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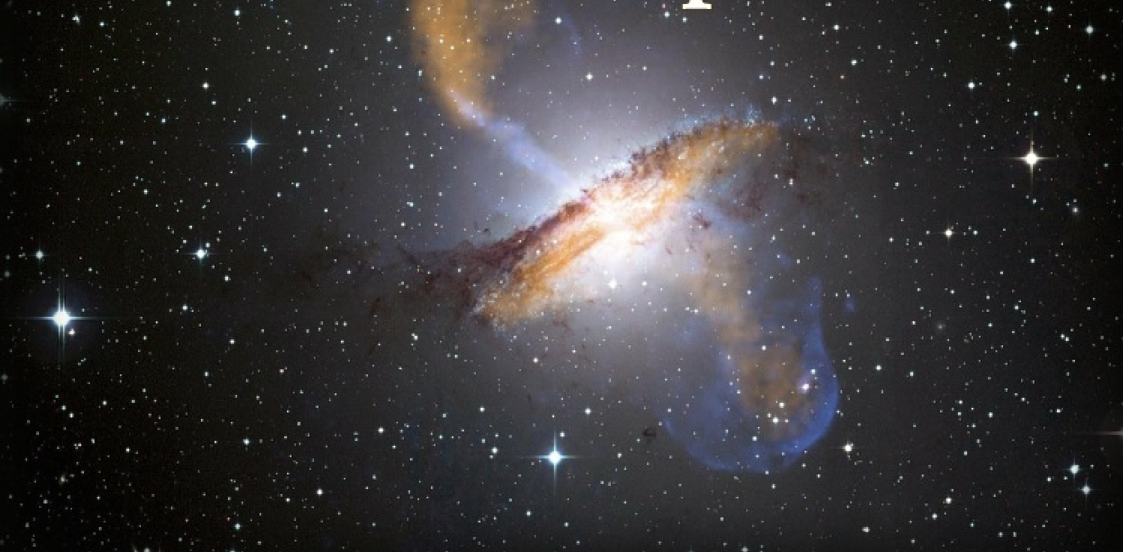
Scientific Concepts and the Nature of Conscious Experience



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SCIENTIFIC CONCEPTS AND THE NATURE OF CONSCIOUS EXPERIENCE[1]

> The ability of purely physical processes to account for all externally observable details of behavior means, among other things, that no aspect of another person's activity—tone of voice, facial expression, appearance of the eyes, or any of the other cues by which we judge what is 'in his mind' —can provide proof that he experiences the kind of awareness that we call consciousness. By the same token, every detail of the past and future history of mankind would be the same if consciousness were completely nonexistent, just so long as the physical laws of nature were kept unchanged.

Dean Wooldridge,

Mechanical Man [P. 134]

The nature of conscious experience is the most conspicuously perplexing enigma that challenges the mind of man. There has been an explosion of new information about the brain, especially in the last three decades, about its molecular and cellular machinery, its neural circuitry, and its complexly organized hierarchies of systems. What does this new information tell us about conscious experience? Wooldridge, as quoted above, states the extreme of one position clearly and forcefully. The evidence and logic supporting it is available in three of his books. These books provide a panoramic view of the interface between the sciences and the mystery of life, including the nature of man. As their titles suggest, they document the concept, accepted explicitly or implicitly by many scientists, that life and man himself are to be understood as machinery, subject only to the "physical" laws of nature as currently defined and, therefore, in no way influenced by phenomena like conscious experience, which are currently relegated to a "nonphysical" status. Borrowing from Wooldridge, I shall henceforth refer to this as the "mechanical-man" concept. The question of whether this is the most tenable scientific view of conscious experience will be approached first by examining weaknesses in the mechanical-man concept. Alternative concepts will then be considered, especially with regard to framing questions that seem important for a science of conscious experience. Finally, examples from current neuroscience research will be used to illustrate certain approaches that bear on these questions. The goal is to use new knowledge to reformulate old questions and to discover new ones about relationships between scientific knowledge and conscious experience, and how both might be integrated into a new conceptual model, encompassing both "objective" and "subjective" realities. Unlike the mechanical-man concept the approach here assumes that no scientific position about consciousness is yet established, and that science itself, especially its logical and conceptual structure, must be seen as part of the problem rather than as merely the tool to use for understanding conscious experience. Science develops from, and is part of, conscious experience, and one can find in science, reflected as in a mirror, properties of the human mind that express themselves in all human thought. To recognize this clarifies the need for a new scientific frame of reference taking into account characteristics of conscious experience that have influenced the development of science.

Science, Common Sense, and Subjective Experience

The notion that "mankind" would be no different without consciousness seems outrageous to common sense. So do many scientifically established models of reality, but these are accepted because they are supported by compelling evidence. This is the case, for example, with regard to the conflict between common sense and certain concepts of relativity theory. The dimensions of a meter stick do not depend on its velocity under conditions of common experience on earth, but the concept that its length *is* a function of its velocity under uncommon conditions (i.e., *not* ordinary experience) is accepted as a valid model of reality. For the mechanical-man concept, however, it should be noted that the problem is complicated by the fact that it is not just common sense but especially subjective experience that is outraged by the notion that consciousness has no function. For each individual human, the power of "mind over matter" is confirmed by the daily experience of volitional activity, even down to such trivial and frivolous actions as lifting a little finger. This subjective experience is private and inaccessible to confirmation by outside observers, but disturbances in the ability to initiate volitional activity are easily recognized through behavioral observations as a serious deviation from normal. If "common sense" is taken to mean knowledge gained via the sensory system and subject to consensual validation, then the subjective sense of conscious control of mind and body might be termed "common experience," to suggest knowledge that is directly accessible only to the individual subject. To evaluate the mechanical-man concept it is necessary to consider not only common sense and scientific evidence, but also the evidence of common subjective experience, and how these domains of knowledge can be brought into a unifying frame of reference. These are epistemological quicksands where many have struggled, and I shall confine myself to only a few points, hoping thereby to avoid the risk of getting bogged down. The comments here extend and develop some thoughts about scientific and subjective reality that are presented in an earlier paper, "Questions About Man's Attempt To Understand Himself."

Mechanical Man Has Some Problems

There are both factual and logical problems in the mechanical-man concept. If it be stipulated that "purely physical" processes account for *all* externally observable behavior, then it is tautological to argue that, ipso facto, externally observable behavior cannot be evidence of processes that are not "purely physical" (i.e., consciousness). Furthermore, as a matter of fact, observable behavior remains a mystery to science that cannot explain the initiation of even the most simple voluntary action. Considerable progress has been made toward understanding the neurophysiology of sensory systems and of motor systems, but almost nothing is known about how sensory inputs and ongoing brain activities culminate in the generation of those patterns of efferent activity that mediate behavior.

It is a non sequitur to conclude from the fact that awareness is not externally observable and not part of the current scientific understanding of the “physical” laws of nature that, therefore, it has no biological function. The argument depends upon accepting the premise that nothing about reality remains to be discovered that is not already within the scope of scientific observation. To accept this means that, by definition, subjective experience springs from and is, inherently, “nonreality.”

To argue that mankind would be the same without consciousness, provided the physical laws of nature are kept unchanged, is either a self-contradictory or a metaphysical assertion. Insofar as conscious experience is taken to be an emergent property of some unknown level of brain functioning, it would contradict the “laws of nature” to postulate the same functional machinery without this emergent property, whether or not consciousness plays an influential role in human behavior.

On the other hand, the assertion that consciousness has no function cannot be empirically tested because there is no way to abolish it without modifying any other aspect of brain function. This would require postulating that consciousness is not an aspect of any level of brain function, but is rather a disembodied and supernatural phenomenon. Thus, the question of its function would be subject to metaphysical or philosophical evaluation, but not to refutation or confirmation on an observational basis, even in principle.

Wooldridge places consciousness in the domain of science on the ground that it is an effect caused by physical processes in the brain:

> In short, according to this thesis the evidence for the operation of physical cause and effect in conscious phenomena is convincing and therefore consciousness, in the mid-twentieth century, is finally ready to make the same transition from metaphysics to physics that was set in motion for the other functions of the body in the early 1600's. [P. 162]

It seems to me that conscious experience remains assigned to metaphysics, because science models reality exclusively in terms of objects and cannot explain how some objects, like the brain, are also subjects of experience. To rescue conscious experience from metaphysics will require new scientific models of reality that correct for the distortion of the subjectively imposed dichotomy between the observer and the observed, upon which rests the whole structure of present-day science.

The concept of man as a machine that cannot be influenced by consciousness interferes in no way with the pursuit of further scientific knowledge about "purely physical" (i.e., nonmental) processes. At the same time, it may preclude progress toward a better understanding of conscious experience because it perpetuates without question the dichotomy mental versus physical, and rejects the possibility that the gap between them is only a hiatus in man’s current understanding, rather than an irreconcilable difference between mental and physical realities.

If the mechanical-man hypothesis cannot be tested empirically, is there some other basis on which it can be evaluated? Popper suggests a useful approach:

> In other words every *rational* theory, no matter whether scientific or philosophical, is rational in so far as it tries to solve *certain problems.* A theory is comprehensible and reasonable only in its relation to a given *problem-situation,* and it can be rationally discussed only by discussing this relation.
>
> Now if we look upon a theory as a proposed solution to a set of problems, then the theory immediately lends itself to critical discussion—even if it is non-empirical and irrefutable. For we can now ask questions such as, Does it solve the problem? Does it solve it better than other theories? Has it perhaps merely shifted the problem? Is the solution simple? Is it fruitful? Does it perhaps contradict other philosophical theories needed for solving other problems? [P. 199]

If we adopt this pragmatic approach suggested by Popper, it appears that two old and important problems are solved by the concept of mechanical man: How can mental phenomena influence physical processes? How can self-determination (free will) be reconciled with causal determinism? Historically, these questions have proven so endlessly inscrutable as to suggest that they are not properly framed to permit progress toward understanding the problems, whatever they are, that give rise to them. This suggests that it might be important to evaluate not just putative answers, but also the validity of the questions themselves.

Can Mind Influence Matter?

The scientific method approaches reality on the basis of information reaching the mind via the sensory systems. In this approach, science has taken conscious awareness as the "given" for two reasons: (1) Awareness arrives directly at the mind, without benefit of the sensory systems (i.e., it is experienced not observed), and science has found no way to inspect it via the sensory systems. (2) Subjective experience (perception and cognition) is the basis on which the scientist carries out his efforts to discover new knowledge. The observing process itself is accessible in subjective experience only as an infinitely regressive "I" that feels itself to be inherently separated from whatever is being observed. This quality of conscious experience leads to a model of "reality" in which no interaction is possible across the dichotomy between "mental" and "physical."

In the era of modern neurophysiology, Sherrington has stated the problem eloquently, and struggled with it in detail, especially in the Gifford lectures given in 1937-38. He cites Eddington's account, contrasting the difference between the perceptible qualities of his table and his elbow and the scientific understanding of them in which they are conceived to be electric charges and fields of force in space. Sherrington goes on to illustrate how science uses the concept of energy to explain the perceptible world.

> The width of applicability of this concept 'energy' bears witness to its analytic depth. It unites all sensible structure and brings it into a form of doing. By it the atom, the rose we cultivate, and the dog our companion are alike describable. Within the descriptive competence of this unification comes our whole perceptible world, what it is and what it does. [P. 235]

Elsewhere I have discussed the fact that scientific explanations depend upon a logic of cause and effect that treats objects, even if they are alive and subject to experience, as if they were objects without subjective experience and influenced only by impersonal "causes." The system of explanatory logic that tries to deal with living subjects as subjects is humanistic logic, in which meanings, rather than causes, are invoked as explanatory principles. Meanings, unlike causes, cannot be observed but are experienced directly, and so humanistic explanations of subjective behavior have to rest upon inferences derived by one subject from projective identifications with another subject. The power of the scientific system lies in the fact that it gives a more reliable and useful picture of the perceptible world than does the projective method underlying the animistic approach to the outer world. The notion that rain depends upon a friendly person in the sky does not lead to effective attempts to predict, let alone influence, the weather. On the other hand, unreliable as it may be, the only successful approach to understanding the "inner world" of other living subjects is the method of projective identification that takes observable behavior (facial expression, tone of voice, acting, etc.) and uses it to support an inference answering the question, If I were behaving that way, how would I be feeling? That this method works is illustrated by the success with which people transact the complexities of their relationships with each other; the fallibility of the method is illuminated by the problems that so richly characterize human affairs.

Sherrington is correct to say that science can use the energy concept to describe the dog, but incorrect when he says it can describe "the dog our companion," because "companion" is a subjectively experienced meaning to which the logic of science is blind.

On the problem of object and subject, as it pertains to the brain, Sherrington wrote:

> Physiology has got so far therefore as examining the electrical activity in a 'mental' part of the brain when activity there is in normal progress. But has it brought us to the 'mind'? It has brought us to the brain as a telephone-exchange. All the exchange consists of is switches. What we wanted really of the brain was the subscribers using the exchange. The subscribers with their thoughts, their desires, their anticipations, their motives, their anxieties, their rejoicings. If it is for mind that we are searching the brain, then we are supposing the brain to be much more than a telephone-exchange. We are supposing it a telephone- exchange along with the subscribers as well. Does our admirably delicate electrical exploration vouchsafe us any word about them? Its finger is ultra-

sensitive, but energy is all that it can feel. And is the mind in any strict sense energy? [P. 222]

Despite this dilemma, Sherrington refused to reject subjective evidence that the “mental” can influence the “physical” as is clear in this passage:

> Mind, always, as we know it, finite and individual, is individually insulated and devoid of direct liaison with other minds. These latter too are individual and each one finite and insulated. By means of the brain, liaison as it is between mind and energy, the finite mind obtains indirect liaison with other finite minds around it. Energy is the medium of this the indirect, but sole, liaison between mind and mind. The isolation of finite mind from finite mind is thus overcome, indirectly and by energy. Speech, to instance a detail, illustrates this indirect liaison by means of energy between finite mind and finite mind. [P. 206]

The role attributed by Sherrington to mind depends on a relationship to energy that Sherrington, and science, cannot explain. The mechanical man solves this issue by asserting that consciousness has no role, and therefore there is nothing to explain. It postulates that the subjective evidence that mind can influence matter is an artifact of the limited view of brain mechanisms provided by conscious awareness.

An alternative view would be that consciousness is an emergent property of certain unknown levels of brain function, and that it can influence other, known levels of brain function, and that failure to understand how it does so is an artifact of limitations in the scientific view of reality. Implicit in this assertion is the premise that the current scientifically achieved model of reality can be modified to correct for this artifact, and to make understandable how consciousness and physical energy are related.

Can Self-Determination Override Causal Determinism?

Subjective evidence in support of the concept of free will and personal responsibility is difficult to reconcile with the deterministic cause- and-effect logic of science. Man has struggled with this issue for centuries, invoking explanations at a variety of levels ranging from theology and metaphysics to empiricism and behaviorism. The concept of mechanical man solves this by asserting that free will is, like the influence of mind on brain processes, merely an artifact of subjective experience and that all aspects of human life are, therefore, causally predetermined. Wooldridge states this as follows:

> In the context of a completely physical biology, free will poses no problem —it simply doesn't exist. Obviously, it cannot, if conscious personality is no more than a derived, passive property of certain states of organization and electrochemical activity of the neurons. On this basis our thoughts and actions must be as rigidly controlled by the operation of inexorable physical law among the material particles of the universe as is the movement of wind and wave. [P. 183]

At a recent conference reported in the book *Brain and Conscious Experience*, Sperry commented on causal predetermination as follows:

> In other words, behavioral science tells us that there is no reason to think that any of us here today had any real choice to be anywhere else, nor even to believe in principle that our presence here was not already in the cards,

> so to speak, five, ten or fifteen years ago. I do not like or feel comfortable about this kind of thinking any more than you do, but so far I have not found any satisfactory way around it. [P. 304]

In order to reconcile the breadth of freedom of choice that man appears to have with the logic of causal determinism, Sperry goes on to suggest:

> If one were assigned the task of trying to design and build the perfect free will model—let us say the perfect all-wise decision-making machine to top all competitor's decision-making machines— consider the possibility that instead of trying to *free* the machinery from causal contact, it might be better perhaps to aim at the opposite: that is, to try to incorporate into the model the potential value of *universal causal contact*; in other words, contact with all related information in proper proportion—past, present, and future.
>
> It is clear that the human brain has come a long way in evolution in exactly this direction when you consider what goes on between its input and output in the process of making a decisive response. [P. 305]

We do not yet have a scientific knowledge of machines having "universal causal contact," but if the brain is such a system, to understand the constraints under which it functions will clearly require modification of the concept of causal determinism. Such modification might eliminate the apparent conflict between self-determination and causal determinism, and thereby provide an alternative solution to that of the mechanical-man concept.

The Question of Machine "Intelligence"

Machines have been built that “observe” and “recognize” patterns, that retrieve from a store of “memory,” that “play” checkers and chess, that “learn” from experience, and that otherwise display what is called machine “intelligence.” The words in quotation marks ordinarily imply conscious experience and their use in reference to machines tends to reinforce the analogy between machine performance and human thinking. From this analogy an extrapolation is made to future machines that will have conscious experience. For example, Wooldridge writes:

> Indeed our thesis requires that we keep an open mind as to the possibility that among the wires and transistors of existing electronic computers, there already flickers the dim glimmering of the same kind of personal awareness as that which has become, for man, his most precious possession. [P. 174]

The possibility that present-day computer performance justifies the hope of building machines capable of conscious experience is important because it is cited as evidence in favor of the concept that the living brain is merely a complex machine. In a classic paper, Turing points out that the question, “Can machines think?” is too meaningless to discuss, and he proposes alternative ways of formulating it. He lists objections to the idea of an intelligent machine and provides answers for each. A more recent review of many of the same issues suggests that the strongest argument against the practicability of an intelligent machine is the fact that the brain has so many components. Curiously, Turing did not even include this argument in his article. He suggested that one of the strong arguments against the possibility of a thinking machine is based upon the phenomena of extrasensory perception! Other reviews of progress in the computer and brain sciences are available in the volume *Computers and Brains*.

Three considerations seem important to me for the question of whether present day machine performance suggests that someday conscious, intelligent machines can be built. The first is the question of whether machine performance does, in some rudimentary way, resemble brain performance. The second is the question of whether a design can even be imagined for a machine with as many components as the living brain. The third issue concerns problems that might arise in the attempt to build an extraordinarily complex machine of nonliving components.

I believe that the use of anthropomorphic language has seriously blurred the distinction between machine performance and human performance. Benson, reporting a conference on artificial intelligence, describes examples of this type of misuse of language, and comments: “There is a twofold danger in such linguistic abuse—for man’s conception of himself, and for his understanding of the capabilities of machines.” Weizenbaum, writing on the dangers of allowing the “technological metaphor” to dominate our thinking, comments :

> Computer science, particularly its artificial intelligence branch, coughed.

> Perhaps the press has unduly amplified that cough—but it is only a cough nevertheless. I cannot help but think that the eagerness to believe that man’s whole nature has suddenly been exposed by that cough, and that it has been shown to be a clockwork, is a symptom of something terribly wrong.
>
> What is wrong, I think, is that we have permitted technological metaphors, what Mumford calls the ‘myth of the machine’, and technique itself to so thoroughly pervade our thought processes that we have finally abdicated to technology the very duty to formulate questions. [P. 611]

One factor in this abuse is the manifestly incorrect reasoning that, if two outputs are equivalent, then the processes leading to those outputs must be equivalent. This logical error is compounded by an observational error wherein part of the output of the human brain is taken as the whole of the output. For example, a machine is said to be playing chess if it can generate a series of moves that will win a chess game or, at least, look like a well-planned game. It should be obvious that similarity in the type of moves generated does not imply that the processes in the machine are similar to the processes going on in man. For the human being, playing any game is enjoyable by reason of many different levels of conscious and unconscious meanings attached to the pieces and to the procedures of the game. The motivational and emotional significance of these meanings derives from analogical and metaphorical associations linking various aspects of the game with such human dramas as war, sex, family relationships, and other patterns of personal experience. These motivational factors are separate from those logical considerations required for the analysis of the positions and values of the various chess pieces, and the choice of the next move. It is the interaction of these non-logical conscious and unconscious processes with the logical ones that contributes to the style of play, whether careless, careful, aggressive, plodding, imaginative, or subtle. If chess consisted solely of the unfeeling logical analysis of contingency trees, it is doubtful that humans would play, and certainly it would be a chore more than a game. It is instructive to try to imagine a method of play that might reduce human performance to that of a machine. One may think of a giant list, computer printed, of unequivocal instructions for every contingency possible in a chess game. For each move by his opponent, the human player would flip to the appropriate page and execute the indicated move. Actually, even in these circumstances, the thoughts and feelings of the human would enliven the procedure in a most unmachine-like fashion, including perhaps even playful or spiteful deviations from instructions.

Another way of putting this argument is to suggest that future machines may be constructed that can produce outputs equivalent to certain aspects of human thinking, but there is not yet any evidence that the means of producing the outputs will include conscious awareness. Production of a sentence in a natural language is not evidence that a computer, or a parrot, is using the same type of conscious systems as a man speaking the same words.

Presumably the design of the human brain has some importance for the problem of designing a thinking machine. Unfortunately, it is not yet clear even how many components there are in the human brain. In discussing the component argument, Good cites figures for neurons (five billion) and synapses (one thousand million million, or 10^{15}) in the gray matter of the cerebral cortex, but available evidence suggests that, far from being restricted to the cortex, neural activities subserving conscious experience are spread throughout most, if not all, of the cortical- subcortical interacting systems of the brain. There are substantially more than ten billion neurons in these systems, and each neuron is in intimate functional relationships with large numbers of glial cells that may well be as influential for brain function as the neurons themselves. Thus, at the level of cells, it is reasonable to postulate a ball-park figure of at least fifty billion components in the brain (5×10^{10}).

This estimate is a serious oversimplification because it is now clear that each neuron is an exceedingly complex computer within itself, and that it therefore should not be regarded as an elemental component of the brain. The neuronal membrane carries an array of complex molecular machinery that mediates transactions between the cell membrane and other elements (e.g., nucleus) of the neuron, and between one neuron and other neurons, and between the neuron and the rest of the body, as via substances (e.g., hormones) circulating in the blood. How many of these molecular machines exist in one brain is not clear, but work on the acetylcholine receptor in torpedo fish and on neuromuscular junctions in rat diaphragm yields estimates on the order of 10 receptor molecules per square micron of the motor end plate. Available data suggest a similar density for receptor molecules in post synaptic membranes of the central nervous system. Many different types of specific molecular receptor mechanisms have already been identified, but we do not know how many more remain to be discovered. It is therefore not possible to guess how many such molecular receptors are arrayed on an individual neuron, but assuming 5 X 10^{10} neurons per brain, there would be at least 10^{20} molecular receptors arrayed on their surfaces.

It is already clear that these receptors mediate extremely sophisticated recognition tasks and produce powerful amplification effects. For example, the cyclic adenosine monophosphate (AMP) system acts as the intracellular mediator of a wide variety of cellular responses to triggers (e.g., hormone molecules) that activate specific molecular receptors on the cell membrane. The staggering number of such molecular machines, and the still undiscovered processes that they may mediate, suggests a far more difficult goal for machine mimicry than does a model of the brain that takes the neuron as its basic element.

The organization of brain components into hierarchical systems is complex beyond any imaginable machine, and even with progress in micro-circuitry there is no foreseeable prospect of a machine involving such myriad systems of components. The possibility exists that a conscious thinking machine might be constructed with fewer components than the human brain, but until more is known about conscious experience, it seems fruitless to try to guess how many less components might be needed.

The third, and to me the most important consideration, is the problem of constructing such a machine from nonliving components. If it is to have anything of the order of complexity of the human brain, the use of nonliving elements will introduce serious problems. For example, in ontogenesis the living cells of the human brain proliferate, differentiate, and literally connect themselves up in specific circuitry on the basis of genetic information contained in DNA molecules interacting with fields, gradients, and other physical and chemical factors operative during brain development. Since neurons may have as many as one hundred thousand dendrites and since each dendrite has many thousands of synaptic connections with other neurons, the task of attempting to wire the circuitry of such a system out of dead elements would require a technology so radically new as to stagger the imagination.

Secondly, during brain function each living element, however small, continuously adjusts itself in relationship to hierarchical systems acting at organizational levels above and below it. These include housekeeping systems that maintain the nutrition and metabolism of the cells, as well as information-processing features such as the regulation of changes in excitability thresholds, the influence of current and past experience on response patterns of individual cells, and other processes still little understood or unknown.

The maintenance of the human brain also depends on the fact that its living elements continuously replenish themselves. For example, the protein constituents of neurons change as a result of a balance maintained between the degradation of proteins and the synthesis of new proteins.36 This ongoing turnover and renewal of brain substances would not, of course, be available in the machine.

Reviewing the turnover of proteins in living cells, Schimke points out that all of the cellular proteins turn over, that the turnover rates are heterogeneous (the half-life of proteins ranges from less than one hour to many days) and that both the processes of synthesis and of degradation are subject to complex regulatory mechanisms. Variables influencing protein turnover include substrate concentration, nutrition, and genetic and developmental factors. In neurons, substances synthesized in the cell body are delivered by axoplasmic flow to nerve terminals. Furthermore, the triggering of electrical activity (action potentials) is an important factor influencing chemical processes and morphological features in the neuron. It is clear from these facts that a dynamic potential for plastic change in the cell, on both a short and a long-term basis, is provided through the diversity of these mechanisms for regulating the turnover of cellular substances. In systems having great levels of complexity, such a potential might be critically important for normal function.

It should be noted, also, that the properties of living systems reflect principles, as yet undiscovered, that are not active in nonliving elements; these principles may well be crucial for the emergence of conscious experience. In other words, it is not possible to explain life on the basis of physics and chemistry. With regard to progress in the application of physics and chemistry to biology, Bohr wrote:

> In this promising development we have to do with a very important and, according to its character, hardly limited extension of the application of purely physical and chemical ideas to biological problems, and since quantum mechanics appears as a rational generalization of classical physics, the whole approach may be termed mechanistic. The question, however, is in what sense such progress has removed the foundation for the application of so-called finalistic arguments in biology. Here we must realize that description and comprehension of the closed quantum phenomena exhibit no feature indicating that an organization of atoms is able to adapt itself to the surroundings in the way we witness in the maintenance and evolution of living organisms. [P. 100]

In summary, the main point to be emphasized is that the performance of electronic computers provides a rational basis for hoping that future machines may be capable of complex tasks now performed only by humans, perhaps even the translation of one natural language into another, the writing of poetry, or the formulation of new hypotheses significant for research progress. At the same time, there is no rational basis whatsoever for thinking that present-day computers produce their output by processes that represent a step, however rudimentary, toward conscious intelligence as displayed by the living human brain. The complexity of electronic computers, the use of anthropomorphic labels for machine performance, and the failure to appreciate that human intelligence is necessary to design, build, program, and recognize the output of the computer, all of these factors have encouraged the belief that present-day electronic machines are a step toward the eventual development of a machine capable of conscious experience. The slide rule is clearly a tool of human intelligence, but no one assumes that its use for calculation means that it is showing intelligent behavior. Even if the movements of a slide rule were automated by machinery that could be programmed for long sequences of calculations, with optical scanners to read the products, magnetic tape to accumulate the results, and perhaps an audio system to read aloud intermediate and final stages of the calculation, it seems unlikely that intelligence would be attributed to the system because the key element, the slide rule, is so simple a device. Replacement of the slide rule, however, by solid state micro-circuitry, might encourage some to believe that in some mysterious manner the performance of the machine amounted to a small step toward conscious experience.

One may ask what difference it makes whether future machines are conscious or not so long as they accomplish sophisticated tasks now possible only for intelligent humans. One difference is that, no matter how complexly elaborated, nonconscious machines will function only as passive extensions of human intelligence, no different in principle from a slide rule. That is, such machines, in the absence of interaction with human intelligence, would grind out their products, or grind to a halt, their successes unrecognized and unused, and their failures unnoticed and unmourned. One might object that the same could be said for the human being, but this would not be relevant to the question of the fate of nonconscious machines writing poetry or composing music in the absence of interaction with conscious human intelligence. Indeed, it may be that the emergence of conscious experience in human evolutionary development was contingent on the inherently social nature of man; this suggests that a conscious machine might require "social relations" with other conscious machines, or with man.

Another difference that consciousness might make for a machine depends upon the question of how conscious experience contributes to brain function. In particular, are there information processing tasks that simply cannot be accomplished without conscious experience? If so, then machines without the property of conscious experience could not perform such tasks.

The Observer and the Observed in Science

The mechanical-man concept attempts to reconcile conscious experience with the materialistic view of reality constructed by science. This mechanistic and materialistic view, as applied so successfully in Newtonian mechanics, draws a sharp dichotomy between the observer, taken for granted, and the observed, taken as an object for study. It seems curious that the first definitive effort to include the observer in scientific explanations was made in physics, presumably the most "objective" discipline, rather than in psychology, for which the problem of subjectivity might seem more relevant. Physics was forced to make the observer an integral part of its description of nature when it attempted to account for the behavior of atomic particles. A truly revolutionary event for epistemology was Planck's discovery of the universal quantum of action. Of it, Bohr writes:

> This discovery revealed in atomic processes a feature of wholeness quite foreign to the mechanical conception of nature, and made it evident that the classical physical theories are idealizations valid only in the description of phenomena in the analysis of which all actions are sufficiently large to permit the neglect of the quantum. While this condition is amply fulfilled in phenomena on the ordinary scale, we meet in atomic phenomena regularities of quite a new kind, defying deterministic pictorial description. [P. 71]

Even the Einstein correction of the Newtonian view to take account of subjective bias, as for observers traveling at close to the speed of light, did not imperil the dichotomy between nature and the observer that underlies the materialistic model of reality. Only with the development of quantum mechanics was the whole conceptual structure of scientific knowledge brought into question as described by Heisenberg:

> For the materialistic world view, it is important only that the possibility remains of taking these smallest constituents of the atoms as the final objective reality. On this foundation rested the coherent world view of the nineteenth and early twentieth centuries. . . .
>
> It has turned out that the hoped-for objective reality of the elementary particles represents too rough a simplification of the true state of affairs and must yield to much more abstract conceptions. When we wish to picture to ourselves the nature of the existence of the elementary particles, we may no longer ignore the physical processes by which we obtain information about them. When we are observing objects of our daily experience the physical process transmitting the observation of course plays only a secondary role. However, for the smallest building blocks of matter every process of observation causes a major disturbance; it turns out that we can no longer talk of the behavior of the particle apart from the process of observation. In consequence, we are finally led to believe that the laws of nature which we formulate mathematically in quantum theory deal no longer with the particles themselves but with our knowledge of the elementary particles. ... [P. 99]
>
> The conception of the objective reality of the elementary particles has thus evaporated in a curious way, not into the fog of some new, obscure, or not yet understood reality concept, but into the transparent clarity of a mathematics that represents no longer the behavior of the elementary particles but rather our knowledge of this behavior. [P. 100]

The role of the observer in the structure of scientific knowledge is, of course, not restricted to quantum theory, but underlies the question of all human knowledge, as emphasized by Wigner:

> The principal argument against materialism is not that illustrated in the last two sections: that it is incompatible with quantum theory. The

> principal argument is that thought processes and consciousness are the primary concepts, that our knowledge of the external world is the content of our consciousness and that consciousness, therefore, cannot be denied. On the contrary, logically, the external world could be denied—though it is not very practical to do so. [P. 290]

The rejection of materialism and causal determination in quantum theory does not invalidate all scientific knowledge gained within the framework of these doctrines, any more than Einstein's theories invalidate Newtonian physics. In both cases, limitations are discovered beyond which an older conceptual system has to be supplemented by a newer frame of reference. The history of science documents the reluctance with which scientists, like other human beings, recognize the need for shifting to a new frame of reference.

> Scientific research in many domains of knowledge has indeed time and again proved the necessity of abandoning or remoulding points of view which, because of their fruitfulness and apparently unrestricted applicability, were regarded as indispensable for rational explanation. [P. 67]

Although the classical materialistic doctrine has certainly been fruitful, it should be noted that scientific progress with it has been limited to the explication of systems that are simple to the point of triviality by comparison with the brain. Indeed, the hope that life processes, including brain function, could be explained in the reductionistic, cause-and-effect logic applicable to simple mechanisms suggests that the appeal of classical materialistic doctrine may include nonrational factors as powerful, or more powerful, than rational considerations. For example, the concept of causality appears in human conscious experience as a fundamental principle of nature, even though it is a characteristic of thought itself rather than of the world outside the mind. As Mach said:

> There is no cause nor effect in nature; nature has but an individual existence; nature simply *is.* Recurrence of like cases in which A is always connected with B, that is, like results under like circumstances, that is again, the essence of the connection of cause and effect, exist but in the abstraction which we perform for the purpose of mentally reproducing the facts. [P. 1788]

In discussing the danger to clear thinking from the misuse of terms of language, Weiss speculates on the historical emergence of the concept of "cause":

> I shall not dwell on its historical roots; they are I would submit, deeply embedded in man's extrapolation to nature of his own spontaneity in willing an act. Presumably, primitive man then went on to populate the universe in his imagination with 'actors' after his own image. Sophisticated man simply reversed the process by invoking primary causes' which he then let be followed in linear ascending series, domino-fashion, by secondary, tertiary, etc., causes, confident or persuaded that ultimately the causal chain will 'explain' man's own spontaneity, which had served him as the model for the whole argument in the first place. [P. 927]

The peculiar power of the logic of causality may be due to the fact that it is presented to us without conscious effort, and with the subjective quality of seeming to be independent of the unreliability of thinking. That is, it masquerades as something to be thought about, rather than as a way of thinking.

> Much of the authority of the ideas of cause and effect is due to the fact that they are developed instinctively and involuntarily, and that we are distinctly sensible of having personally contributed nothing to their formation. We may, indeed, say that our sense of causality is not acquired by the individual, but has been perfected in the development of the race. [P. 1789]

Insofar as the logic of causal determinism is modelled after voluntary action, the problem of reconciling free will with it can be seen to be a particularly poignant and circular paradox.

There are, of course, also rational reasons for the appeal of the classical materialistic doctrine. Methodologically, simple systems can be studied more easily than complex ones. It is technically feasible to record from one neuron, or even several neurons simultaneously, but there is little prospect of recording from, say, ten thousand neurons. Furthermore, the logic of causality is adequate for explaining the behavior of a neuron artificially isolated from the system in which it functions, but completely new conceptual tools will have to be developed to comprehend the behavior of large populations of neurons. It follows that all scientific knowledge of the brain takes the form of information about artificially isolated and identified subsystems within it, seen as mechanisms obeying the principles of rather direct causality. According to the logic of science, no matter at what level of brain organization it is applied, the subsystem under study is conceptualized as an object, so that conscious experience always remains a built-in will-o’-the-wisp. For example, no matter where one goes in the brain, sensory neurophysiology always sees an objective system that registers inputs in neural “codes,” and transforms them into neural outputs. The question is never addressed of how these neural processes culminate in, or are read out as, a subjectively experienced percept (e.g., a visual or a sound image). To leave the observer out of a science of clockworks is a useful artifice of the mind, but to leave the observer out of a science of the brain is to see nothing but clockworks while overlooking that sentience, without which clocks are a meaningless absurdity.

The fact that the brain is an observing system is probably a better reason for modifying materialism than the difficulty of trying to describe atomic particles without reference to the observing process. Clearly progress depends upon recognizing the limitations of the doctrines of classical materialism and causality, and replacing these models of reality with new concepts that bring so-called “objective” and “subjective” knowledge together in a unifying theory.

Requirements for a Science of Conscious Experience

If we postulate that conscious experience is an emergent property of certain levels of brain organization and that it plays an important role in brain function, what kind of questions have to be answered to develop a scientific understanding of it? Perhaps more importantly, what kind of questions do *not* have to be answered? For example, it is important to recognize that science need not explain what consciousness is, how it is produced, nor even how its effects are brought about. Science does not explain what gravitational force is, how it is created by, or generated from, mass, nor how the effects of gravity can act across vast reaches of space. The laws of gravity take gravitational force for granted, as a fundamental property, and restrict themselves merely to defining those lawful relationships existing between mass and gravitational force. In a similar fashion, a science of conscious experience can begin by describing precisely what kinds of systems have the property of awareness, what conditions within these systems are necessary and sufficient for the emergence of this property, what aspects of brain systems are influenced by the conscious property, and what lawful relationships exist between the quality of consciousness and the nature of the effects it has on the brain.

In this light, conscious experience is an enigma only insofar as science cannot yet define either the systems having this property or those influenced by it. This is not surprising since, as we have seen, science has so far been methodologically and conceptually limited to simple systems perceived as objects, whereas those living systems capable of being subjects are exceedingly complex.

It would be fruitless, not to say irrational, to suggest methodological or conceptual developments that will lead to a science of systems complex enough to have conscious awareness. Hard work and new discoveries are required for this progress to occur. It does seem worthwhile, however, to make a few comments about certain properties of the hierarchical organization of living systems. For a more thorough introduction to the topic, readers are referred to publications by Koestler, Polanyi, Weiss, and Szentagothai and Arbib.

By definition, a system is said to be hierarchically organized if, at each level of its organization, properties emerge that cannot be understood or predicted on the basis of information at the next lower level of organization. This, of course, precludes the hope that, by accumulating enough information about artificially isolated subsystems of the brain, a position can be reached where it can all be added together to yield an understanding of the whole brain. The concept of "boundary conditions" defines relationships between different levels of organization. For example, the performance of an electronic computer in solving a mathematical problem cannot be understood on the basis of the physics of its solid-state devices, nor even on the basis of the diagram of its circuitry, but only at the level of the program defining the sequence of steps in the computation. Each of these levels of organization provides boundary conditions within which the principles at the next lower level are allowed to operate. That is, the circuit design is not determined by the laws of physics, nor does it change the laws of physics, it merely provides a harness within which the laws of physics contribute to the function of the machine. Similarly, the software program is a boundary condition not explained by the circuit diagram, but providing limits within which the circuitry functions.

A further property of unique importance for living systems, distinguishing them from all machines and other nonliving systems, is that the elements of which they are composed “cooperate” to preserve the configuration of structure and behavior of the system. Weiss writes:

> The notion of ‘cooperation’ is, of course, a useful and excusable relapse into the analytic mental artifact of ‘independence’; it really means that subunits, which always have been interrelated just *somehow,* now seem to follow a common pattern —some *integral guidance.* If outside their systemic domain they displayed a high degree of freedom, this freedom has within the assembled state become severely restricted by restraints that can only be described in reference to all the members of the group. At every instant, the behavior of any one component unit is affected in unique fashion by the behavior of all the others, which to an outside observer, of course, gives the impression as if they all had a common aim—stability—and knew how to attain it. Whenever one group of components of the system deviates fortuitously, or is made to deviate, from its standard course too far in one direction, the rest automatically change course in the reverse direction so as to counteract the distortion of the pattern of the whole. But, one may ask, how do they come to know what happens everywhere and anywhere in their crowd and how do they manage to react appropriately? [P. 14]

This remarkable capacity for the whole to recover from distortions through the redeployment of subunits characterizes every level of living hierarchical systems—from those within cells to those at the level of multicellular organisms functioning as whole animals.

Another problem is directly related to the need for science to advance from simple mechanisms to complex systems. This is the question of how the breadth and diversity of brain systems are integrated into the unitary quality so characteristic of conscious awareness. In part, at least, this problem is an artifact of the analytical approach that investigates artificially isolated subsystems of the brain, and as science progresses to higher levels of brain organization it may discover systems having a more unified functional quality, reflecting the convergence of many subsystems. It is a possibility, perhaps highly probable, that this convergence will involve communicational processes that transcend the structural and functional limits of brain circuitry as represented by transmission of action potentials over the system of axons, synapses, and dendrites. At any rate, it is clear that only a fraction of total brain activity is represented within the focus of attention at any moment, and that the contents of this fraction change from moment to moment so that, over time, many, but by no means all, brain activities can gain conscious representation. It is further clear that information defined at the level of brain physiology is translated and transformed through conscious representation into information defined at the level of the whole organism. That is, the frame of reference changes from what kind of inputs make a difference for the output of one or another brain system to the question of what environmental circumstances confront the adaptive behavioral resources of the animal. This requires the selection and synthesis of information from many different brain systems in order to reconstruct, on the basis of past experience and the current sensory input from the external and internal (bodily state) worlds, an integrated representation or model of the whole organism and its relationships in time and space to meaningful objects in the environment. Sherrington contrasted the limited and mechanical adaptive value of a protective reflex with the flexibility introduced by conscious awareness:

> A mental event, pain, superadded to a reflex, the protective reflex, seems here to reinforce and amplify the physical act. The local reflex itself affords its limited protection and relief, e.g., by holding the part taut and quiet. But the 'pain' through the mind can enjoin keeping the whole body motionless though tense. In ourselves, social and sophisticated, it may provoke the train of action of 'calling in' the doctor. In short, under the rubric 'pain' we meet mind moving matter to help mind in mind's distress. [P. 225]

It is not yet possible to guess how the transform from brain to conscious levels of information occurs, but there is no compelling reason to believe that the flexibility with which conscious awareness selectively and shiftingly integrates the outputs of so many brain processes depends upon the same connectionistic circuitry that mediates transactions between different areas of the brain. Indeed, the importance of action potentials and circuitry may have been greatly exaggerated by the adventitious fact that neurons are easier to find with the exploring electrode if they fire an action potential. For example, recent advances in the study of retinal physiology reveal that non-spike, slow potential processing of information is important in retinal circuitry from the receptor to the ganglion cell. This discovery was facilitated by the fact that the retinal elements are more accessible to investigations than are brain cells, but since the retina is embryologically formed as an extension of the brain, these results suggest the possibility that nonaction potential processes may play a much more important role in the brain than has been suspected previously.

Certain requirements for a science of conscious experience have been suggested. Can science ever meet these requirements? Two considerations are critical. The first is that conscious awareness is private, so that its presence in other persons or in animals is only an inference. In principle, this problem will be resolved when the effects of conscious influences on brain systems have been discovered and specified. Consciousness would then be as observable as gravitational force, at least in principle. In the meantime, experimentation can proceed on the basis of assuming that other persons and higher animals are, indeed, as subject to conscious experience as the investigator himself.

The second consideration seems more ominous to me. The need to investigate more complex systems may require methods that become increasingly incompatible with life. Only future research can reveal how much of a hindrance to progress this will come to be.

Brain Research and Conscious Experience

As we have seen, the classical frame of reference of science is mechanistic, and the explanatory logic of science deals with objects but cannot deal with subjects. In this section, a few examples will be given to illustrate the kind of problems faced by investigators attempting to deal with conscious experience in experimental programs.

Penfield has used electrical stimulation to examine mind-brain relationships in more than one thousand conscious human patients undergoing craniotomy under local anesthesia. He suggests that conscious attentive states "program" the developing brain:

> Each man 'programs' his own brain by focusing and altering his attention, especially in childhood. In a sense, each individual mind is creating the brain mechanisms, establishing the brain connections that are functional. He does this by the selection of things to which he attends. It is easier to think of it during the earlier years of childhood. The child is establishing the functional pattern of connections. If the brain is tested later by electrical stimulation, it becomes evident that he has done one thing in one part of his cortex and another thing in another. In a sense, the child's mind is stepping in and creating the machinery of the brain. [P. 248]

With electrical testing of the waking brain, Penfield has identified a system of "interpretive cortex," the electrical stimulation of which evokes a stream of conscious experience. This may take two forms:

> Either he is aware of a sudden alteration in his interpretation of present experience (what he sees and hears seems suddenly familiar, or strange, or frightening, or coming closer or going away, etc.), or, he has a sudden 'flashback', an awareness of some previous experience.
>
> Although he is still aware of where he is, an earlier experience comes to him and the stream of that former consciousness moves forward again in full detail as it did in some previous period of time. . . .
>
> The sudden interpretation of the present and the flashback of the past are evidently parts of a scanning mechanism that normally enables an individual to compare present experience with similar past experience automatically. [P. 221]

If the neural activities evoked by this type of electrical stimulation could be defined, it would be a considerable step toward identifying the type of functional brain systems having the property of conscious awareness. Unfortunately, stimulation at a cortical point induces widespread cortical and subcortical activities, so that defining them would require animal experiments; but in these, reports of the evoked conscious experience would not be available.

Another type of observation reported by Penfield involves blocking of the speech mechanism by electrical stimulation of the cortex without impairing the patient's capacity for perception and reasoning. During electrical stimulation of the posterior speech area, a patient remained silent when shown a picture of a butterfly, which he knew he was supposed to name aloud.

> After withdrawal of the electrode, he exclaimed as though with relief: "Now I can talk, butterfly!" Then he added, "I couldn't get that word butterfly" and then I tried to get the word "moth."
>
> The speech mechanism had failed when called upon. To his surprise, he found himself aphasic. If he had not tried to speak, he would not have known that he was aphasic. [P. 230]

In this instance, a visual stimulus evokes a nonverbal percept of a butterfly, and an intention by the patient to label the percept with a word. On the basis of extensive experience with circumscribed cortical excisions, Penfield concludes that this nonverbal idea of a butterfly, and the intention to name it, arise from diencephalic centers. "The initiating demand arriving at the speech area must come from the diencephalon, whether it is an idea calling for a word or a word calling for the idea."

The fact that the idea of a butterfly arises through a neural system separate from that subserving the word by which the idea is labelled is, of course, a long way from understanding the functional neural systems that have the property of being aware of the idea and of the word; but, at the same time, such observations are a beginning.

In another type of research, the central mechanisms mediating voluntary movement are being investigated with new experimental methods for recording from conscious animals making reflex movements, stimulus-triggered movements and spontaneously initiated movements. For example, Evarts describes a monkey fitted with devices for immobilizing the head so that microelectrode recordings from pyramidal tract neurons can be made while the animal grasps a handle and makes certain movements in response to visual stimuli. Through standard operant conditioning techniques, the animal can be trained to make very complex movements, holding the handle in a certain position, or exerting a certain force, or pushing or pulling it. A microelectrode is lowered through motor cortex, while electrical stimuli are applied via implanted electrodes to the medullary pyramidal tract, so that cortical pyramidal tract neurons can be identified by the fact that antidromic spikes are evoked.

Important features of this experimental paradigm are that the responses of one neuron can be recorded during many repetitions of the same motor act, and many different neurons can be recorded during very similar motor movements. Comparisons can be made between neurons in the precentral motor cortex and those in the postcentral cortex, as well as between neuronal response during 'spontaneous' as contrasted with stimulus-triggered movements. During tasks of the 'reaction-time' type, time intervals can be measured between visual stimulus and motor-cortical response, and between motor cortex and the movement measured electromyographically. It can be determined whether a particular neuron’s response is temporally locked to the stimulus or to the motor response, and whether the pattern of its response differs as a function of the type movement (e.g., some neurons respond differently when the monkey pulls the lever than when he pushes, etc.).

In experiments of this kind, the possibility exists for observing differences in neural mechanisms as a function of variables such as attention, intention, and learning, so that even though only isolated mechanisms are observed, each of these mechanistically seen subsystems represents a glimpse of part of the complex systems having the conscious properties characteristic of the waking brain. For example, Fetz and Finocchio14 report that the relationship between activity in a precentral cortical cell and a motor response can be disassociated through the use of operant conditioning techniques. A precentral cell, activity of which had been correlated with a specific muscle response, began to fire in bursts without its correlated electromyographic response after a period of training in which reinforcement was contingent on activity in that cortical cell with simultaneous suppression of all muscle activity. In other words, the monkey learned to disrupt the physiological correlation between a particular cortical motor neuron and a specific muscle response. It seems probable that this flexibility is dependent upon the fact that one cortical cell, seen in relative isolation, is but a small component in the complex cellular systems underlying motor activity.

A final example of the experimental approach to conscious experience is the study of human subjects in whom the main communication systems between the two cerebral hemispheres (corpus callosum, anterior commissure, hippocampal commissure, and massa intermedia) have been surgically interrupted. Sperry and his group have been studying such “split brain” animals and humans for some years, using techniques whereby stimulus inputs, whether visual or tactile, reach one cerebral hemisphere but not the other. For example, for both eyes, a stimulus in the left half field, presented tachistoscopically to prevent scanning eye movements, reaches only the right hemisphere, whereas a stimulus in the right half field reaches only the left hemisphere. In right-handed persons, the dominant (left) hemisphere can express itself in speaking, but the minor (right) hemisphere, is mute. By the use of nonverbal testing procedures, the mute hemisphere can report on its experiences much as an aphasic patient can. For example, a tactile form presented, out of sight, to the left hand, can be selected from a set of different forms by the left hand, but not by the right hand. Questioning reveals that the dominant left hemisphere doesn’t know what form the left hand, controlled by the right hemisphere, has identified.

Two parallel tasks can be accomplished simultaneously, without interference, and with no awareness in one hemisphere of what the other hemisphere is doing. If the number “5” is flashed in the left half field simultaneously with a “7” in the right half field, the two hands, out of sight, can retrieve the corresponding tactile forms simultaneously, a “5” by the left hand, and a “7” by the right hand. If questioned, the subject will be able to identify only the “7” picked up by the right hand on the basis of information in the left (speaking) hemisphere.

Complementary specialization of each of the hemispheres for particular types of information processing (e.g., recognition of faces, unfamiliar forms, etc.) was investigated by using “chimeric” stimuli that result in simultaneous parallel processing of two different inputs. These stimuli are made up of two different half pictures, split vertically down the middle. For example, a chimeric “face” is made up of the left half of one person’s face adjoined to the right half of another person’s face. For the split-brain subject, each half face is filled in by a process of “perceptual completion,” so that one hemisphere perceives one face while the other hemisphere sees the other face. When questioned, the subjects were unaware of anything peculiar about the stimuli, even though with nonverbal responding (pointing to a set of pictures from which the chimeric picture had been constructed) it was clear that each hemisphere had recognized a different face.

Sperry concludes from these results that there are two separate spheres of conscious awareness running in parallel in each of the two hemispheres, particularly with regard to visual, tactile, and auditory information processing. Certain aspects of consciousness (e.g., sleep-wakefulness, hunger) are mediated by brainstem mechanisms that affect both hemispheres.

The inference that the minor (mute) hemisphere subserves conscious awareness is supported not only by the kind of information processing of which it is capable (e.g., facial recognition, pattern recognition) but also by evidence that it responds emotionally. Sperry writes:

> The minor hemisphere also seems to demonstrate appropriate emotional reactions, as for example, when a pin-up shot of a nude is interjected by surprise into a series of neutral or nonemotional stimuli being flashed to right and left visual fields at random. The subject under these conditions will characteristically say that he or she saw nothing, just a white light, as regularly happens for stimuli projected into the left field. However, one may then notice an inner grin beginning to spread over the subject's features which then lingers and carries over through the next couple of trials or so. It may also cause blushing and giggling and affect the tone of voice coming from the major side. If one then asks the subject what he is grinning about, the reply suggests that the talking hemisphere has no idea what it was that turned him on. He may say something like, 'That's some machine you have there!' or 'Wowee—that light!' Apparently the emotional tone alone gets across to the speaking hemisphere as if the cognitive aspect could not be articulated through the brainstem. [P. 319]

These results are not congruent with the traditional view that only unitary persons have conscious experience. For the split-brain person, choices made on the basis of information available only to one hemisphere are unknown to the other hemisphere, suggesting that each hemisphere is an adequate neural substrate for conscious awareness.

On the basis of his research with animals and humans, Sperry has postulated that conscious processes play a causal role in brain function. In response to questions by Bindra, Sperry further clarifies some of the issues involved in such a postulated functional role for conscious experience, differentiating his concept from dualistic notions, psychoneural interactionism, the theory that subjective phenomena are "identical" with neural activity, and the gestalt concept of parallelistic isomorphism.

It seems obvious from these few examples that as neuroscience research has begun to approach conscious experience more directly, it is increasingly handicapped by the analytical and mechanistic approach. As methods for approaching conscious phenomena in physiological experiments are improved, conceptual developments will become increasingly necessary. History suggests that this necessity will be the mother of invention, and that conceptualizations will be developed in the neurosciences that encompass more and more complex systems, including those having conscious awareness as an emergent property.

Concluding Remarks

The materialistic and mechanistic frame of reference, of nineteenth- and early twentieth- century science, has been examined with reference to the problem of conscious experience. It is emphasized that science itself is a product of conscious experience, and that the dichotomy between the observer and the observed that characterizes conscious experience has been impressed upon the classical materialistic model of reality, thereby consigning conscious experience to nonreality by excluding it from scientific reality. Logical and factual weaknesses in the mechanistic concept of man and conscious experience are reviewed, and a critique is given of the analogy between electronic computers and brains, especially insofar as it holds that machine performance is already a primitive step toward machines with conscious awareness. Some conceptual requirements for a science of conscious experience are suggested, especially the need to discover the relationships existing between complex hierarchically organized brain systems and the property of conscious awareness. The logic of cause and effect that treats living subjects as if they were only objects analytically dissected into artificially isolated simple mechanisms is contrasted with the conceptual requirements for understanding those extraordinarily complex, living systems that manifest conscious awareness. Examples from neuroscience research are given to illustrate how, as investigators become more directly concerned with conscious phenomena, the inadequacies of the classical materialistic doctrine are increasingly troublesome, giving rise to the search for better conceptual systems.

Bibliography

Barondes, S. H. "Axoplasmic Transport," in O. Schmitt, T. Melnechuk, G. C. Quarton et al., eds., *Neurosciences Research Symposium Summaries,* pp. 191-299. Cambridge: MIT Press, 1969.

Bass, L. and W. J. Moore. “A Proteolytic Memory Element Based on the Integrating Function of the Neuron,” *Brain Res.,* 33 (1971), 451-462.

Benson, I. “Machines That Mimic Thought,” *N. Scient. Sci. J.,* 51 (1971), 525-528.

Berry, R. W. “Ribonucleic Acid Metabolism of a Single Neuron: Correlation with Electrical Activity,” *Science,* 166 (1969), 1021-1023.

Bindra, D. “The Problem of Subjective Experience: Puzzlement on Reading R. W. Sperry’s ‘A Modified Concept of Consciousness,”’ *Psychol. Rev.,* 77 (1970), 581-584.

Bohr, N. *Atomic Physics and Human Knowledge.* New York: Science Editions, 1961.

De Robertis, E. “Molecular Biology of Synaptic Receptors,” *Science,* 171 (1971), 963-971-

Dowling, J. E. and F. S. Werblin. “Synaptic Organization of the Vertebrate Retina,” in T. Shipley and J. E. Dowling, eds., *Visual Processes in Vertebrates.* Vis. Res. Suppl. No. 3. Oxford: Pergamon, 1971.

Eccles, J. C. *Brain and Conscious Experience.* New York: Springer-Verlag, 1966.

Edds, M. V., D. S. Barkeley, and D. M. Fambrough. “Genesis of Neuronal Patterns,” *Neurosci. Res. Program Bull.,* 10 (1972), 253-367.

Evarts, E. V., E. Bizzi, R. E. Burke et al. “Central Control of Movement,” *Neurosci. Res. Program Bull.,* 9 (1971), 1-170.

Evarts, E. V. “Central Processing of Sensory Input Leading to Motor Output,” in F. O. Schmitt and F. G. Worden, eds., *The Neurosciences: Third Study Program.* Cambridge: M.I.T. Press, 1974.

Fambrough, D. M. and H. C. Hartzell. “Acetylcholine Receptors: Number and Distribution at Neuromuscular Junctions in Rat Diaphragm,” *Science,* 176 (1972), 189-191.

Fetz, E. G. and D. V. Finocchio. “Operant Conditioning of Isolated Activity in Specific Muscles and Precentral Cells,” *Brain Res.,* 40 (1972), 19-23.

Gisiger, V. “Triggering of RNA Synthesis by Acetylcholine Stimulation of the Postsynaptic Membrane in a Mammalian Sympathetic Ganglion,” *Brain Res.,* 33 (1971), 139-146.

Gisiger, V. and A-C Gaide-Huguenin. “Effect of Preganglionic Stimulation Upon RNA Synthesis in the Isolated Sympathetic Ganglion of the Rat,” *Prog. Brain Res.,* 31 (1969), 125-129.

Good, I. J. “Human and Machine Intelligence: Comparisons and Contrasts,” *Impact Sci. Soc.,* 21 (1971), 305-322.

Guntrip, H. “The Concept of Psychodynamic Science,” *Int. J. Psychoanal.,* 48 (1967), 32-43.

Hammes, G. G., P. B. Molinoff, and F. E. Bloom. “Receptor Biophysics and Biochemistry,” *Neurosci. Res. Program Bull.,* 11 (i973). 161-294.

Heisenberg, W. “The Representation of Nature in Contemporary Physics,” *Daedalus,* 87 (1958), 95-108.

Home, H. J. M. “The Concept of Mind,” *Int. J. Psychoanal*., 47 (1966), 42-49.

Koestler, A. The Ghost in the Machine. New York: Macmillan, 1967.

Levy, J., C. Trevarthen, and R. W. Sperry. “Perception of Bilateral Chimeric Figures Following Hemispheric Deconnexion,” *Brain,* 95 (1972), 61-78.

Mach, E. “The Economy of Science,” in James R. Newman, ed., *The World of Mathematics,* Vol. 3, pp. 1787-1797. New York: Simon & Schuster, 1956.

Penfield, W. “Comments in Discussion,” in John C. Eccles, ed., *Brain and Conscious Experience,* p. 248. New York: Springer- Verlag, 1966.

----. “Speech, Perception, and the Uncommitted Cortex,” in J. C. Eccles, ed., *Brain and Conscious Experience,* pp. 217. New York: Springer-Verlag, 1966.

----. "Epilepsy, Neurophysiology, and Some Brain Mechanisms Related to Consciousness," in H. H. Jasper, A. A. Ward, and A. Pope, eds., *Basic Mechanisms of the Epilepsies,* pp. 791-805. Boston: Little, Brown, 1969.

Penfield, W. and P. Perot. "The Brain's Record of Auditory and Visual Experience," *Brain,* 86 (1963), 595-696.

Polanyi, M. "Life's Irreducible Structure," *Science,* 160 (1968), 1308-1312.

Popper, K. R. *Conjectures and Refutations: The Growth of Scientific Knowledge.* New York: Harper Torch Books. Harper and Row, 1968.

Pysh, J. J. and R. G. Wiley. "Morphologic Alterations of Synapses in Electrically Stimulated Superior Cervical Ganglia of the Cat," *Science,* 176 (1972), 191-193.

Rall, T. W. and A. G. Gilman. "The Role of Cyclic AMP in the Nervous System," *Neurosci. Res. Program Bull.,* 8 (1970), 221-323.

Schade, J. P. and J. Smith, eds. *Computers and Brains.* Progress in Brain Research, Vol. 33, New York: Elsevier, 1970.

Schimke, R. T. "Principles Underlying the Regulation of Synthesis and Degradation of Proteins in Animal Tissues," in F. O. Schmitt and F. G. Worden, eds., *The Neurosciences: Third Study Program,* pp. 813-825. Cambridge: MIT Press, 1974.

Sherrington, C. *Man On His Nature,* 2nd ed. London: Cambridge University Press, 1953.

Singer, S. J. and L. J. Rothfield. "Synthesis and Turnover of Cell Membranes," *Neurosci. Res. Program Bull.,* 11 (1973), 1-86.

Sperry, R. W. "Brain Bisection and Mechanisms of Consciousness," in J. C. Eccles, ed., *Brain and Conscious Experience,* pp. 298-313. New York: Springer-Verlag, 1966.

----. "Mental Unity Following Surgical Disconnection of the Cerebral Hemispheres," in *The Harvey Lectures, Series 62,* pp. 293-323. New York: Academic, 1968.

----. “A Modified Concept of Consciousness,” *Psychol. Rev.,* 76 (1969), 532-536.

----. “An Objective Approach to Subjective Experience: Further Explanation of a Hypothesis,” *Psychol. Rev.,* 77 (1970), 585-590.

Szentagothai, J. and M. A. Arbib. “Conceptual Models of Neural Organization,” *Neurosci. Res. Program Bull.,* 12 (1974), 305-510.

Turing, A. M. “Can A Machine Think?,” in James R. Newman, ed., *The World of Mathematics,* Vol. 4, pp. 2099-2123. New York: Simon & Schuster, 1956.

Weiss, P. A. “Depolarization: Pointers to Conceptual Disarmament,” *Stud. Gen.,* 23 (1970), 925-940.

----. *Hierarchically Organized Systems in Theory and Practice.* New York: Hafner, 1971.

----. “The Basic Concept of Hierarchic Systems,” in P. Weiss, ed., *Hierarchically Organized Systems in Theory and Practice,* pp. 1-43. New York: Hafner, 1971.

Weizenbaum, J. “On the Impact of the Computer on Society,” *Science,* 176 (1972), 609-614.

Wigner, E. P. “Remarks on the Mind-Body Problem,” in I. J. Good, ed., *The Scientist Speculates,* pp. 284-302. New York: Basic Books, 1962.

Wooldridge, D. E. *The Machinery of the Brain.* New York: McGraw-Hill, 1963.

----. *The Machinery of Life.* New York: McGraw-Hill, 1966.

----. *Mechanical Man, The Physical Basis of Intelligent Life.* New York: McGraw- Hill, 1968.

Worden, F. G. “Questions About Man’s Attempt To Understand Himself,” in Robert R. Holt and Emanuel Peterfreund, eds., *Psychoanalysis and Contemporary Science,* Vol. 1, pp. 38-59. New York: Macmillan, 1972.

Notes

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