns of wave fronts by holography has provided a visible artifact whose properties can be readily conceptualized.

Essentially space and time become enfolded in the holographic domain. This accounts for translational invariance, the fact that transformation into the ordinary domain can be accomplished from any part of the encoded record. In the holographic record information becomes distributed, spread over the entire surface of a photographic film or brain module much as the waves produced by throwing a pebble into a pond spread to its edges. Several such waves initiated by several pebbles will interact or "interfere," and the record of these interference patterns constitutes the hologram. If a moving picture were made of the origin and development of the interference patterns, the movie could be reversed and the image of the pebbles striking the pond could be recovered. Image reconstruction by holography accomplishes much the same effect by an operation that performs an inverse transform on the record. Thus image (and object) and holographic record are transforms of each other, and the transformations involved are readily reversible.

Consider further the fact that in the holographic domain space and time are enfolded. Only the density of occurrences is manifest. These densities can be recorded as wave number or in scattering matrices representing n-dimensional (Hilberth) domains such as have been used in quantum physics. Holography has become a window through which we are able to conceptualize a universe totally different from that which characterizes the world of appearances. David Bohm

points out that most of our conceptions of the physical world depend on what we can observe through lenses.[42] Lenses focus, objectify, and draw boundaries between parts. Lenses particularize. Holograms by contrast are distributive, boundaryless, and holistic. Bohm refers to our lens-given ordinary perceptions and conceptions as explicate and those that are holographiclike as implicate. Thus there are at least two discernible orders in the universe—an explicate and an implicate. The explicate order gives an account in terms of particles, objects, and images. The implicate order, still poorly cognized, begins with densities of the fluctuating properties of wave forms.

Bohm and other physicists have become excited by the similarity of conceptualizations of the implicate order and those described by mystics who have experienced a variety of religions and other "paranormal" phenomena.[43] The lack of spatial and temporal boundaries, the holographic characteristic that the whole is represented in every part, and the transformational character of shifting from explicate to implicate order are all beyond ordinary human experiencing which apparently is limited to the everyday, explicate, Euclidean, Newtonian universe to which we have become accustomed.

It is probably not an accident that holograms were a mathematical invention (by Dennis Gabor, who received the Nobel Prize for the discovery) which used a form of mathematics—the integral calculus—invented by Gottfried Wilhelm Leibniz, who also came to a vision of the implicate order. Leibniz's monadology is holographic; his monads are distributed, windowless forms each of which is representative of the whole. Substitute the term lensless for windowless, and the description of a monad and a hologram is identical.

To summarize this section, I propose that Eccles's suggestion of a distributed "mind" operating in some "as yet mysterious" way on brain can be supported by a highly rigorous, mathematical formulation. The fact that the brain is, among other things, a wave-form analyzer, that it encodes information in a distributed fashion akin to that which characterizes a hologram also means that the structural boundaries that characterize the ordinary limits of "brain" and "body" are transcended. Take as an example our current-day world in a large city. The space surrounding us is filled with wave forms generated by radio and television stations. We are insensitive to these wave forms unless we obtain the use of a receiver tunable to one or another of the wave forms. Only then do we "explicate" into the everyday domain the wave forms enfolded in the space about us. The "mystery" is resolved not by holding to the stance that Eccles has taken which is appropriate to Popper's formulation but by recognizing the transformational nature of the implicate domain.

In concluding I will attempt to summarize my position as developed in this paper. I began by accepting a dualistic view of everyday experience: We humans can distinguish clearly between the process of experiencing and the contents of that experience. This led in the centuries since Descartes to the view that the process of experiencing is mental while the contents of the experience, if not themselves material, are at least indicators of a material, physical world. I then went on to show that modern physicists working both at the microphysical quantum and nuclear level and at the macrophysical "universe" level have called into question the material basis of matter. Matter is constituted of energy which in several forms interacts to produce that which we normally experience in ordinary perception. Normal experience is characterized by Euclidean geometry and Newtonian mechanics. Thus the material nature of matter is limited to the ordinary world of experience unless one wants to adopt the bias that energy is material since it can be converted to matter as indicated by Einstein's equation $E = mc^2$. But then why would we have to call such a transformation a conversion? Does not such a materialist bias cloud rather than clarify the fact that we as yet do not know how to characterize properly such energy forms? And by this question I do not wish to suggest that they be characterized as mental.

Beginning from the other end of the mental/material dichotomy we run into a similar limitation on its usefulness. Information and information processing, as when a computer is programmed or a brain is informed by sensory signals, are shown to involve minute amounts of energy that can organize or reorganize large-scale systems. The configurations which energy systems display rather than their raw amount are shown to be critical. Are such figural changes to be conceived as mental or material when they involve languages, cultures, etc.? Once again a limit is reached where the mental/material distinction becomes useless

Next I analyzed the issue of dualism on its own ground, that is, within the purview of ordinary experience. Here dualism is found to be based on mirror-image views constituted by different analytic procedures. The reductive "materialistic" view held by most scientists is found by looking downward from one's experience into the hierarchy of components that constitute that experience. This reductive view is balanced ordinarily by the recognition that novel properties "emerge" when specific configurations of components are formed. Later I showed this view to be shared by Popper in *The Self and Its Brain*.

Looking upward from one's experiences involves validating the experience with that of others. Experienced "phenomena" are described

and compared. Emphasis is on the existence of the experience per se, its existential nature, and when precision is attempted the emphasis is on the structural relationships among phenomena. Consensual validation, enactment, and structural analysis of relationships constitute the tool of inquiry, not separation into parts causally related to one another as in the reductive sciences. Thus the language of phenomenology, existentialism, and structuralism is "mental" since it is experience per se that constitutes the focus of interest.

Recognition of the procedural difference that is responsible for dualism in the ordinary world of experience allows one to transcend this dualism without denying its usefulness to deal with the problems of that ordinary world. I propose that dualism can be transcended by carefully combining the techniques and results of both the reductive and the phenomenal approaches to inquiry. Structure having been made the central, enduring, single quality of a pluralistic monism, both reductive entities and phenomena are seen as realizations of identical structures derived from a more basic existential given.

Once this constructional realism is formulated it has to face another issue, however. True, dualism is not denied; it simply is shown to operate in a limited sphere. But transcending dualism with a structural monism violates the very spirit of what dualists believe in and are trying to articulate. As shown, Eccles attempts such articulation by suggesting what seems to be a rather naive interactionism: mind operating on the association areas of the brain, its intrinsic, "liaison" cortex. A constructional realism does not deal with the issue that is being posed by Eccles's formulation: a "mental" universe "independent" of, though "interacting in some mysterious way" with, the material.

My final proposal meets the requirement of this aspect of dualism. Brain physiologists have shown the nervous system to be, among other things, a wave-form analyzer. Further, input apparently becomes distributed and stored in the wave-form domain in the manner of a holographic record. And physicists have suggested that a holographiclike order may well characterize the microstructure of the physical world. In the wave-form domain, space and time become enfolded; only density of occurrences is represented.

Descriptions of this domain and other similar orders that account for the observations of modern physics seem to be remarkably similar to mystics' descriptions of paranormal and religious experience. I propose therefore that the duality between the normal, everyday domain of appearances and the wave-transform domain captures the spirit of dualism and accounts in a scientific and precise

mathematical fashion for what hitherto has been incomprehensible.

Structural realism thus deals with a number of dualities of which two are especially significant for unpacking the issues involved in a mind/brain dualism: (1) a procedural duality that faces upward and downward in the hierarchy of systems discerned in the ordinary world of appearances and (2) a transformational duality that apposes the ordinary world of appearances to that viewed through the window of the wave-transform domain characterized by descriptions akin to those of the experiences of mystics which provide the basis for some important insights in various religious traditions.

Other dualities may well be discovered to underlie as yet unarticulated premises of dualism. What appears clear at the moment is that a dualism based on the distinction between mental and material is too limited to deal with the very issues that it poses. Other dualities can articulate answers to the problems raised by these issues and deal not only with their substance but also with their spirit. Further, these dualities can be specified by scientifically sound procedures and mathematically precise formulations. Finally recognition of these dualities stems directly from discoveries in the physical, information, and behavioral sciences. Thus the often-made argument that the results of scientific research have no bearing on philosophically framed issues has been shown to be wrong. In fact what has been shown is that only through the results of scientific research can philosophical issues, even at the ontological level, be refreshed.

NOTES

1. See, e.g., R. W. Sperry, "Neurology and the Mind-Brain Problem," *American Scientist* 40 (1952): 291-312; Gordon G. Globus, "Mind, Structure and Contradiction," in *Consciousness and the Brain: A Scientific and Philosophical Inquiry*, ed. Gordon G. Globus, Grover Maxwell, and Irwin Savodnik (New York: Plenum Press, 1976), pp. 273-92; Karl R. Popper and John C. Eccles, *The Self and Its Brain* (New York: Springer-Verlag, 1977).

2. See, e.g., J. W. N. Watkins, "A Basic Difficulty in the Mind-Brain Identity-Hypothesis," in *The Search for Absolute Values in a Changing World*, 2 vols. (San Francisco: International Conference on the Unity of the Sciences, 1978).

3. Niels Bohr, *Atomic Physics and Human Knowledge* (New York: Vintage Press, 1966); Werner Heisenberg, *Physics and Philosophy* (London: Allen & Unwin, 1959).

4. Eugene P. Wigner, "Epistemology of Quantum Mechanics: Its Appraisals and Demands," in *The Anatomy of Knowledge*, ed. Marjorie Grene (London: Routledge & Kegan Paul, 1969).

5. Erwin Schroedinger, "Quantization as a Problem of Proper Values," in *Collected Papers on Wave Mechanics*, trans. J. F. Shearer and W. M. Deans (London: Blackie & Son, Ltd., 1928); Louis Victor prince de Broglie, *The Current Interpretation of Wave Mechanisms: A Critical Study*, trans. Express Translation Service (Amsterdam: Elsevier, 1964).

6. E.g., L. Brillouin, *Science and Information Theory*, 2d ed. (New York: Academic Press, 1962); E. von Weizsacker, *Offene Systeme I* (Stuttgart: Verlag, 1974).

7. See, e.g., G. A. Miller, E. H. Galanter, and Karl H. Pribram, *Plans and the Structure of Behavior* (New York: Henry Holt & Co., 1960).

8. Maurice Merleau-Ponty, *The Structure of Behavior*, trans. Alden L. Fisher (Boston: Beacon Press, 1963); Miller, Galanter, and Pribram.

9. Karl H. Pribram, "Behaviorism, Phenomenology and Holism in Psychology: A Scientific Analysis" (paper presented at the annual meeting of the American Psychological Association, Toronto, Ontario, Canada, August 28-September 1, 1978).

10. Franz Clemens Brentano, *Psychology from an Empirical Standpoint,*, trans. Antos C. Rancmello, D. B. Terrell and Linda L. McAlister (London: Routledge & Kegan Paul, 1973); R. M. Chisholm, *Realism and the Background of Phenomenology* (New York: Free Press, 1960).

11. Karl H. Pribram, "Proposal for a Structural Pragmatism: Some Neuropsychological Considerations of Problems in Philosophy," in *Scientific Psychology: Principles and Approaches*, ed. B. Wolman and E. Nagle (New York: Basic Books, 1965), pp. 426-59.

12. See, e.g., William James, *A Pluralistic Universe* (London: Longman's, Green & Co., 1909); Bertrand Russell, *Human Knowledge, Its Scope and Limits* (New York: Simon & Schuster, 1948).

13. Karl H. Pribram, "The Realization of Mind," *Synthese* 22 (1971): 313-22.

14. Pribram, "Proposal for a Structural Pragmatism" and "Realization of Mind"; idem, *Languages of the Brain: Experimental Paradoxes and Principles in Neuropsychology*, 2d ed. (Monterey, Calif.: Brooks/Cole, 1977).

15. Popper and Eccles (n. 1 above).

16. E.g., ibid., p. 449. [For a discussion of Popper's three worlds see John C. Eccles, "Cultural Evolution versus Biological Evolution," *Zygon* 8 (September-December 1973): 282-93.—ED.]

17. Popper and Eccles, p. 163.

18. E.g., ibid., p. 127.

19. Ibid., p. 35.

20. See Popper's discussion of Gilbert Ryle, ibid., pp. 104-7.

21. See the "subjective behaviorism" of Miller, Galanter, and Pribram (n. 7 above).

22. Popper and Eccles, p. 514.

23. Sigmund Freud, "Project for a Scientific Psychology" (1895), in *The Standard Edition of the Complete Psychological Works of Sigmund Freud*, trans. James Strachey et al. (London: Hogarth Press, 1950), 1:281-397; Karl H. Pribram and M. M. Gill, *Freud's "Project" Reassessed* (New York: Basic Books, 1976).

24. Popper and Eccles, pp. 104-8; James Jerome Gibson, *The Perception of the Visual World* (New York: Houghton Mifflin, 1950).

25. Karl H. Pribram, "Language in a Sociobiological Frame," *Annals of the New York Academy of Sciences* 280 (1976): 798-809.

26. Wigner (n. 4 above).

27. Karl H. Pribram, "Problems Concerning the Structure of Consciousness," in Globus, Maxwell, and Savodnik (n. 1 above).

28. See, e.g., my "Realization of Mind" (n. 13 above).

29. Popper and Eccles, pp. 365-66.

30. Pribram, *Languages of the Brain* (n. 14 above).

31. D. N. Spinelli, "Visual Receptive Fields in the Cat's Retina: Complications," *Science* 152 (1966): 1768-69; R. W. Phelps, "Effects of Interactions of Two Moving Lines on Single Unit Responses in the Cat's Visual Cortex," *Vision Research* 14 (1974): 1371-75; B. Bridgeman, "Metacontrast and Lateral Inhibition," *Psychological Review* 78 (1971): 528-39; Karl H. Pribram, M. Nuwer, and R. Baron, "The Holographic Hypothesis of Memory Structure in Brain Function and Perception," in *Contemporary Developments in Mathematical Psychology*, ed. R. C. Atkinson et al. (San Francisco: W. H. Freeman & Co., 1974), pp. 416-67.

32. Pasko Rakic, *Local Circuit Neurons* (Cambridge, Mass.: M.I.T. Press, 1976).

33. See, e.g., Francis O. Schmitt, Parvati Dev, and Barry H. Smith, "Electrotonic Processing of Information by Brain Cells," *Science* 193 (1976): 114-20.

34. G. M. Shepherd, *The Synaptic Organization of the Brain: An Introduction* (New York: Oxford University Press, 1974); W. Rall, "Dendritic Neuron Theory and Dendrodentritic Synapses in a Simple Cortical System," in *The Neurosciences: Second Study Program,* ed. Francis O. Schmitt (New York: Rockefeller University Press, 1970), pp. 552-65.

35. Pribram, *Languages of the Brain*, chap. 8.

36. G. S. Ohm, "Uber die Definition des Tones, nebst daran geknupfter Theorie der Sirene und ahnlicher tonbildener Vorrichtungen," *Annalen der Physikalischen Chemie* 59 (1843): 513-65; Hermann von Helmholtz, *Lehre von den Tonempfindungen* (Braunschweig: Vieweg, 1863).

37. George von Bekesy, "Neural Volleys and the Similarity between Some Sensations Produced by Tones and by Skin Vibrations," *Journal of the Accoustical Society of America* 29 (1957): 1059-69.

38. F. W. Campbell and J. G. Robson, "Application of Fourier Analysis to the Visibility of Gratings," *Journal of Physiology* 197 (1968): 551-66; J. A. Movshon, I. D. Thompson, and D. J. Tolhurst, "Receptive Field Organization of Complex Cells in the Cat's Striate Cortex," *Journal of Physiology* (in press); idem, "Spatial Summation in the Receptive Field of Simple Cells in the Cat's Striate Cortex," ibid. (in press); idem, "Spatial and Temporal Contrast Sensitivity of Cells in the Cat's Areas 17 and 18," ibid. (in press); R. L. De Valois, D. G. Albrecht, and L. G. Thorell, "Spatial Tuning of LGN and Cortical Cells in Monkey Visual System," in *Spatial Contrast,* ed. H. Spekreijse (Amsterdam: Royal Netherlands Academy of Sciences, in press); idem, "Cortical Cells: Line and Edge Detectors, or Spatial Frequency Filters?" in *Frontiers of Visual Science*, ed. S. Cool (New York: Springer-Verlag, in press); Karl H. Pribram, M. C. Lassonde, and M. Ptito, "Intracerebral Influences on the Microstructure of Visual Cortex: Classification of Receptive Field Properties (I)" (manuscript).

39. Karl H. Pribram, "Some Dimensions of Remembering: Steps toward a Neuropsychological Model of Memory," in *Macromolecules and Behavior*, ed. J. Gaito (New York: Academic Press, 1966), pp. 165-87.

40. For evidence see Karl H. Pribram and D. McGuinness, "Arousal, Activation and Effort in the Control of Attention," *Psychological Review* 82 (1975): 116-49.

41. Pribram, *Languages of the Brain* (n. 14 above) and "Problems Concerning the Structure of Consciousness" (n. 27 above); Pribram, Lassonde, and Ptito (n. 38 above).

42. David Bohm, "Quantum Theory as an Indication of a New Order in Physics: The Development of New Orders as Shown through the History of Physics (Part A)," *Foundations of Physics* 1 (1971): 359-81; idem, "Quantum Theory as an Indication of a New Order in Physics: Implicate and Explicate Order in Physical Law (Part B)," ibid. 3 (1973): 139-68.

43. David Bohm, *Fragmentation and Wholeness* (Jerusalem: VanLeer Jerusalem Foundation, 1976); Fritjof Capra, *The Tao of Physics* (Berkeley, Calif.: Shambhala Publications, 1975).