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Science and the Mind/Brain Issue

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Introduction

Grover Maxwell, philosopher, was a student and esteemed colleague of Herbert Feigel, one of the founders of the Vienna Circle, so influential in shaping the positivist and operational approach to philosophical and scientific problems during the twentieth century. My respect for this tradition and for Maxwell's dedicated probings into territory which lay beyond the limitations this tradition imposed, made me deeply appreciate his references to my work. He treated evidence in neurophysiology and neuropsychology as seminal to the development of his position on mind/brain issues. My appreciation was enhanced by the fact that on several occasions I have been told by other philosophers that whatever scientists accomplish in the laboratory, it will have no bearing on the problem of the relationship between mind and brain: The mind/brain problem is a logical one and data are irrelevant, they say. Since my research career is devoted to collecting data which I believe relevant, I find such statements disconcerting. My hope is that such data will resolve the issue of mentalism in psychology, much as the synthesis of the organic compound urea from its inorganic constituents has resolved the issue of vitalism in biology.

This hope has been shared by those who have followed closely the operational approach which resulted in classical behaviorism. Elsewhere (Miller, Galanter and Pribram 1960, Pribram 1962, 1965, 1970, 1971, 1973, 1976a, 1976b, 1978a, 1978b, 1980, 1981a, 1981b), I have reviewed not only the harvest of data, but also the reasons why the solutions proposed by classical and radical behaviorists have failed.

This failure is due to the attempt to dismiss for scientific analysis, the subjective reports of experience rather than to integrate these reports with other aspects of behavior. The failure became especially pronounced major philosophical approaches which has been proposed. At the same time meeting the criticisms which have been levied against each of them are met. After all, despite these negative assaults, each approach, as well as several modifications and amalgams, have shown remarkable staying power. This makes one wonder whether perhaps each approach has some real merit, has captured part of the truth, but that it becomes flawed when it tries to encompass the entire spectrum of problems which composes the mind/brain relationship.

It is the fact that the mind/brain relationship involves a spectrum of problems which is the keystone of the current essay. As noted, scientists go about their business by breaking down globally conceived issues into more tractable problems. As more and more of the part solutions come into focus, the larger issue itself becomes resolved provided the part-solutions are reflected back to the issue which spawned the research in the first place. The danger of the scientific approach is that it may result in an extreme reductionism or, alternatively, in instrumentalism. Reduction, as has so often been said, leads the scientist to learn more and more about less and less in order to secure a limited certainty based on technical competence. Instrumentalism leads him to eschew any search for validity in theoretical construction, and to a failure to reflect the results of his observations and experiments onto the frame of reference (often held implicitly) which generated those observations and experiments in the first place.

But reductionism and instrumentalism are not *necessary* consequences of the scientific approach. As so clearly developed by Grover Maxwell (1976), to whom this essay is dedicated, a constructional realism is not only philosophically tenable but is 'the way of life' of most scientists. Scientists test conjectures and hypotheses, based on observation and experiment, and subject to refutation by further observation and experiment. Karl Popper (1968) has rightly pointed out that much of scientific procedure is based on such 'conjecture and refutation.' What he failed to emphasize is that this procedure leads to the construction of ever more comprehensive views of what we interpret as reality. Maxwell and I shared the judgement that the constructive aspects of scientific procedure ought not to be ignored.

William James (1931), discussing the relationship between scientific work and philosophical inquiry stated the issue as follows:

> When Clerk-Maxwell was a child it is written that he had a mania for having everything explained to him, and that when people put him off with vague verbal accounts of any phenomenon he would interrupt them impatiently by saying, 'Yes; but I want you to tell me the *particular* go of it!' Had his question been about truth, only a pragmatist could have told him the particular go of it....Truths emerge from facts; but they dip forward into facts again and add to them; which facts again create or reveal new truth....and so on indefinitely. The facts themselves meanwhile are not *true*. They simply *are*. Truth is the function of the beliefs that start and terminate among them (pp. 197, 225).

By contrast, a purely philosophical approach relies largely on conceptual analysis as expressed in language. And as Quine (1960) and others have pointed out, linguistic expressions rarely convey identical meanings to different audiences. A case in point is the meaning of mind in various European languages.

In all languages, most approaches to the mind/brain relationship treat a single unity "mind" as different from a single unity "brain". But of course we now know that the brain is composed of different systems: Some of these systems are in fairly direct connection with the sense organs and striped muscles of the body, and are thus fitted to carry out extrinsic, extensional, extrapersonal aspects of relationships between the organism and its environment. Other systems are characterized by their chemical specificities and connections with visceral and endocrine structures which makes them ideally suited to the more intensional aspects of mental processes. Still other brain systems feature intrinsic connections among brain systems without any direct connections with more peripheral body structures. The results of clinical observation and of experiment have shown those systems to be involved with a variety of cognitive processes.

The concept "mind" also is composed of a variety of attentional (i.e., current), memory (retrospective), and intentional (prospective) processes. In English the concept is derived from "minding," as Gilbert Ryle has pointed out, and originates from the Teutonic "mynden," a root common to both mind and memory. But in some continental languages the meaning of "mind" is more ambiguous. The French "esprit" and the German "Geist" are closer in meaning to the English "spirit" than to mind. By spirit is meant the relationship of mental processes to more cosmic orderings, which include the human social order. The German "Geisteswissenschaft" has therefore been translated as "social science." Thus in the very languages which have been the most influential in shaping our approach to the mind/brain issue, the distinction between mind and spirit is not self evident, while in English, discussions of the relationship between brain and mind rarely focus on social or cosmic issues. No wonder there has been occasion for confusion.

I shall adhere here to the English distinction between mind and spirit, and discuss the major approaches that have been taken to the mind/brain relationship. In each case I shall attempt to show the range of data to which the particular approach applies. As will become evident, identity, duality, plurality, and even monism have their place in a comprehensive theory regarding mind/brain relationships.

Hierarchy, Reciprocal Causation, and Mind/Brain Identity

The computer and its programs have provided 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 (codes) and high-level programs (software). 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. On the other hand, high-level languages such as Fortran, Algol and Pascal are more universal in their application, and there is less obvious similarity between their implicit logic and the logic of machines. At the highest level, languages such as English, with which I am addressing my computer in order to use it as a word processor, the relation between its logos (word, concept, logic) and that of the machine is still more remote. However, English relates me to a sizable chunk of the human social order.

Understanding how computer programs are composed helps to tease apart some of the issues involved in the "identity" approach espoused by Grover Maxwell in dealing with 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 which remains invariant across transformations. The terms "information" (in the brain and cognitive sciences) and "structure" (in linguistics and in music) are the 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 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), the structure (arrangement) is recognizable in many realizations. The materials which make the realizations possible differ considerably from each other, but these differences are not part of the essential property of the music form. In this sense, the identity approach to the mind/brain relationship, despite its realism, partakes of Platonic universals, i.e., ideal orderings which are liable to becoming flawed in their realization.

In the construction of computer languages 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 which maintains a constant environment, reciprocal causation was 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.

Equally important, programming allows an analysis to be made into the evolution of linguistic tools which relate the various levels of programming languages. Digital computers with binary logic require a low-level language (coded in the numerals 0 or 1) which 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 8 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; 2081 becomes SKIP and so forth. In high-level languages, *groups* of words are integrated into whole routines which 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 physical energy into 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.

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-same; morph-form), i.e., 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. Thus, as in the case of computer programming, levels of processing are recognized, each cascade in the level producing transformations which progressively alter the form of the pattern while maintaining intact some basic order, information and structure.

In short, holding the identity "position" with regard to the mind/brain issue involves specifying what it is that remains identical. Unless something remains constant across all of the coding operations which 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 iso-morphism. Trans-formations, coding operations, occur which hierarchically relate levels of complexity with one another. A level is defined by the fact that its description, i.e., its code, is in some non-trivial sense more efficient (i.e., requires less work, less expenditure of energy) than use of the code of the components which compose it. In the case of the word processor the coding is arbitrary, and the arbitrariness is stored on a diskette and copyrighted. In the case of the mind/brain relationship the nature of the coding operations is more universal and the efforts of a century and a half of psychophysical, neuropsychological and cognitive research have provided knowledge concerning at least some of the coding operations involved.

Nominalizations, Propositions and Mind/Brain Dualism

In the beginning was the word, but the word was put to peculiarly human uses only when propositional utterances became the currency of communication. The great apes are clearly able (see reviews by Pribram, 1971;

Rumbaugh, 1980) to make signs and symbols which stand for concepts (logos = word, concept). Apes can string several such signs together and arrange symbols hierarchically. They also occasionally make propositions, but this mode of communication is severely restricted when compared to human children of the same age (and using the same modality of communication, i.e., Ameslan, American Sign Language; Bellugi & Klima, 1972).

A proposition uses words as nouns and predicates, and is made up of a subject, verb, and object. It is as natural for humans to make propositions as for rose bushes to grow thorns. Propositions grow from holophrases which symbolize existing situations, both external and internal. Also natural is the tendency for the holophrases to become nominalized, i.e., to make objects of the situations symbolized. Thus a symbol, which originally referred to a process, tends later to refer to an object. The Hebrew term "Yaweh" demonstrates such an evolution: initially the word stood for "being," then a being who finally became the all encompassing being, God. More currently, physiologists discover a function of a gland, such as the pituitary, by injecting it into animals. This function is first named but the name quickly becomes reified, and biochemists go to work to find the "substance" which has been named. And, of course, they are often successful. Nuclear physics proceeds in a similar fashion, although only traces of the named "particles" are discovered.

Because nominalization objectifies the holophrastic utterance, its process aspect is either lost (as in Yaweh), or process becomes symbolized by another word, a predicate. It is then but a step to a true proposition which portrays the process more fully: a subject acting on an object. The human disposition to dichotomize subject and object is, I believe, the primordium which, when applied to the mind/brain issue, gives rise to dualism.

Philosophers and thinkers, especially Brentano, von Uexkill, and Hegel, have emphasized this relationship between human linguistic capability which derives from reflective awareness, and human "intentionality." As noted, however, some confusion has arisen because the German language in which these philosophers worked does not clearly distinguish between mind and spirit. Thus, when translated into English, spiritual overtones creep in where none are intended in the German original.

As Brentano (1874) clearly stated, humans can tell the difference between that which is observed and the observer who is making the observation: i.e., between object and subject. This duality is enhanced by the fact that, when the subject is an introspector, his introspections are private until and unless made public by way of verbal or instrumental behavior. The privacy issue is emphasized by those holding the dualistic "position" to the extent that these philosophers claim for privacy a uniqueness which is unparalleled anywhere else in the search for knowledge. As a behavioral scientist, I cannot support this claim. I see little difference in kind between the work involved in breaching the privacy of the atom and breaching the privacy of a fellow human being. Both are fraught with uncertainty and incompleteness.

A related and, for me a more cogent issue, is the primacy of phenomenal experience. All I know is what I have experienced. But again, primacy extends to all knowledge and is thus not limited to problems in the behavioral and brain sciences. Nonetheless, because of primacy, my private experience is somehow special and at the level of the ordinary sensory world as described in Euclidian, Cartesian and Newtonian concepts, I find mind/brain dualism to be useful.

Take for example the computer metaphor discussed above. There is certainly a non-trivial difference between computer hardware and program software. The hardware is material; the software, as noted, is composed of codes which maintain some structural identity of information which is independent of any specific material realization. A similar situation describes the brain/mind duality: the wetware of the brain is material; mental processes are composed of codes which maintain some structural identity of information, which is independent of any specific material realization. This property of mind to maintain constancies across transformations is, I believe, responsible for reification, the natural tendency to objectify as mind, what are initially experienced as mental processes.

This analysis makes clear once again the reciprocal causation which obtains in hierarchically organized biological systems. The functions of certain brain systems (those which when they malfunction produce the syndrome of "neglect") are responsible for, causally determine reflective consciousness, intentionality. At the same time, the behavior generated under the control of reflective consciousness, determines, causes inputs to be provided to the very brain systems upon which reflective consciousness depends.

Process, Predication, and Mind/Brain Interactions

Recently Popper and Eccles (1977) and Sperry (1969, 1976) have addressed the problem of modes of interaction between mental process and brain. All possible combinations of interaction have been suggested. Popper has even added a "third world" of culture as a medium for interaction. Essentially, the possibilities are: (1) that mental process are engendered by the brain (a view held by most brain and behavioral scientists and by Popper); (2) that some encompassing order in the universe organizes brain processes and is thus responsible for the spiritual nature of man (a view held by Eastern philosophers and many Western philosophers of an existential and/or phenomenalistic persuasion); (3) that interaction is a two-way street with the street remaining unspecified (Sperry) or specified as culture (Popper).

Behavioral scientists understand that mental processes are inferred from observations of the behavior of organisms, as well as from introspection. And behavior is organized by both the organism (for complex behaviors, especially his brain) and his environment. Organisms learn from their environment and act on their environment from memory (both genetic and experiential). Behavioral scientists are therefore supportive of two-way mind/brain interaction almost by definition. And as noted, reciprocal causation, the feedback process, is the commonplace of hierarchically organized biological processes. What is at issue for biologists are the mechanisms whereby the interactions can occur. Philosophers, on the other hand, worry that interaction implies something fundamental and unbridgeable between the interacting parts: mental and material. As we have seen, coding operations, informational structures, provide the bridge and thus blur the distinction between interaction and identity.

Human natural language is the mediator between introspection and observed behavior. A child experiences a flying object. His mother names the object a bird. Later other flying objects are experienced and mother explains that these are airplanes, and helps make the distinction between the experiences of bird and plane. (In my family the course of distinguishing went in this direction only for the earlier children. Later children first learned what planes were and then became aware of birds.) Naming has coordinated the introspections of the child with those of his mother—and through this coordination he can share his introspection with that part of the human community which speaks the same language. Sharing is interactive.

Cognitive Commodities and Instrumental Dualism

Sharing is also accomplished by other language-like human communicative activities. Mathematics, music, rituals and similar "cognitive commodities" (Pribram, 1983) are the instruments which make possible the interactions among human minds and therefore, via sensory input, among human brains. What is special about the mind/brain relationship is the primacy of experience, and the fantastic generative organizing capability of the human brain. It is these characteristics which give the dualistic approach and its derivatives a special appeal.

Dualism also derives strength from the hierarchical arrangement of the search for knowledge (Pribram, 1968). Beginning as it does with personal experience, the search can proceed through consensual (among the senses) validation to interpersonal and intra and intercultural validation via the instrument of language. The social sciences and humanities follow this course toward knowing. Of course, analytical procedures can be instituted at every step, and usually are. Overall, however, there is a looking upward in a hierarchy of disciplines whose object is to know together, to become aware, conscious (con-scient, with knowledge).

On the other hand, it is possible to begin to dissect one's experience, usually first-hand. Here the instrument of search is direct observation and experiment. The bird falls and we feel its feathers and perhaps later perform experiments in an attempt to understand (stand under) what makes possible its flight. The plane lands and we examine its instruments, and if possible, disassemble them and the rest of the plane in order to understand what makes *it* fly. We dissect bodies and find brains. We dissect brains and find tissues. We dissect tissues and find cells, and then membranes, and molecules and atoms and hadrons and leptons and quarks. But at this level of investigation it becomes clear that the tools of observation and the mathematical operations necessary to share the experiences of dissection are critically involved. We are again dependent on cognitive commodities, on language, on mathematics, on mental processes much as in the social sciences and the humanities. Dissection, the reductive approach, has led full circle to the mental processes which not only inaugurated the process of reductive analysis but which have been ever present, though in less easily recognized form, at every step of analytical understanding. Overall, the reductive approach is nonetheless a downward process in a hierarchy of disciplines and it is the rare scientist who turns his face upwards to look once more at the problems which seized him when he started.

To summarize: Mind/brain dualism stems from the same roots which generate linguistic behavior. Dualism is also rooted in the hierarchical structure of the organization of the means, the instruments by which we know and construct our sciences. Looking (from the experiential center) upward in this hierarchy, one encounters the social (often referred to as the "soft") sciences and the humanities. In these endeavors language is the instrument which makes possible the sharing of experiences. Looking downward (from the experiential center), one encounters the natural (often referred to as the the "hard") sciences. In these endeavors direct observation and reproducible experiment are the instruments which make possible the sharing of understanding. However, dualism does not explain the actual processes of validation and investigation where there is a continual transaction between language and observation.

Dualism also fails at the limits of inquiry: at the infinitesimal, observations become critically dependent on the instruments chosen by the observer, so that questions arise as to what might constitute an "observable" (Wigner, 1969). Furthermore, the relationships between these observations are framed in mathematical terms and it is primarily these mathematical theories (and not observables) which are shared. Since observations per se and mathematical communications are mental rather than material, a pan-psychism follows readily. However, since neither the observations nor the mathematical theories can be instantiated, i.e., realized, in the absence of material instruments, a pervasive materialism becomes equally plausible.

Materialism, Phenomenalism, and Multiple Aspects

Critical philosophers, especially those of the Vienna Circle, attempted to solve this mental/material dilemma by resorting to the fact that our knowledge is described linguistically and that it is the descriptions, which are either mental or material, not that which is being described. This "multiple aspects approach" appears to eat its cake and have it as well: a material/mental duality is affirmed as a linguistic necessity, but identity is rescued in that the linguistic descriptions are about something else, which of course is identical to itself. What is lacking in this formulation is any specification of the nature of that "something else."

As noted, materialists can readily argue that actualization, embodiment, realization of any experience is completely dependent on the material nature of the physical universe, including the brain. Thus the something else must in essence be material if it is to be real.

As also noted, phenomenalists can make an equally persuasive claim: all that is real to us is our experience, including our experience of the physical world. The something else must therefore be mental.

A third alternative exists and this alternative claims that the something else is neutral with respect to the material/mental duality. Most critical philosophers, (e.g., Herbert Feigl, 1960; Bertrand Russell, 1948) espoused this form of "neutral monism." As most materialist and phenomenalists will insist, however, the issue remains unresolved until the neutral essence is identified. Despite these limitations, the approach taken by critical philosophers has helped enormously to encompass and clarify the mind/brain issue and to identify many of the remaining problems.

The Construction of Multiple Realizations

The deficiencies of the multiple aspects approach to the mind/brain issue can in part be resolved. Resolution comes with a fundamental modification: the many guises which reality takes are not just different linguistic forms. Rather, the different guises are different realizations. As noted, realizations are experienced physical actualizations, material embodiments, of informational structures. The realizations are constructions, often requiring work to accomplish.

In this formulation, as in that of the critical philosophers, the important aspects of mind/brain dualism are incorporated. In fact, dualism can readily be expanded into a pluralism in which what is mental and what is physical need not be specified. Such specification often gets in the way, as for instance when it is necessary to deal with measures on information, as in communication systems and with computer programs. Are such measures as bits and bytes to be regarded as physical and public, or mental and private? Is a program patentable or only subject to copyright? The most appropriate reaction to such questions is impatience: somehow such questions seem to be wide of the mark, probing neither the essence of the mind/brain issue nor the practical matter at hand. The difficulty is inherent in attempting to specify informational structure as either mental or physical.

The difficulty is highlighted by the old question: Is the pursuit of mathematics invention or discovery? If invention, why does the mathematics so often presage a physical discovery which fits? If discovery, what mental lode is being mined? Obviously, mathematics partakes of both invention and discovery, and pertains to an informational structure which is potential and neutral to the mind/brain duality. In short, mathematics is the science which deals with structure.

Energy and Entropy (Informational Structure) as the Neutral Potential

Another attractive feature of the multiple realization approach is that it allows the specification of informational structure as the something else which is neutral to the mental/material duality. That something else must be potential to becoming realized. In science, such potentials are defined in terms of the actual or possible work which is necessary for realization to occur and is labeled Energy. Thus multiple realizations imply a neutral monism in which the neutral essence, the potential for realization, is energy. And, as stated in the second law of thermodynamics, energy is entropic, i.e., it has structure.

Heisenberg (1969) developed a matrix approach to understanding the organization of energy potentials. Currently this approach is used in s-matrix, bootstrap theories of quantum and nuclear physics by Henry Stapp and Geoffry Chew (Chew, 1966; Stapp, 1965). These investigators have pointed out that measures of energy potential are related to measures of location in spacetime 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 coefficients representing different amplitudes and frequencies. These coefficients can in turn be superimposed, convolved, with one another and by way of the inverse Fourier transform to obtain the original spacetime configuration. The reason for using this mathematical transformation is that it allows patterns to be correlated with one another. Thus the Fourier transform of a set of patterns which have been correlated displays an organization different from that which is displayed after the inverse Fourier transform has again converted it to spacetime.

In terms of the proposition put forward by Stapp and Chew, this means that the organization of energy potentials is considerably different from the spacetime organization of our ordinary perceptions which can be expressed in Euclidean, Cartesian and Newtonian terms. David Bohm (1971, 1973) has identified these nonclassical organizations of energy potentials as "implicate," i.e., 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 wave forms 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 of the stored potential for reconstruction is related to the unfolded spacetime description of the object by a Fourier transform.

The Fourier theorem has also played an important role in recent discoveries in the brain sciences. In the late 1960s several groups of investigators found that they could explain their findings in visual research by framing their results in terms of "spatial frequency." This term was coined by Fergus Campbell and John Robson (1968) of Cambridge University when they discovered unexpected regularities in their data. Responses to gratings of different widths and spacings adapted not only to the particular grating shown but also at other data points. These additional adaptations could be understood by describing the gratings as composed of regular wave forms with a given frequency. The frequency was determined by the spacings of the grating, and thus the term "spatial frequency." Spatial and temporal frequencies are related of course: scanning by a steadily moving beam would describe the grating's temporal frequency. Physicists therefore use the term "wave number" to denote this form of description of patterns.

In the late 1950s, 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 (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 wave form 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 which were presented, much as did the organism as a whole. Finally, Russell and Karen DeValois (1980) and their collaborators demonstrated that the response of these visual cortical cells is only poorly described by the orientation of a line, while it is accurately described in terms of the spatial frequency of a grating; i.e., the cell is tuned to a spatial frequency range of approximately one-half to one octave. Further, 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 spacetime patterns, as determined by computer display, and that the cells were essentially unresponsive to the orientation of the lines which composed the checkerboards and plaids. In short, it appears that the visual system performs a Fourier transform on the image produced by the lens of the eye.

What this means is that the optical image is decomposed into its Fourier components: regular wave forms 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 which has characteristics 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 which distributes the information contained in a spacetime image throughout the transform domain. In the visual nervous system, distribution is limited anatomically to the input channeled to a particular cortical cell. There are, however, holographic techniques that use similar "patch" or multiplex constructions. 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, spacetime images of the whole composite can be viewed in three dimensions.

Further, the transform which best describes the process in the visual system is a Gabor, not Fourier. The Gabor transform (1946) is formed by placing a Gaussian envelope on the otherwise unlimited Fourier transformation. This is another way of stating that the transformation is not global, and gives mathematical precision to the limits involved.

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 spacetime coordinates, while its fine grain describes the Fourier components.

What advantage is gained by this fine grain holographic-like organization? In 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 of an enfolded fine grain (technically, the receptive field organization) and a gross grain spacetime organization applies to other sense modalities as well, although the experimental evidence is not as complete. Georg von Bekesy performed critical studies in the auditory and somasthetic modalities (1967), Walter Freeman in the olfactory (1960), and Pribram et al. have shown that cells in the sensorymotor cortex are tuned to specific frequencies of movement (1983). 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 which receive the sensory input.

In summary, there is good evidence that there lies another class of orders behind the ordinary classical level of organization, which we perceive and which is described in terms of Euclidian and Newtonian views, and mapped in Cartesian space-time coordinates. This other class of orders is constituted of fine-grain organizations which describe potentials which have been poorly understood because of the radical changes which occur in the transformational process of realization. When a potential is realized, information becomes unfolded into its ordinary spacetime appearance; in the other direction, the transformation enfolds and distributes information as this is done by the holographic process. Because work is involved in transforming, descriptions in terms of energy are suitable. Because the structure of information is what is transformed, descriptions in terms of entropy (and negentropy, i.e. information) are suitable. Thus complete understanding involves enfolded orders manifested as energy potential as well as unfolded orders manifested in spacetime.

Conclusion and Prolegomenon

As this essay shows, research in the information, physical and biological sciences has shed a good deal of light on the relationship between brain, mind and spirit. Still, there is much to be accomplished. Issues devolving around the nature of feelings, the possibility of free will in an apparently determined frame, and the continued demonstration of creativity among humans have not yielded to the observations recorded above. It is therefore appropriate to ask how an epistemologically pluralistic and ontologically neutral monism can handle these issues. My suggestion is that the key to understanding the problems associated with these issues lies in unravelling the nature of the transformational processes involved in each specific realization of potential.

Constraints on the transformational process are best conceived in terms of the degrees of freedom which they entail. Freedom, therefore, is relative to the constraints which define the transformation. Folk wisdom has proclaimed that freedom entails responsibility and Fritz Perls has pointed out that this means response-ability (1971). According to the views presented here, entailment is a two-way street: thus response-ability also begets freedom. In turn, the ability to respond to a situation may involve altering the constraints, the degrees of freedom which characterize it. In changing the degrees of freedom which constrain a situation lie the roots of creativity, and of free will.

The "particular go" of how this change in constraints is achieved is, of course, different in each situation. But examples from music, linguistics and invention can be detailed. A string is plucked, then bowed, then a keyboard is devised which removes the musician still further from the plucking. Instrumentation allows new combinations of sounds to be constructed. Instrumentation has increased the degrees of freedom, the ability to respond to the opportunity entailed in the fact that strings vibrate at certain frequencies. In order for all this to occur, the brain of the inventor of the instruments had to correlate and correlate and correlate. In order to utilize the instruments, the brain of the musician has to correlate and correlate and correlate. As noted, correlations are the hallmark of processing in the enfolded order. Of course, correlation is not all that is involved, but correlation takes us a long way. Think for a moment of the usefulness of IBM punched cards in the development of computer programming. Essentially the cards furnished filters which were superimposed, correlating the information common to all the cards in the stack. The Fourier filters described above are much more powerful, but the principle is the same.

Changes in the constraints which guide linguistic communication, transportation, game playing, economic regulation all can be shown to display a similar course of development. Culture is composed of such cognitive commodities which become realized in the material commodities of the marketplace, only to become the forebears of novel cognitions.

But what about feelings and the interpersonal relationships which they reciprocally entail? The results of brain research over the past three decades have made substantial contributions to our knowledge of the mechanisms regulating pain and suffering, pleasure and wellbeing. Once again, a dual organization of brain processes is involved: in this instance the fine grain enfolded and distributed processes are neurochemical, while the courser grain unfolded spacetime processes remain functional anatomical systems. The results of this research are, as yet, too recent for much effective theory to have emerged. However, it is of interest that Arnold Mandell (1973) has developed a Fourier model of several behavioral manifestations of feelings based on distributed neurochemical interactions.

I do not mean this outline to suggest that all problems are resolved or even near resolution in regards to how the brain operates in manifestations of freedom, of feelings, of creativity. What I do propose is that relevant questions can now be posed in experimentally operational and mathematical terms so that resolution can proceed. I have presented a philosophical stance within which these questions can be framed, and have attempted to give substance to this stance and to relate it to other proposals by encompassing them rather than by refuting them. I also feel deeply that what I have written is consonant with the spirit in which Grover Maxwell worked and would have us continue.

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Implications Of Science For Epistemology And Metaphysics

Brian Ellis

I

Grover Maxwell holds that epistemology and metaphysics are subordinate to science. So that, in the case of conflict between science, on the one hand, and epistemology or metaphysics on the other, it is normally our epistemology or metaphysics which should give ground. There is, he would say, a presumption in favour of the well established scientific theory.

Maxwell's position presupposes the interconnectedness of science, epistemology and metaphysics. Epistemic and metaphysical theories, he thinks, are theories, like any other, which can be subject to external as well as internal criticism, the external criticism coming particularly from science. The claims of epistemology and metaphysics are not *a priori*, or a mere reflection of linguistic conventions; they are abstract, high level, theories about the nature and structure of knowledge we may have concerning these things.[1] On this point, at least, I think Maxwell is right. But I have no wish to argue it here.

More interesting is the judgement, which is essential to Maxwell's position, that epistemology and metaphysics should be answerable to science, not the other way round, and that science in turn should be answerable to observation and experiment. It is true that observation is selective, and coloured by the theories we hold. So there is some interaction between theory and observation. And in the same sort of way we should expect there to be interaction between science and philosophy, particularly those areas of philosophy which are the traditional concerns of epistemology and metaphysics. We should expect our philosophy to influence our theory construction, and our interpretations of the theories we construct. But our philosophical theories should, nevertheless, be answerable to our scientific ones.