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Brain, mind, and consciousness:
The science of neuropsychology

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Introduction

Interest in the relationship between mind and brain has become invigorated by the surge of activity in the neurosciences and in what has come to be called "cognitive science." The time is therefore ripe to take a new look at this age-old problem, but now from the standpoint of the scientist as well as from that of the philosopher. Despite what some philosophers may hold (e.g., Dewan et al. 1976), we are today in a position not only to reevaluate major philosophical stances but also to develop more limited and precise theories and models of mind/brain relationships, each of which subsumes a restricted database.

The surge of interest in mind/brain issues has come in various guises. Cognitive scientists have argued whether "representations" or "computations" characterize the relationship (see, e.g., Gardner 1985, "Special Issue" in *The Behavioral and Brain Sciences*, 1980). A philosopher and a neuroscientist have banded together only to find themselves maintaining an interactive separateness of mind and brain (Popper and Eccles 1977). And a neuroscientist (Sperry 1952, 1969, 1976), as well as a philosopher (Searle 1979) have declared themselves solidly on the side of mind (Sperry 1980), whereas a psychologist (Skinner 1971, 1976) has given up hope that a "science of mental life", as William James (1901) and more recently George Miller (1962), have dubbed it, is possible at all because such a science would depend on verbal communications, which are notoriously ambiguous.

It is this variety in the attempts to deal with mind/brain relations that calls forth my reevaluation. I know most of the protagonists personally and have high regard for all of them, as I have for much of the philosophical discourse that bears on the issues. It seems to me that these intelligent scholars cannot all be wrong despite the fact that their respective contributions are at variance with one another. Could it then be that they are all correct, in some nontrivial sense? If so, how?

My approach, to be developed here, is that each of these espoused philosophical positions has captured a part of the domain of issues and that what is necessary is to determine the database on which each position rests. The failure of philosophy to resolve the issues comes when a position is maintained beyond the confines of its relevant database to a point where another position is more appropriate.

The danger of this approach is that one may end up with an "any worlds" or at least with a "many worlds" relativist viewpoint, which is fine if one wishes to show merely that there are many different answers to the questions posed. But I am not satisfied with such a result. I hope to be able to show that despite the fact that several databased theoretical frames fit different agendas in philosophy, a unified view can be constructed out of the diversity of theories.

One caveat: The approach taken here is new and, as will become evident, entails some surprises. The result must, therefore, of necessity be inadequate and even "wrong" in detail. The important consideration is that the approach is a viable one and that it can be progressively sharpened by recourse to experimental disconfirmation (see Popper 1968a, 1968b). The approach is essentially scientific but heeds the questions so carefully honed by philosophical inquiry.

The story of current thinking on the mind/brain issues begins with Ernst Mach (1914) and the positivist approach. Mach was a dualist and a parallelist; mind and brain for him had identical structures but were forever separate entities. Mach's position gave rise to two major approaches, each centered on a particular problem. The first of these approaches accepted Mach's dualism but noted that mind and brain do interact, that is, influence each other. The question arose as to how that interaction might take place. Popper and Eccles (1977) answered this question by suggesting that mental processes created a "World 3" of language and culture that in turn feeds back, through the senses, to influence brain mechanisms. Mind itself was noted to be an emergent of this interaction, an emergent immersed in the sensory (and motor) processes that relate the brain to the organism's environment.

The Vienna Circle, and especially Feigl (1960), addressed a different problem in Mach's formulation. If indeed identical structures characterize brain and mind, what is it that is structurally identical? Feigl, in keeping with the positivist tradition, focused on language and suggested that mind talk and brain talk were different aspects of some underlying Machian structure. In his identity theory, Feigl gave up dualism and opted for the monistic emphasis on basic structure.

Both Popper's and Feigl's programs have much merit, but each also poses new questions, questions that can lead to further insights. By what process is World 3 constructed? What are the primitives of language and culture that so readily influence the brain? In the multiple aspects view, what is it that the aspects refer to? My answer to these questions is presented in scientific rather than philosophical terms. By this I mean that I attempt to identify the data-set that each of the philosophic programs addresses rather than to push each program to its logical limit. The outcome of this approach is a neutral monism, in which energy, entropy and information are identified as ideals, neutral to the mind/brain duality, and endowed with the potential for multiple embodiments. Feigl's linguistic dual aspects (i.e., mind talk and brain talk) are replaced by a plurality of realizations.

Do experiences matter or does matter become experienced?

In contrast to philosophers, psychologists under the banner of a radical behaviorism, eschewed any scientific reference to mind. As noted, the reasons for this are not arbitrary.

Rather, as both Skinner (1971, 1976) and Quine (1960) have pointed out, the issue is that no two people mean exactly the same thing when they use a particular word or phrase. Furthermore, we can never be sure that even when we use a word such as green that it denotes the same experience to each person using it. But this is an issue common to all of science and indeed to all cognition, as Berkeley (1904) so persuasively argued. Are we therefore to give up, hang our heads, and sit in isolation in our respective existential corners? Of course not. Nor does it mean that in constructing a science we must exclude reference to our conscious experiences. A common alternative is to make inferences and to proceed to deal with them. Cognitive science can and does proceed in just this fashion (see, e.g., Johnson-Laird and Johnson-Laird 1983).

Mechanism

A triumph of nineteenth-century science was the application of a mechanistic approach to the problem of biology. Experiment and observations showed that biological phenomena could be explained without recourse to a "vital principle." The issue had been whether such a principle would have to animate nonliving substances in order for life to exist. It was shown that, with due regard for the emergence of new properties when complex combinations of substances occurred, no single "vital" attribute remained to be accounted for.

It was only natural that scientists would attempt to extend this success of the mechanistic approach to psychology. And it would have been surprising if mechanism did not go a long way toward explaining a great deal. Beginning with Freud (1895) and Pavlov (1927) and culminating in the behaviorism of Watson (1959), Hull (1951), Spence (1956), and currently Skinner (1971), phenomena observed in the clinic and classroom were in some measure explained in terms of their biological and environmental antecedents.

These successes of the mechanistic approach ought to have eliminated mentalism from psychology as assuredly as they had eliminated vitalism from biology. But the facts have led in a different direction: Patients have shown dissociations between verbal reports of their introspections and their behavior as demonstrated instrumentally (for example, Pribram 1964, Sidman, Stoddard and Mohr 1968, Weiskrantz and Warrington 1974). Such observations suggest that caution must be exercised in making inferences about psychological processes exclusively from one or another class of behavior and that certain inferences are more akin to our subjective experience (what we ordinarily call "mental") than others.

Meanwhile, physicists have had their own difficulties with "mechanism." Though mechanistic principles are powerful in explaining the Newtonian level of everyday experience, at both the micro- and macro-physical level relationships between variables fail to be readily specifiable in simple mechanistic cause-effect terms. Heisenberg (1959) in his indeterminism principle noted the intrusive effects of observation at the microphysical quantum level and Einstein (1956) in his special and general theories of relativity called attention to the same phenomenon at the macrophysical, cosmic level of inquiry.

Thus, both in psychology and in physics the distinction between observer and observed cannot be so simply delineated. But it is on this distinction that the Cartesian dichotomy, mental versus material, ultimately rests. When Wigner (1969), a Nobel laureate in physics, has to declare that modern microphysics no longer deals with "relations among observables but only with relationships among observations," minding (mind) has intruded into whatever is observed to be matter. In a sense, matter has become demechanized.

The issue of minding matter can be traced to earlier formulations. For instance, physics was conceptually understandable in Clark Maxwell's day when light waves were propagated in a material 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 Schrödinger (1928) or de Broglie (1964). One can readily conceptualize waves traveling in a material medium —such as when sound waves travel in air; but what could be the meaning of electromagnetic waves "traveling" in a vacuum? Currently, physicists are beginning to fill that vacuum with dense concentrations of radiant energy. Is energy material? More on this subsequently.

Information Processing

Research on 'mind' using behavioral techniques also blurs the distinction which seems so clear when only the ordinary Euclidean, Newtonian domain of appearances is considered. The organization of behavior can best be comprehended by recourse to concepts such as "information" and "programs" or "plans" which serve equally well in understanding the operations of machines (see, for example, Miller, Calanter and Pribram 1960). Here the question can be posed: is information processing mental or material?

Philosophers and psychologists of a nonbehaviorist persuasion will immediately 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 match the introspections to mental constructs inferred from behavior (Pribram 1962, 1971) and to organize the descriptions (structurally). Thus, Merleau-Ponty, an existential philosopher, has authored a book entitled *The Structure of Behavior* (1963) which both in spirit and content shows remarkable resemblances to our own *Plans and the Structure of Behavior* (Miller, Galanter and Pribram 1960) which tackles the issues from a behavioral and information-processing vantage.

I do not mean to convey here that there is no distinction between a behavioristic and an existential-phenomenalistic approach to mind. This distinction can be formulated in terms of a search for causes by behaviorists and a search for informational structures meaningfully composed (that is, reasonable) by phenomenalists (Pribram 1979). But, there are limits to understanding achieved solely through introspection as well as solely through the observation and experimental analysis of behavior. These limits are especially apparent when problems other than overt behavior are addressed, problems related to thought or to decisional processes, to appetitive and other motivational mechanisms, to emotions and feelings and even to imaging and perception. These problems make up a large bulk of the interests that bring students to the study of psychology, and at least one behaviorist (Skinner 1976) has grouped them under the rubric "covert behavior." Being covert, they need to be enacted to be studied (Miller, Galanter and Pribram 1960). Enactment by computer simulation is, however, only one avenue of study; the recording and analysis of brain electrical activity may prove just as effective in achieving scientific understanding —perhaps even more so when used in combination with enactment.

In a very real sense, therefore, psychology as a science reaches out beyond behaviorism to these covert processes. Ordinarily, when consciously experienced, these covert processes have been labeled "mental" and there is no good reason to abandon this label. Our perceptions such as vision and hearing are mental processes. Our feelings of emotion and motivation are mental, our intentions and decisions are mental, and thus much of what drives the *organization* of behavior is mental.

Mind as emergent and as actor: Conscious and unconscious processes

The centerpiece of phenomenological interest is consciousness. The term is used in a variety of ways and a comprehensive account of what we know about how the brain systems coordinate with consciousness can be found in Pribram 1976a, 1976b, 1977, 1978a, 1978b, 1978c, 1980, 1983, 1990b, 1991, in press. Here I will deal only with the evidence that relates four brain systems to four rather different forms of conscious and unconscious processes.

But first some distinctions. There are states of consciousness such as sleep and wakefulness; stupor and coma; hunger and thirst; love and anger; interest and boredom which are, to the best of current knowledge, coordinate with distinguishable neurochemical states.

Then there are the contents of consciousness, our perceptions. A great deal is known about how the brain systems coordinate with perception and how they operate (see Pribram 1991). Finally, there are the attentional processes that relate states and contents. As William James once remarked, perhaps we should eschew the term consciousness in favor of attention. Attention, minding (the origin of mind), concerns the selective processing of sensory input (Pribram and McGuinness 1975, 1991). It is with regard to attention that a distinction can readily be made between conscious and unconscious processing —or, in the terminology current in attention research— between controlled and automatic processing. (In memory research, the terms explicit and implicit processing are popular.)

Objective and Subjective Consciousness

In the clinic, four different conscious/unconscious systems can be distinguished. The first centers on patients with occipital lobectomies who experience blindsight (Weiskrantz 1986). These patients can instrumentally identify objects by pointing and verbally guessing their shape but report that they cannot see what they are identifying. Consciously these patients are blind; unconsciously they behave appropriately. In intact subjects, therefore, the ability to consciously experience objects indicates that there exists a brain system coordinate with what can be called *objective consciousness*.

Patients with lesions further forward (in the parietal lobe) experience a similar sort of disassociation but with regard to their bodies. Clinically they *neglect*, e.g., an arm or leg because it no longer feels to be a part of their body. They can identify an arm as an arm visually but the neglected part is no longer experienced as a part of the patient's "me". In intact subjects, therefore, there is a system that allows the experience of a corporeal self, the "objective me". This then is part of objective consciousness. Thus, objective consciousness can be divided into a part which experiences "self" and a part which experiences "other."

In a very different part of the brain are two systems that are involved in what can be called *subjective consciousness*, the "experiencing I". These systems comprise the frontolimbic formations of the forebrain. One system, centered on the amygdala lying within the pole of the temporal lobe, is involved in experiencing familiarity. Patients with lesions in this part of the brain can enter their home and *feel* estranged, as if they had never been there despite being able to objectively identify every aspect that they see or touch. Such "jamais vu" experiences come in episodes as do their opposites "déjà vu" experiences in which an objectively strange location is experienced as familiar. During "jamais vu" and "déjà vu" episodes abnormal electrical seizure activity can be recorded from the amygdala.

In other patients the episodic brain disturbance can lead to a failure to incorporate experiences into the subjective stream of consciousness. Following the episode there is total amnesia for what occurred during the seizure activity. Depending on the intensity and duration of the abnormal seizure, during the episode, the patient can blank out temporarily, behave essentially normally, or demonstrate episodic violence totally out of his/her normal character.

When more extensive bilateral lesions of the medial portion of the temporal lobe are sustained, patients cannot consciously remember their examiners despite repeated encounters over a 30 year period (see, e.g., Milner 1966) while at the same time they perform accurately in an operant situation learned many months previously (Sidman, Stoddard and Mohr 1968).

With a frontal placement of the brain disturbance the patient will either produce volumes of diary material or, when the disturbance is greater, communicate with markedly reduced fluency. Both of these abnormalities indicate a disruption in what can be called the narrative aspects of subjective consciousness. Narrative ties together episodes experienced by the "subjective I."

There has been considerable debate in philosophy as to whether consciousness is an emergent epiphenomenon (as many behaviorists would have it) or whether consciousness plays an important active adaptive role in determining action. As any of the patients experiencing disturbances either in objective or subjective consciousness can readily witness, consciousness is critically important not only to their own well being but to that of their fellow human beings. Anyone who rapes or murders during a period of episodic violence will do *anything* (brain surgery, imprisonment) to prevent the reoccurrence of such episodes. Losing one or more episodes in his/her narrative is disrupting even when no violence occurs during the lost episodes. How does one respond to friends when one has "lost" the episode experienced with them the night before?

Nor are neglect and blindsight any less disruptive. Disturbances of objective consciousness are often more localized, to one side or part of one side of spatial experience, thus not as pervasive as those of subjective consciousness. Nonetheless, the disturbances are truly disabling and attest to the utility of consciousness.

Kairos and Chronos

A final point. As noted, the distinction between objective and subjective consciousness also distinguishes between the spatial and the temporal aspects of experience. However, this temporal aspect is what the Greeks called Kairos and Bergson (1922/1965) called Duré. By contrast, chronos or clock time is directly related, as Einstein pointed out, to space: movement through space takes time. The "narrative-I" experiences Kairos in terms of relatively filled and empty episodes (Ornstein 1969). Paradoxically, what may seem to be a short episode while it is being experienced, may loom long in retrospect. There is no relation to clock time either way.

Some confusions and some clarifications

Psychology needs to have clearly defined what is meant by mental and what is meant by behavior. Confusion has plagued psychology because both the term "mental" and the term "behavior" have remained ambiguous. Each term has in fact been used in two very distinctly separate ways and the distinctions have not been clearly kept apart.

Behaving

To begin with, the meaning of the term "behavior": When a behaviorist ordinarily analyses behavior, he is studying a record of responses emitted by an organism in a specified situation. The record can be studied in any location, it could have been produced in any of a number of ways by any number of different response systems—arms, legs, beaks, and so on. The behavior under study is an environmental consequence of any of these response systems (Pribram 1971).

At other times, however, behavior is understood to mean the pattern of the organism's movements, or of his endocrine or neural responses in a situation. This definition of behavior is especially common to biological behaviorists such as ethologists, but it is also invoked by psychologists (even staunch behaviorists) when they begin to address the problem of covert behavior.

What then is the concern of a science of behavior? Are its laws to be formulated on the basis of descriptions of the behaviors of organisms or the behaviors of organ (response) systems? Classically, the laws describing the behavior of organ systems have been the province of physiology. There are physiologists (and physiological psychologists) who believe that a lawful description of brain processes should be coordinate with the laws derived from observations of behavior. These physiologists may well be correct, but because the brain is contained within the organism, such identifications fall easy prey to the category errors warned against by Kant, by Russell and Whitehead and by all subsequent critical philosophers. In a strict sense, a brain cell does not "see" its "visual" receptive field; the cell responds to excitation of its dendritic (receptive) field which results from luminance changes that have been transduced into neuroelectric potentials by retinal receptors. Perhaps the behaviorist will be content when the laws of behavior and those describing brain function coalesce —but that has not been the tenor of those who espouse the establishment of a science of behavior, separate from physiology.

Minding

The mentalists have not fared much better than the behaviorists in stating clearly what psychology, the study of mental life, is to be about. Are mental processes to be identified on the basis of verbal reports of introspection? Are they, therefore, the contents of introspection? Or are mental processes the resultants of an organism's being-and-acting-in-the-world as Whitehead, Husserl, the phenomenologists, Gestalt psychologists, and existentialists would have it? Are the contents of introspection nothing more than these resultants of being-(or acting)-in-the-world? If they are, what then is the difference between what a behaviorist calls covert behavior and the existentialist calls mental? Logically, there is none.

However, though logic can find little to distinguish an existential psychologist from a sophisticated behaviorist, historically the gap is great between how each goes about constructing his science. The behaviorist, as already noted, is devoted to objectively observable discrete behavioral responses —he makes inferences, yes, but these inferences must be operationally and explicitly tied to the environmental manipulations that produce these discrete observable behaviors of organisms.

By contrast, phenomenologists, Gestalt psychologists, and existentialists analyze subjective experience. Contrary to opinions expressed by some behaviorists, these investigators do not eschew observation. Nor do their concepts, when derived scientifically, lack in operational rigor. As with behaviorists, the operations to which these concepts are tied are operations performed on the environment, not on the organism. Thus, they share the interest of psychophysicists. As psychologists, they use these operations to attain concepts about subjective experience (as reported verbally or inferred from nonverbal communication) instead of using them to attain laws describing behavior.

It is this remoteness of the measurable dependent variable from what is being studied that makes the mentalist's job more difficult than that of the behaviorist. But inference from observable events to nonobservable ones is a commonplace in the natural sciences. Quantum and nuclear physicists have built precise models of the micro-universe from observing the effects of events on measurable variables rather than by observing the events themselves. Physiological chemists often postulate the presence of a biologically active substance from the effect it has, many years before that substance is identified chemically.

In like manner, a mentalist may investigate hunger, visual illusions, states of consciousness, with the aim of modeling these experiences via their observed effects on reports of their occurrence or of finding a neuroelectric response to be coordinate with the experience.

Viewed in this fashion, a science of mental life is as likely to become rigorous and respectable as a science of behavior. This does not mean that the models of psychological experience and the laws of behavior will prove to be similar any more than the models of quantum physics resemble the laws of mechanics. Psychology should be able to readily encompass both levels of inquiry—and perhaps other levels such as explorations of social communication, as well. Biology as well as physics have their molecular and molar divisions—why not psychology?

The Mental and the Material

Strictly speaking, however, mentalism implies dualism because there is no need for mentalism if there were no materialism. There is no up without a down. Thus, Sperry (1980) and Searle (1984) have need to limit their persuasive development of mentalism to those structures that are organized by and in turn organize the material brain. Their intuition regarding the biological roots of mentality is certainly accurate: To confuse the analogy of the computer with the historically-based biological homologies that have given rise to psychological processes is akin to calling a whale a fish. By the same token, however, Sperry and Searle are adamantly opposed to an "independent existence of conscious mind apart from the functioning brain" (Sperry 1980, p. 195) and thus their mentalism does not stretch to cover the very essence of what motivates mentalism in the hands of many who oppose it to materialism; that is, the priority and independence of mental structures.

Materialism and phenomenology run into difficulty 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 the existence of a real material world. This is the essence of the argument made by Sperry and Searle; paradoxically, however, their argument sounds very much like the materialism of Bunge: We do appear to be experiencing something(s), so our experiences may well become organized by those real (material) somethings (see Bunge 1980, for a persuasive development of this position).

There is a resolution to this mental/material paradox. In the ordinary world of appearances human experiencing can be distinguished sharply from the contents of the experience. The issue has been labeled "intentionality" (or intentional inexistence) by Franz Clemens Brentano and has given rise to inferences about the nature of reality (Brentano 1973, Chisholm 1960). The question is often phrased: Are my perceptions (my phenomenal experiences) the "real" world, 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.

A Procedural Difference

The mental-material dichotomy holds, as will now be detailed, only for the ordinary scale of the Euclidean-Newtonian world of appearances. 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 an airplane. Up to now, her mother has allowed her to say "bird" whenever any flying object is pointed to. But the time has come to be more precise, and the experience of airplane becomes validly different from that of a bird. Mental language is derived from such upward validations in a hierarchy of systems.

Phenomenal-existential mentalism is rooted in being-in-the-world. Basically, therefore, there is an upward —or perhaps better stated as an outward— reach, if experience is considered the starting point of inquiry. Experience is of a piece with that which is experienced. Issues of self, of intention and intentionality, are derivative and always include a being-in-the-world approach to solution. Phenomenal and existential approaches thus share with social psychology the derivation of self or person from the being-in-the-social-world.

Elsewhere I detail the differences in scientific approach that this upward —or outward— look entails (Pribran 1965). 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 ones. It is these relativisms that existentialists and phenomenologists constantly 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 structured 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. 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, although 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, conceptual structures, not of any basic duality in nature.

Mind/brain identity: Metaphysical idealism

Let us look at the issue of structure in terms of computers, programs, and the processing of information in some detail because in many respects these artifacts so clearly portray some of the problems involved in the mind/brain issue. As has been repeatedly noted (see, e.g., Searle 1984, Dreyfus and Dreyfus 1986), the computer is not a brain; the programs that make it run are constructed by people who do have brains. Nonetheless, computers and their programs provide a useful metaphor in the analysis of the mind/brain issue in which the distinction between brain, mind, and spirit can be seen as similar to the distinction between machine (hardware), low-level programs (e.g., assemblers) mid-level programs (e.g., operating systems), and high-level programs (e.g., word processing programs). Low-level programs such as machine languages and assemblers are not only idiosyncratic to particular types of computer hardware, but there is also considerable similarity between the logic of these languages and the logic operations of the machines in which they operate. In a similar vein, to some extent, perceptual processes can be expected to share some similarity to brain processes. On the other hand, mid-level languages such as Fortran, Pascal, and C are more universal in their application, show important individual differences in aptitude much as there are individual differences in mental aptitudes. Furthermore, there is less obvious similarity between their implicit logic and the logic of machines. At the highest level, in languages such as English, with which I address my computer in order to use it as a word processor, the relation between the logos (word, concept, logic) of English and that of the machine is still more remote. However, English relates me to a sizable chunk of the human social order. To complete the metaphor, humanity's spiritual nature is that aspect of mind which strives to make contact with more encompassing orders whether they be social, physical, cosmological, or symbolic.

Invariances Across Transformations

Understanding how computer programs are composed helps to tease apart some of the issues involved in the "identity" approach to the mind/brain relationship. Because our introspections provide no apparent connection to the functions of the neural tissues that comprise the brain, it has not been easy to understand what theorists are talking about when they claim that mental and brain processes are identical. Now, because of the computer/program analogy, we can suggest that what is common to mental operations and the brain "wetware" in which the operation is realized, is some order that remains invariant across transformations. The terms *information* (in the brain and cognitive sciences) and *structure* (in linguistics and in music) are most commonly used to describe such identities across transformations.

Order invariance across transformations is not limited to computers and computer programming. In music we recognize a Beethoven sonata or a Berlioz symphony irrespective of whether it is presented to us as a score on sheets of paper, in a live concert, over our high fidelity music system, and even in our automobiles when distorted and muffled by noise and poor reproduction. The information (form within) and the structure (arrangement) are recognizable in many embodiments. The materials that make the embodiments possible differ considerably from each other, but these differences are not part of the essential property of the musical form. In this sense, the identity approach to the mind/brain relationships, despite the realism of its embodiments, partakes of Platonic universals, that is, ideal orderings that are liable to becoming flawed in their realization.

In the construction of computer languages (by humans) we gain insight into how information or structure is realized in a machine. The essence of biological as well as of computational hierarchies is that higher levels of organization take control over, as well as being controlled by, lower levels. Such reciprocal causation is ubiquitous in living systems: Thus, the level of tissue carbon dioxide not only controls the neural respiratory mechanism but is controlled by it. Discovered originally as a regulatory principle that maintains a constant environment, reciprocal causation is termed *homeostasis*. Research over the past few decades has established that such (negative) *feedback* mechanisms are ubiquitous, involving sensory, motor, and all sorts of central processes. When feedback organizations are hooked up into parallel arrays, they become feedforward control mechanisms that operate much as do the words (of bit and byte length) in computer languages (Miller et al. 1960, Pribram 1971).

Codes

Equally important, programming allows an analysis to be made of the evolution of linguistic tools that relate the various levels of programming languages. Digital computers with binary logic require a low-level language (coded in the numerals 0 or 1) that sets a series of binary switches. At the next level, switch settings can be grouped so that the binary digits (bits) are converted into a more complex code consisting of bytes, each of which is given an alphanumerical label. Thus, for example, the switch setting 001 becomes 1, the setting 010 becomes 2, and the setting 100 becomes 4.

Given that 000 is 0, there are now eight possible combinations, each of which is an octal byte.

This process is repeated at the next level by grouping bytes into recognizable words. Thus 1734 becomes ADD; 2051 becomes SKIP, and so forth. In high-level languages, *groups* of words are integrated into whole routines that can be executed by one command.

It is likely that some type of hierarchical integration is involved in relating mental processes to the brain. Sensory mechanisms transduce patterns of neural energy. Because sensory receptors such as the retina and the cochlea operate in an analog rather than a digital mode, the transduction is considerably more complex than the coding operations described above. Nonetheless, much of neurophysiological investigation is concerned with discovering the correspondence between the pattern of physical input and the pattern of neural response. As more complex inputs are considered, the issue becomes one of comparing the physically determined patterns with subjective experience (psychophysics) and recording the patterns of response of sensory stations in the brain.

Transcending Mental/Material Dualism

These comparisons have shown that a number of transformations occur between sensory receptor surfaces and the brain cortex. These transformations are expressed mathematically as transfer functions. When the transfer functions reflect identical patterns at the input and output of a sensory station, the patterns are considered to be geometrically isomorphic (*iso* means same; *morph* means form), that is, of the same form. When the transfer functions are linear (i.e., superposable and invertible, reversible), the patterns are considered to be secondarily or algebraically isomorphic (Shepard and Chipman 1970). Thus, as in the case of computer programming, levels of processing are recognized, each cascade in the level producing transformations that progressively alter the form of the pattern while maintaining intact some basic order, an informational structure.

Were these structures to be identified as mental, my formulation would be akin to those of Alfred North Whitehead (1925), Roger Sperry (1980), John Searle (1983), and Eugene Wigner (1969) —a form of mentalism or pan psychism. But, I am not willing to go that far. Rather, I prefer to hold the line by stating that informational structures transcend *both* the material and mental realities in which they become realized.

What remains is that holding the identity "position" with regard to the mind/brain issue, involves specifying what it is that remains identical. Unless something remains invariant, constant across all of the coding operations that convert English to binary machine code and back to English, my word processing procedures would not work. Identity implies reciprocal stepwise causation among structural levels. Contrary to the usually held philosophical position, identity does not necessarily mean geometrical or even algebraic isomorphism. *Transformations*, coding operations, occur that hierarchically relate levels of complexity with one another. A level is defined by the fact that its description, that is, its code, is in some non-trivial sense more efficient to use (i.e., requires less work, less expenditure of energy) than the code of the components that compose it. In the case of the word processor, the coding is arbitrary, and the arbitrariness is stored on a diskette and copy-righted. In the case of the mind/brain relationship, the nature of the coding operations is more universal and the efforts of two centuries of psychophysical, neuropsychological, and cognitive research have provided knowledge concerning at least some of the coding operations involved.

Transformations and constructions: Epistemological realism

How then are we to think about and address these transformations? Are the contents of our consciousness, our perceptions truly transformations leaving essential informational structures intact or are we betrayed and beguiled by our naive acceptance of a reality beyond our ken? More fundamental disagreement has plagued this issue than almost any other topic affecting the mind-brain relationship. At one extreme, is the common sense feeling that perception can be trusted to reliably inform the perceiver about the world in which he navigates —in philosophy this position is called naive or, when bolstered by evidence, direct realism (Gibson 1979, Shaw, Turvey and Mace 1982).

At the other extreme is the feeling that we can never "really" be sure of anything, including the validity of our perceptions —in philosophy this position is called solipsism or, when specified by evidence, autopoiesis. Autopoiesis is the view that our perceptual apparatus operates autonomously as a closed system (Maturana 1969, Varela 1979).

In between are compromise views and these also range from various materialisms (e.g., Bunge 1980) to phenomenalist, mentalist (e.g., Sperry 1980, Searle 1984) and constructional (e.g., Maxwell 1976, Pribram 1971) positions. A recent brief review of these issues is given by Epstein (1987).

As noted, when intelligent and deeply thoughtful scientists and scholars come to such disparate conclusions it is often fruitful to search for the specific data on which the conclusions are formed. When this is done, it can usually be shown that each "position" has intrinsic merit when limited to its data base but becomes untenable when extended beyond these limitations (Pribram 1986a). What remains is the view that brain processes undergo a dynamic matching procedure until there is a correspondence between the brain's microprocesses and those in the sensory input.

As will be shown, the sensory aspects of perception entail brain processes separable from those involving the cognitive aspects. Transformational realism fits the data that deal with sensory driven aspects of percepts; constructivism characterizes cognitively driven processes. Ordinarily, the cognitive operations (noumena) operate back onto those (phenomena) that are sensory driven: Kant (1965 edition) was not far off in his constructional realism.

Perception

An issue critical to realism surfaces immediately: How does the sensory array, the input to receptors, become processed? The difficulty arises in an attempt to specify how the input to the senses is related to receptor processing. In figural vision, the issue comes center stage when scientists try to specify the nature of a "retinal image."

Many difficulties are resolved by focusing on the single fact that everyone agrees to: when a diffracting object is placed in the front focal plane of the optical apparatus (pupil, and converging lens), a Fourier transform exactly describes the optical "image" at the back focal plane within the eye (e.g., Taylor 1978, p. 37). Thus, the optical apparatus (especially the lens) operates as a phase adjuster integrating interference patterns among wave [illegible]ms (due to diffraction) into an optical image. Taking this anchor of agreement as a starting point allows the concept of a retinal image to be separated into an "optical image" or "flow" and a "retinal process." From this beginning, clearcut differences can be readily identified in the organization of optic array, optical flow, and retinal process.

Next, consider the reasonable probability that retinal processes resonate to the patterns in the optical flow performing a harmonic analysis (see e.g., Hecht and Zajac 1974). This approach commits one to realism. But the commitment entails accepting the full implications of an ecological, "layered," approach to perception by including the layers of brain processes beyond the retina.

Shaw, Turvey, and Mace indicate the commonly assumed barriers to taking such a realist stance and the broad implications of overcoming them:

> What are the major conceptual barriers to a successful realism? ... [It is] the assumption ... [(a)] that the mapping of distal object properties onto proximal stimulus properties is destructive; [(b) that] the structuring of the light by the laws of reflection does not preserve the structure of the environment. On this assumed failure of the proximal stimulus to specify the distal object, it is a simple matter to generate skepticism about an animal's knowledge of what is real. Given the non-specificity assumption, perception must be a matter of making propositions (about what the proximal stimulus stands for) with neither a guarantee of their truth nor any apparent way to determine their truth.
>
> A second related barrier to realism is raised by the mind-body subtheme of animal-environment dualism. It is the promotion of ... two different and irreducible languages. ... skepticism arises about the animal's ability to perceive what is real, because the perception of reality depends on ...the physical and the mental being coordinated. It has seemed in the past a relatively trivial matter to show slippage between the object of reference and the object of experience.
>
> Animal-environment dualism thwarts realism in another, though more subtle, way: It invites a science of psychology largely separate from a science of physics and vice versa ...Realism is hamstrung to the extent that the sciences hold distinct the knower and that which is known.
>
> Consider, however, a program of theory and research committed to realism. ... Such a program would have to seek a definition of reality that would be animal-relative, but no less real for being so. (Shaw, Turvey, Mace 1982: 160-161).

Taking the stance implied by realism ("a program of theory and research committed to realism") is akin to an act of faith: The initial sensory experiences of infants are disparate; even as adults, introspection yields perceptions differing in kind according to the sense involved. When we identify what we hear, see, and touch as referring to the "same" event, we resort to consensual validation. In humans this procedure is repeated when we identify "a red winged black bird," as the "same" object with the "same" attributes referred to by someone else. One makes a pragmatic existential choice early on, either to distrust the process of consensual validation and retreat into solipsism, or to trust and embrace a realist philosophy, and act accordingly.

However, to act simply on the proposition that perception is "direct" skips over several steps in the perceptual process that cannot be ignored. One must confront the fact that the senses are stimulated by patterns of energy perceived as "light," "sound," and "touch" which do not have the same configurations as do the objects with which the patterns of energy interface. This, however, does not mean that these configurations are composed of elements. Rather, a different process is at work: The configurations that define objects become distributed and enfolded in the process of interfacing. They are thus *transformed* into an order which, as in a hologram, is recognizably different from the perceived configuration of objects but which, in some non-trivial sense, "contains" those configurations (Pribram 1991b).

Computation and Representation

Given the transformational aspect of the realist stance, the next issue that needs to be discussed concerns the nature of cognitive influences on percepts. This topic is best addressed under the heading "representations." Representation literally implies hierarchical levels of processing in which what is processed becomes "re-presented" at another level. A level or *scale* of processing can be defined as a presentation, a description of an *entity* that is simpler than if it were made in terms of the collection of constituents of that scale or level. Thus, the entity at each level can be characterized by a description that is a presentation. Components are described in some different fashion than the entity as a whole. Furthermore, there would be no need for a presentation of the entity as a whole were it not, in some basic sense, simpler, that is, more efficient in processing than that available to the components. As noted, bytes are more efficient in use than the equivalent description in bits. A presentation of a program in Fortran is much more efficient than a presentation of the successive switch settings that form the hardware equivalent of the program. The question is whether psychological processes can, in the same manner, be considered to be re-presentations of functions of the brain.

In the sense of hierarchical levels of presentation, the analogy between computer software (programs) and hardware which was detailed earlier serves well. The psychological, mental level is described in presentations that are analogous to presentations at the program level. The "wetware" of the brain can be thought of as analogous to the hardware of the computer (Miller, Galanter, and Pribram 1960, Pribram 1986a). There is an equivalence between program and successive hardware switch settings. Can we say therefore that in some real sense the switch settings are re-presented in the program? If this is so, then in the same sense psychological processes re-present brain function.

This leads to a most tantalizing question: To what extent are the re-presented entities configured in a fashion similar to the entities they re-present? In other words, to what extent are presentation and re-presentation isomorphic to one another? The answer to this question obviously depends on reaching some consensus on the definition of isomorphic. Processes that map into each other in such a way as to preserve structure can be said to be either geometrically or algebraically isomorphic. For instance, although the Gestalt psychologists thought that the electrical fields of the brain have a geometric *shape* resembling that of perceived objects, evidence shows that perspective transformations display algebraic (i.e., secondary) not geometric isomorphism (Shepard and Chipman 1970).

Isomorphism is a non-trivial problem when one assesses the nature of brain representations. Wolfgang Kohler (1964) attempted to show that the geometry of cortical electrical activity conforms not only to the geometry of the physical events that produce sensory stimulation but to the perceptions experienced by the organism. This line of reasoning suggested that brain representations literally "picture" the significant environment of the organism or at least caricature it. Experiments by Lashley (Lashley, Chow, and Semmes 1951), Sperry (Sperry, Miner, and Meyers 1955) and Pribram (reviewed in 1971) created a severe disturbance of the geometry of cortical electrical activity without disrupting behavior dependent on perception. Thus, geometric isomorphism between the gross aspects of brain electrical activity and perception has been ruled out.

By contrast, the computer program-hardware analogy suggests that significant *transformations* can occur between levels of presentation: indeed that the utility of re-presentations is derived from these transformations. Linear algebraically isomorphic (i.e., isoformal), nonlinear or paralinear transformational processing characterizes the relations among brain representations (see Pribram 1990a, 1991 for detailed review). The computer analogy has thus helped make understandable the results of neuropsychological research which showed that the search for "pictures" in the brain (e.g., Kohler's D.C. potentials, Kohler and Held 1949) was misplaced. Understanding comes when the neurophysiologist searches for algorithms, such as computable transforms of sensory input.

In the same vein, Gibson (1966), and Shaw, Turvey, and Mace (1982), among others, have proposed that as the organism becomes attuned to its environment, the relationship between the two is one of "complementation," not representation. Thus, musical instruments "complement" the fingers of the hand, yet piano keyboards, violin strings, and clarinet stops have completely different configurations. Complements share common procedures, common functions, and there has been considerable debate (see Vol. 3, Nº 1, 1980 of the Behavioral and Brain Sciences, especially Fodor, pp. 63-110) as to whether the modeling of psychological processes should be complementary and functional (computational and procedural) or structural (representational).

When this formalism is defined in terms of *transformational* procedures that specify the relationships among complements —presentations— and between re-presentations of these presentations, the re-presentational nature of levels of computations becomes evident. For instance, neuroscientists talk of the "representation" of the spatial ordering of receptors and effectors in the ordering of cortical inputs and outputs —this, despite considerable distortion.

Furthermore, there is good evidence from the work of Sokolov (1963) that brain events "model" sensory input patterns. When a sensory input recurs repeatedly, an organism habituates, that is, fails to react overtly to that input. Sokolov found that when he omitted a stimulus in a regularly recurring series, the organism dishabituates; an orienting reaction occurs. Similarly, if suddenly a signal of reduced intensity is presented within a series of signals of greater intensity, an orienting reaction marks the reduced signal. There must be some enduring brain process that is produced by an input if subsequent variations of that input are "sensed" (although this does not mean that the geometries of input and brain process are isomorphic). Reducing or omitting a signal produces a mismatch, which results in an orienting reaction. During habituation, a "neuronal model," a "representation" of the input appears to be constructed and subsequent inputs are matched to this representation (reviewed by Pribram 1971).

Still, the representation need not be an immutable structure. Rather, re-presentation must be a process, the re-construction of a presentation. (For a sophisticated analysis of what is involved, see Hochberg 1984.) The issue can perhaps be grasped most readily by focusing on memory. Is memory structural in the sense that one may find in the brain an isomorphic form or figure corresponding to a subjectively remembered experience, or is such a "memory" the result of processing neural events stored in some other form? By using primes and probes, Fergus Craik, in an elegant program of experiments (Craik 1989), has shown that disturbances in remembering are almost always due to interference with process and not with a loss of stored items. Neuropsychological evidence (e.g., Pribram 1986b, Weiskrantz 1986) has also repeatedly demonstrated that "engrams" are not "lost" as such as a result of brain damage. Rather engrams are re-constructions that can appear as intrusion errors when amnesics are examined in a systematic fashion: that is, during recall, reconstruction of an engram occurs but in an inappropriate context.

Thus the "deep structure" of memory (in Chomsky's 1965 sense, which distinguishes deep from surface structure) is distributed, as in current image processing and PDP neural network computational models; this distributed, dismembered store must be re-membered, assembled into an experienced "memory" by a content-addressable process. The process can be triggered internally or from a sensory input. In short, re-membering is a process that depends on *transforming* a deep structure, a dismembered re-presentation, and thus of a form different from either the experienced memory or the sensory array that originated the process.

Formally, the re-presentation occurs as a dynamical transformation. Smolensky captures the essence of this formalism as follows:

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

It is these dynamical transformations, these *transfer functions* that critically distinguish current theories from earlier formalisms such as those of General Systems Theory (see Pribram 1990a, 1991b).

Thus, "representations" are shown to be not pictorial forms, but as self-maintaining structures that act somewhat like the setpoints of thermostats. These setpoints serve as "attractors" in more or less temporary stable configurations which are subject to continuous adaptive change. Physiology is replete with examples of self-maintaining structures: the skin remains "the same" despite constantly shedding cells which are replaced with new ones; red blood cells last only a month, yet the red blood cell count remains stable. You as a person, a structure, are recognizable over the years despite the fact thay every cell in your skin, hair, and so forth has probably been repeatedly exchanged during the period of observation. Certainly, every molecule in your body has been exchanged several times. This self-maintenance of structure is often called self-organization, autopoiesis (Maturana 1969, Varela 1979) because the organizing propensity generates the organization since it is genetically specified.

According to this view, structure (representation) and process (computation) are distinguished more by the *scale of observation* (not the scale of re-presentations) than by any intrinsic difference. At the seashore, breakers are processes; they exert considerable force, can move objects, and upset bodies. When viewed from 10,000 feet, these same breakers appear as standing waves, a structure that delimits and represents the boundary between open sea and land.

In Summary

A *transformational* and *constructional* realism thus goes beyond direct realism by specifying the ecological details of the sensory and brain processes involved in perceiving. Specification devolves on recognizing *transformations* that occur between processing levels among brain systems. *Top-down* as well as *bottom-up* influences provide structural constraints on the processes.

Ontological monism

The fundamental assumption that has given rise to the mind/brain problem is that mental phenomena and the material universe are in some essential fashion different from each other. As we have seen, in the ordinary domain of appearances, at the Euclidean-Newtonian level of analysis, this view is certainly tenable. But at the levels of the macro- and microphysical universes dualism becomes awkward. Niels Bohr's complementarity and Werner Heisenberg's indeterminacy principles emphasize the importance of the observer in any understanding of what presumably is observed (Bohr 1966, Heisenberg 1959). As noted, Eugene P. Wigner (1969) stated the issue succinctly: Modern microphysics and macrophysics no longer deal with relations among observables but only with relations among observations.

An objection can be entered that such difficulties of distinguishing observables from observations encountered today by physicists are temporary, superficial, and of no concern to philosophers interested in eternal verities. But that is not the message these thoughtful pioneers 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 I proceed, I shall tender some explanations that may help account for their views.

Energy and Entropy (Informational Structure) as the Neutral Potential

Heisenberg (1959) developed a matrix approach to understanding the organization of observations at the microphysical level. Currently, this approach is used in s-matrix, bootstrap theories of quantum and nuclear physics by Henry Stapp (1965) and Geoffrey Chew (1966). These investigators (among others, i.e., Dirac 1951) have pointed out that measures of energy (change) and momentum (inertia) are related to measures of location in time and space by way of a Fourier transform. The Fourier theorem states that any pattern of organization can be analyzed into, and represented by, a series of regular waveforms of different amplitudes and frequencies. These regular waveforms can in turn be superimposed, convolved, with one another and, by way of the inverse Fourier procedure, can be retransformed to obtain correlations in the original space-time configuration. Thus, the Fourier transform of a set of space-time patterns displays a spectral organization that is, of course, different from that which is displayed after the inverse Fourier transform has again converted the pattern into the space-time order.

In terms of the proposition put forward by Dirac, Stapp, and Chew, this means that the organization of energy and momentum is considerably different from the space-time organization of our ordinary perceptions that can be expressed in Euclidean, Cartesian, and Newtonian terms. David Bohm (1971, 1973, 1976) has identified these nonclassical organizations of energy and momentum as "implicate", that is, enfolded, and has used the hologram as an example of such enfolded orders. Dennis Gabor (1946, 1948), the inventor of the hologram, based his discovery on the fact that one can store interference patterns of waveforms produced by the reflection or refraction of light from an object on a photographic film and reconstruct from such a film the image of the object. The description of the enfolded organization stored for reconstruction is related to the unfolded space-time description of the object by a Fourier transform.

Some Neuroscience

The Fourier theorem has also played an important role in the recent discoveries in the brain sciences. In the late 1960's, several groups of investigators found that they could explain their findings in visual research when they realized that their results indicated that encoding of spatial patterns in the visual system involved what they called *spatial frequency*. This term describes the domain that results when spatial constraints limit the spectral frequency domain resulting from the application of a global Fourier transform. Fergus Campbell and John Robson (1968) of Cambridge University initiated the series of discoveries by observing unexpected regularities in their psychophysical data. Responses to gratings of different widths and spacings adapted not only to the particular grating shown but also to the harmonics of this grating. The spectral frequency is determined by the width of the bars that make up the grating and their spacings. Physicists use the term *wave number* to denote spectral frequency.

Physiologically, however, the receptive field properties of visual neurons are spatially constrained. In the late 1950s and early 1960s, David Hubel and Thorsten Wiesel (1959, 1968) had discovered that single cells in the visual cortex responded best when the visual system was stimulated with lines at a certain orientation. In the early and mid 1970s, Daniel Pollen and his colleagues (Pollen, Lee, and Taylor 1971, Pollen and Taylor 1974) noted that when such lines were drifted across the visual field, the response of the cell was not uniform but described a waveform similar to that which described the gratings used by Fergus Campbell. Campbell (1974) meanwhile showed that the responses of single cells in the visual cortex also adapted to the harmonics of the gratings that were presented, much as did the organism as a whole. Finally, Russell and Karen DeValois and their collaborators (DeValois, Albrecht, and Thorell 1978a, 1978b, DeValois and DeValois 1980, DeValois, DeValois, and Yung 1979) demonstrated that the response of these visual cortical cells is only poorly described by the orientation of a line, whereas it is accurately described in terms of the orientation and spatial frequency of a grating, that is, the cell is tuned to a spatial frequency range of approximately one-half to one octave. Furthermore, these investigators showed that when checkerboards and plaids were used to stimulate the visual system, the cells responded maximally to the Fourier transform of the space-time patterns, as determined by computer display, and that the cells were essentially unresponsive to the orientation of the individual lines that composed the checkerboards and plaids. In short, it appears that the cells composing the visual system perform a spatially constrained Fourier transform on the optical image produced by the lens of the eye.

What this means is that the optical image is decomposed into its Fourier components: regular waveforms of different frequencies and amplitudes. Cells in the visual system respond to one or another of these components and thus, in aggregate, comprise an optical image processing filter or resonator. Such a resonator has characteristics somewhat similar to the photographic filter comprising a hologram, from which images can be reconstructed by implementing the inverse transform.

There are, however, important differences between ordinary photographic holograms and the visual nervous system. Ordinary holograms are composed by a global Fourier transform that distributes the information contained in a space-time image throughout the transform domain. In the visual nervous system, distribution is limited anatomically to the input channeled to a particular cortical cell. Fortunately, holographic techniques that use similar "patch" or multiplex constructions have been developed. Bracewell (1965) at Stanford University pioneered these techniques in radioastronomy by stripping together the holographic transformations of limited sectors of the heavens as viewed by radiotelescope. When the inverse transform is applied, space-time images of the whole composite can be viewed in three dimensions.

Furthermore, the transform that best described the process in the visual system is a Gabor, not a Fourier. The Gabor transform (Gabor 1946, 1948, Daugman 1985, Marcelja 1980) is formed by placing a Gaussian envelope on the otherwise unlimited Fourier transform. This is another way of stating that the transformation is not global, and it gives important mathematical precision to the limits involved: Gabor, working on the efficiency with which communication could proceed, showed that efficiency entailed indeterminacy much as in Heisenberg's formulation of quantum physics. As Gabor was using Heisenberg's mathematics (a Hilbert phase space in which spectral frequency was constrained by time), the transform was called by Gabor a "quantum of information."

Finally, the arrangement of the visual channels and the cortical cells is not haphazard with regard to one another. A clear retinotopic to cortical spatial arrangement is maintained. Thus, the gross grain of the visual filter determines space-time coordinates, whereas its fine grain describes the Fourier components.

What advantage is gained by this fine-grain quantum and holographic-like organization? Recall that using the transform domain correlations among patterns are readily performed. This is why the Fast Fourier Transform (FFT) as performed by computer is such a powerful tool in statistical analysis and in computerized tomography (CT scans). The brain is an excellent correlator by virtue of its fine-grain processing potential.

The dual properties of an enfolded fine-grain (technically, the receptive field organization) and a gross-grain space-time organization applies to other sense modalities as well, although the experimental evidence is not as complete. Georg von Bekesy (1967) performed critical studies in the auditory and somasthetic modalities, Walter Freeman (1960) conducted studies in the olfactory, and Pribram, Sharafat, and Beekman (1984) have shown that cells in the sensorimotor cortex are tuned to specific frequencies of movement. At the same time, in all these sensory systems the spatial organization of the receptor surface is topographically represented in the gross-grain arrangement of the cortical cells that receive the sensory input.

In summary, there is good evidence that another class of orders lies behind ordinary perceptions. This other class of orders is constituted of fine-grain organizations that describe potentials in terms of energy and momentum (moment) that had been poorly understood because of the radical changes in form that occur in the transformational process of realization. When a potential is realized, information becomes unfolded into its ordinary space-time appearance; in the other direction, the transformation enfolds and distributes quanta of information as this is done by the holographic process. Because work is involved in transforming, descriptions in terms of energy and momentum are suitable, and as the structure of information is what is transformed, descriptions in terms of entropy (and negentropy) are also suitable. Thus, on the one hand, there are enfolded orders manifested as potential energy and momentum; on the other, there are unfolded orders manifested in negentropic space-time.

Is Information Material or Mental?

Furthermore, when forces are postulated to exist between material bodies, the forces are often 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 commonly assumed to be "material." But this is a misreading of the equal sign. The equal sign does not indicate sameness but only *potential* sameness: for instance, $2 + 2 = 4$ and $2 \times 2 = 4$. If the equal sign indicated sameness, "×" and "+" would be the same under all circumstances, but they are not: $2 + 2 = 2 \times 2$ because they are equal though different. This is a point I have had to make repeatedly when I present evidence that men and women are biologically and psychologically different. I am *not* arguing, therefore, that they are unequal.

Energy is not material, only transformable into matter. It is physical in the sense that physicists measure it 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 have shown that properly configured 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 (see, e.g., Brillouin 1962, von Weizsacker 1974). 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 material, what then of the information in a book? Or the entropy that describes the efficiency with which a heat engine operates or a warm-blooded mammal solves a problem? Clearly, we have come to the limit of usefulness of a distinction between the material and the mental.

A New Duality: The World of Appearances Versus the World of Potentiality

The fact that in the spectral domain space and time are enfolded means that only the density of occurrences is manifest. These densities can be recorded as wave number or in scattering matrices representing *n*-dimensional (Hilbert) domains such as have been used in quantum physics. Holography and its offspring, parallel distributed processing (PDP) neural network computation, have become windows through which we are able to conceptualize a universe totally different from that which characterizes the world of appearances. This universe of orders has become transparent to us most readily in quantum field theory, communication theory, and sensory physiology (Pribram 1971). David Bohm (1971, 1973) pointed out that most of our conceptions of the physical world depend on what we can observe through lenses. Lenses focus, objectify, and draw boundaries between parts. Lenses particularize. Holograms quantum fields and PDP networks, by contrast, are distributive, relatively unbounded, and holistic. Bohm referred to our lens-given ordinary perceptions and conceptions as explicate and those that are holographic-like as implicate. Thus, there are at least two classes of discernible orders in the universe: explicate and implicate. Explicate orders give their accounts in terms of particles, objects, and images. Implicate orders, still poorly cognized, begin with paths of changes in distribution densities of occurrences.

Bohm and other physicists have become excited by the similarity of conceptualizations of the implicate orders and those described by mystics who have experienced a variety of religious and other "paranormal" phenomena (Bohm 1976, Capra 1975). The lack of spatial and temporal boundaries, the holographic characteristic that the whole becomes distributed but retrievable from any portion (i.e., the transformational relationship between explicate and implicate orders) 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 no accident that holograms were a mathematical invention (by Dennis Gabor) that used a form of mathematics, the integral calculus, invented by Gottfried Wilhelm Leibniz, who also came to a vision of an implicate order. Leibniz's monadology (1714/1951) 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.

The fact that the brain is, among other things, a spectral analyzer, that it encodes quanta of information (i.e., Gabor transforms) in a distributed fashion akin to that which characterizes the quantum world of microphysics and a spatially constrained hologram, also means that the structural boundaries that characterize the ordinary limits of "brain" and "body" can, on occasion, appear to be transcended. The "mystery" of mind is resolved not by overgeneralizing a dualist view, nor by adhering to either the materialist or the mentalist stance. Rather, the transformational and potential nature of implicate domains must be recognized and the fact that our sense organs "make sense" by tuning in (and out) selective portions of this domain, much as we tune in or out the various radio and television broadcasts (broadly cast) which are distributed and enfolded in our immediate environment.

Summary

In concluding, I will attempt to summarize my position as developed in this essay. I began by accepting the reality of a dualistic view of everyday experience: We humans can distinguish clearly between the process of experiencing and the contents of that experience. In the centuries since Descartes, this led to the view that the process of experiencing is mental whereas the components of 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 level and at the macrophysical cosmic level, have called into question the immutable basis of matter. Depending on one's observations, one's measuring apparatus, matter is viewed as particulate or as waveforms constituted of energy. I am not questioning the premise that both matter and energy are physical, i.e., measured by physicists' instruments. Nonetheless, it becomes necessary to view the material nature of matter as limited to the ordinary world of experience (characterized by Euclidean geometry and Newtonian mechanics), unless one wants to adopt the bias that energy is material because 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, as yet, we do not know how to properly characterize a variety of 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 material systems. The configurations that energy systems display rather than their raw amount are shown to be critical. Furthermore, some immutable ideal, an informational structure, remains invariant across changes in form —across transformations. Are such ideal structures to be conceived as material when they involve languages, cultures, and so on? 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 materialist view held by most scientists is derived from looking downward at the contents of 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.

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 enquiry, not separation into parts causally related to one another as in the reductive sciences. Thus, the language of phenomenology, existentialism, and structuralism is "mental" because 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. But dualism has its problems. It is too easy —and too often done implicitly— to reify the mental as if it were a material of sorts. Thus, I propose that dualism, despite its utility, needs to be transcended. This can readily be accomplished by carefully combining the techniques and results of both the reductive and the phenomenal approaches to enquiry. Informational structure comes to be the central, enduring, single quality that characterizes the result. 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, however, it has to face the issue noted earlier: the primacy and independent existence of mind. By showing that dualism stems from procedural considerations, and trascending it with a realist structural monism, the very spirit of what dualists and mentalists believe in and are trying to articulate is violated: the unique character of mental processes and their contents tends to be ignored.

My final proposal meets the requirement of this aspect of dualism. First, informational structure is demonstrated to be a Platonic ideal that remains invariant across the variety of (coding) transformations. Second, brain physiologists have shown the nervous system to be, among other things, a quantum-like spectral analyzer. Sensory input apparently becomes distributed and stored in the transform domain in the manner of a quantum-like order which also characterizes the microstructure of the physical world. In this domain, space and time become enfolded; only density of occurrence is represented.

Description 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 experiences. I propose, therefore, that the duality between the normal, everyday domain of appearances and the transform domain captures the concerns of mentalists and dualists and begins to account in a specific and precise mathematical fashion for what hitherto has been incomprehensible.

Structural realism is thus primarily a neutral monism that deals with a number of dualities of which two are especially significant for unpacking the issues involved in a mind/brain dualism: (a) a procedural duality that faces upward and downward in the hierarchy of systems discerned in the ordinary world of appearances and (b) a transformational duality that apposes the ordinary world of appearances to that viewed through the window of a quantum-like spectral domain characterized by descriptions akin to those of experiences of mystics.

An ontological neutral monism from which an epistemological plurality becomes constructed 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.

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