Models of the Visual Cortex
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Chapter 2

Methodological problems of neuroscience

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In this paper I argue that neuroscience has been harmed by the widespread adoption of seriously inadequate methodologies or philosophies of science—most notably inductivism and falsificationism.

Any branch of inquiry, in order to be rational, must at the very least obey the following rules:

1. Articulate and seek to improve the articulation of the basic problem(s) to be solved.
2. Propose and critically examine alternative possible solutions.

Many basic intellectual problems are, however, too intractable to be solved by means of this direct approach alone. It proves necessary to create a host of preliminary, subordinate, specialized problems, whose resolution leads gradually and progressively towards a resolution of the basic problem to be solved. Especially important is the strategy of tackling problems that are analogous to but simpler and more solvable than the basic problem to be solved—in this way progressively developing problem-solving methods and capacities which lead eventually to the solution of the basic problem. Indeed, all problem solving may be said to exploit this principle in one way or another: inevitably in solving a new problem we discover how to relate it to analogous already solved problems in such a way that the solutions may be adapted to provide a solution to the new problem. We thus have an important third rule of rational problem solving:

3. Where necessary, break the basic problem up into a number of preliminary, simpler, analogous, subordinate, specialized problems (to be tackled in accordance with rules 1 and 2), in an attempt to work gradually towards a solution to the basic problem to be solved.

The danger in putting this third rule into practice is that the activity of solving preliminary, specialized problems may obliterate all concern for the original, basic problem(s). We need therefore a fourth rule to counteract this danger:

4. Interconnect attempts to solve basic and specialized problems, so that basic problem solving may guide, and be guided by, specialized problem solving.

All science, and indeed all inquiry, needs to put these four elementary methodological rules into practice (Maxwell, 1980, 1984).

Two historically important but seriously defective methodological views—*inductivism* and *falsificationism*—have tended, as a result of being widely accepted by scientists and non-scientists alike, to prevent the above four rules from being put into practice in science, to some extent at least.

Inductivism holds that science begins with observation and experimentation, and only gradually and cautiously moves from observational and experimental knowledge to theoretical knowledge. Inductivism is in effect an exaggerated version of rule 3. It demands of scientists that they restrict themselves, in the first instance at least, to solving preliminary, subordinate problems of observational and experimental knowledge, solutions to such problems only subsequently and gradually leading to the solutions of more general, theoretical problems of knowledge. Francis Bacon, an important proponent of inductivism, was quite explicit on this point. He argued that if we are to acquire genuine knowledge of Nature of real value then we must abandon the sterile theoretical speculations of traditional philosophy about ultimate problems and seek instead to acquire much more limited, but genuine, knowledge soundly based on observation and experiment.

Inductivism is of value to the extent that it does endorse rule 3. Otherwise it is damagingly irrational, in that it violates rules I, 2 and 4. The rational procedure is to *interconnect* philosophical speculation concerning fundamental problems and much more restricted observational and experimental problem solving, as rule 4 stipulates. Pursuing science in accordance with inductivism is profoundly damaging in that it leads to the acquisition of vast amounts of observational and experimental data devoid of any theoretical interest or importance. This is a direct consequence of the irrationality of inductivism—its failure to interconnect theoretical and empirical problem solving.

Falsificationism (or hypothetico-deductivism), as expounded especially by Karl Popper (1959, 1963), holds that science begins not with observation and experiment but rather with *problems* generated by *theories.* Science proceeds by proposing solutions to these problems, namely new theories, which are then critically assessed, especially by experimental testing. Scientific method thus amounts to a process of theoretical conjecture and empirical refutation.

Scientific theories cannot be verified empirically, but they can be empirically falsified. There is thus the possibility of detecting and eliminating error and of making progress towards greater (conjectural) knowledge. In order to exploit this possibility for making progress, however, science must restrict itself to considering theories that are capable of being falsified empirically. Untestable philosophical, metaphysical and methodological ideas must be excluded from science (in accordance with Popper's criterion demarcating science from non-science).

Falsificationism thus demands of scientists that they propose and criticize empirically falsifiable possible solutions to theoretical problems: to this extent it endorses rules 2 and 3 and is a great improvement over inductivism. Falsificationism stipulates, however, that only empirically testable ideas can enter into the intellectual domain of science; this ensures that untestable ideas designed to help clarify and solve basic scientific problems are excluded from the intellectual domain of science. To this extent falsificationism violates rules 1, 2 and 4, and is thus damagingly irrational (Maxwell, 1972, 1974, 1979). The long process of articulating basic (philosophical or metaphysical) problems of knowledge and understanding, and of proposing and criticizing possible solutions to such problems—which is such a vital part of science and which can lead eventually to important new empirically testable theories—is banished from the explicit intellectual domain of science altogether. To this extent fundamental and specialized theorizing and problem solving arc dissociated from one another, in violation of rule 4—philosophy and empirical science becoming dissociated to the detriment of both. One bad consequence of this is that the process of discovery in science becomes a mystery, an irrational affair, as Popper himself acknowledges (Popper, 1959, pp. 31-32).

Inductivism and falsificationism both uphold what Popper has called *'the principle of empiricism*, which asserts that in science, only observation and experiment may decide upon the *acceptance or rejection* of scientific statements, including laws and theories' (Popper, 1963, p. 54). Even if the principle of empiricism were tenable, inductivism and falsificationism would still both be unacceptable for the reason just given, namely for their violation of elementary methodological rules of rational problem solving 1 to 4. What makes the matter much more serious is that the principle of empiricism is *untenable.* Given any scientific theory, however extensively corroborated empirically, not all its predictions will have been tested. By arbitrarily modifying these untested predictions, we can create as many rival theories as we please, all just as successful empirically as the given theory (Maxwell, 1974, pp. 127-136; 1984, pp. 206-214). Thus any honest attempt to pursue science in accordance with the principle of empiricism would overwhelm science with infinitely many different, horribly complex, *ad hoc* theories—all, at any given stage, equally acceptable because of equal empirical success.

This would instantly bring science to a standstill. In practice science usually avoids this disaster by considering only simple, coherent, unified, explanatory or comprehensible theories that meet with empirical success—thus at a stroke violating the principle of empiricism, which states that empirical considerations *alone* determine choice of theory in science. The scientific enterprise is obliged, in other words, to presuppose that the universe is comprehensible in some way or other; in order to be acceptable a theory must at least be. compatible with the best current version of this presupposition (or more compatible than any rival theory). Thus two kinds of consideration govern the choice of theory in science: (a) considerations of empirical success and failure; (b) non-empirical considerations concerning the inherent unity, explanatory character or comprehensibility of the theory in question.

The best current version of the metaphysical assumption (or conjecture) that the world is comprehensible, implicit in the current basic concepts and methodology of science, inevitably exercises a profound influence over the whole of science. This assumption must also, however, for obvious reasons, be profoundly problematic. Even if the world is comprehensible in some way or other, almost certainly it is not comprehensible in just the way it is assumed to be by science at any given stage of its development. An elementary requirement for intellectual rigour, for rationality, is that problematic and influential assumptions be made explicit so that they can be criticized and, we may hope, improved. Therefore, if science is to comply with even the most elementary of requirements for intellectual rigour, it is essential that profoundly influential and problematic metaphysical assumptions about how the world is comprehensible be made explicit in science. If such metaphysical assumptions are articulated, criticized and improved within science, we may hope to improve *the aims and methods* of science as we proceed. As we improve our scientific knowledge of the world, we may hope to improve our knowledge about how to improve knowledge—scientific progress accelerating as a result (Maxwell, 1974, 1979, 1984, Chaps. 5 and 9).

All this once again illustrates rules 1 to 4, and especially rule 4, the importance of interconnecting basic and specialized problem solving.

Inductivism and falsificationism, however, both seek to exclude influential and problematic metaphysical assumptions about comprehensibility from science. They seek to do this in a misguided attempt to preserve the intellectual rigour, the scientific character, of science. Actually they do the exact opposite: they *undermine* the intellectual rigour, the scientific character, of science. They render influential and problematic assumptions undiscussable within science.

The rules 1 to 4 are, of course, put into practice in science to a very great extent: without this, science would not have achieved the success that it has achieved. Widespread attempts to pursue science in accordance with inductivism or falsificationism have, nevertheless, had damaging consequences for science (Maxwell, 1976, 1984). This holds for the physical sciences to some extent at least; it holds to a greater extent for the biological sciences, and is especially pronounced, 1 wish to argue, for the neurosciences. In the physical sciences falsificationism nowadays predominates; inductivism at least has been almost universally repudiated. Biological science, by contrast, has not yet reached even this degree of methodological sophistication. Here inductivism still predominates. Biological scientists are still reluctant to propose empirically unsupported, falsifiable speculations. In neuroscience this inductivist reluctance has resulted in the accumulation of a vast amount of empirical knowledge in the almost complete absence of any testable, empirically progressive theory as to how the brain works overall—any theory, that is, that is comparable in stature to the great unifying, explanatory theories of physics. If physics was like neuroscience in this respect, then we would have in physics a vast amount of empirical knowledge, but we would be without Newton's theory of gravitation, Maxwell's theory of the electromagnetic field, Einstein's special and general theories of relativity, and the quantum theories of Bohr, Heisenberg, Schrödinger, Dirac, Schwinger, Feynman, Weinberg and Salem.

Not only is there in neuroscience an *inductivist* reluctance to publish falsifiable speculations, in addition there is a *falsificationist* reluctance to publish unfalsiliable speculations as to how the basic problems of neuroscience are to be conceived and solved, in violation of rules 1 and 2. Exceptions to this do of course exist, e.g. Eccles (1970) or Young (1978). On the whole, however, in order to find such unfalsiliable speculations one has to look elsewhere, to the extensive philosophical literature on the mind-body problem: see, for example, Broad (1925), Ryle (1949), Smart (1963), Vesey (1964), Feigl (1967), Armstrong (1968), Campbell (1970), Popper (1977) and Dennett (1979). In this way, philosophical discussion of the basic mind-body problem tends to be harmfully dissociated from scientific discussion of more specialized problems of neuroscience, in violation of rule 4. This division persists even where deliberate attempts are made to overcome it: see, for example, Popper and Eccles (1977).

How then ought neuroscience to proceed, granted that it puts rules 1 to 4 into practice? And how, in more detail, does the current failure to put these rules into practice, as a result of the adoption of inductivism and falsificationism, serve to impede progress in neuroscience?

The first step is to formulate the basic problem of neuroscience, in accordance with rule 1. This ought not to be difficult, as long as we do not attempt to formulate the problem too precisely. It might be put like this. How do our brains enable us to do all the different sorts of things that we can do in life—see, hear, smell, feel, experience, understand, walk, speak, write, love, hate, be conscious of, choose, plan, reason, communicate?

The next step is to put forward diverse possible solutions to the problem, in accordance with rule 2. This has been attempted in the philosophical literature, indicated above.

At once the problem arises as to how a preferred possible solution is to be selected from all these candidates, to guide more detailed neuroscientific research. We need to choose that conjecture which seems to be the most strikingly implicit in, and borne out by, specialized neuroscientific research and which, at the same time, seems to hold out the greatest hope for progress in neuroscience, if true. Of all the proposed solutions to the basic mind-body problem so far put forward, there is one, I suggest, which best satisfies these methodological requirements. It might be called *the control theory of mind and brain.* It asserts that it is our brain, operating in accordance with physical law, which guides or controls us to perform and experience all that we do perform and experience in life. The mind is the brain: it is the control aspect of the brain. Our inner experiences, thoughts, feelings, states of awareness are complex neurological processes construed from the standpoint of their role in guiding or controlling our actions. There is more to us than can ever even in principle be described and explained in purely physical terms, but this is because physics seeks only to describe a selected aspect of all that there is; it deliberately omits experiential, purposive or control aspects of reality (Maxwell, 1966, 1984, Chap. 10).

This metaphysical conjecture about the nature of mind ought, 1 suggest, to influence and be influenced by neuroscientific research in much the same way as metaphysical conjectures about how the universe is comprehensible influence and are influenced by research in physics, in the way indicated briefly above (in accordance with rules 3 and 4).

Once this control theory of mind is conjecturally adopted, the basic problem of neuroscience becomes to specify in detail how neurological processes occurring in our brains both correspond to our inner experiences, thoughts, feelings and states of awareness, and guide us to act in the ways that we do in response to our inner experiences, thoughts, feelings and states of awareness.

This reformulated version of the basic problem of neuroscience is, however, profoundly intractable—if for no other reason than that there are an immense number of neurons in the human brain interconnected in incredibly numerous and complex ways. We need, then, to tackle the problem by attempting in the first instance to solve easier, analogous problems, thus putting rule 3 into practice. An important and by no means obvious matter is to choose the best possible, easier, analogous problems to try to solve, and the best possible route to take to the resolution of the basic problem we wish to solve.

In order to discover the best possible way to put rule 3 into practice, the vital point that needs to be remembered is that human brains have been designed by the twin evolutionary mechanisms of random variation and natural selection—the earliest, simplest kind of nervous system in existence being subjected to a vast number of small modifications over millions of years until eventually the human brain resulted. My suggestion is that it is something like this evolutionary path that we should seek to retrace in attempting to solve progressively the problem of how the human brain works. We need to begin by attempting to understand how the simpler nervous systems work—those of jellyfish, for example, or sea anemonies—progressively moving on to more and more sophisticated and complex nervous systems until we come to those of humans.

In putting this evolutionary research programme into practice we do not need to retrace precisely the path taken by evolution in developing the human brain. Rather, the basic idea is to develop progressively problem-solving capacities (in accordance with rule 3) by moving from simpler to progressively more complex brains, in a way that is roughly in accordance with evolutionary development. Thus the fact that species from which we have evolved have long become extinct does not constitute a major obstacle for the *methodologically* evolutionary research programme proposed here, even though it does constitute a serious obstacle for those who seek to retrace precisely the path taken by evolution in developing the human brain.

This latter problem of how nervous systems have actually evolved has received considerable attention: see, for example, Sarnat and Netsky (1981). The evolutionary research programme proposed here has not, however, received the sustained and coordinated attention that it deserves—essentially because not enough explicit attention has been given to the problem of how rule 3 ought to be put into practice, due to the prevalence of inductivism or falsificationism amongst neuroscientists, as opposed to the methodology of rational problem solving outlined above.

Five striking indications of the failure even to attempt to put this evolutionary research programme into practice are the following.

First, in order to put the programme into practice, it is essential that there is close collaboration between the specialized disciplines of evolutionary biology, ethology, neuroanatomy, neurophysiology, artificial intelligence, psychology and the philosophy of mind. This absolutely essential collaboration has not always been very apparent—philosophy of mind and artificial intelligence, especially, and psychology, to a lesser extent, being pursued somewhat independently of the biological sciences.

Second, artificial intelligence has quite strikingly failed to adopt the evolutionary path to understanding the human brain. Instead, almost without discussion, rule 3 has been put into practice in a quite different way. Artificial intelligence has sought to design artefacts which imitate more or less elementary *fragments* of intelligent human activity—recognizing patterns and objects, manipulating objects manually, reasoning, chess playing, speaking, translating—the hope being, presumably, that these fragments of human activity can be put together to form eventually an artefact that can imitate *all* that we do. This way of putting rule 3 into practice fails lamentably, however, to tackle the problem of how the brain achieves *overall* control, in easy stages, from elementary to highly complex, sophisticated versions of the problem. This problem of how the brain achieves overall control is the problem of understanding the primary control system of the brain—that which activates subordinate control systems to guide the animal, from moment to moment, to act as it does in its given environment. Only the evolutionary application of rule 3 can enable us to tackle this basic problem of overall control in a progressive fashion, from simple to complex versions of the problem by easy stages. Thus, in a quite elementary way, the entire research programme of artificial intelligence has been misconceived, due to a failure to consider intelligently how rule 3 is to be put into practice. The very title of the discipline is indicative of this mistake: 'artificial intelligence' ought to be called 'artificial life', or perhaps 'artificial control' or 'artificial goal pursuing'.

Third, artificial intelligence has failed in an elementary way to tackle the particular kind of control problems that arise in connection with the nervous system of animals and people. It is quite obvious that even the simplest action performed by an animal or person involves what may be called 'hierarchical-parallel' control. There is the pyschologically elementary decision to run, hunt or whatever, at the highest level of control. This initiates a large number of low-level control systems controlling contractions and relaxations of individual muscles. These low-level control systems must, however, work together harmoniously if individual muscle contractions are to add up to the overall intended action—running, hunting or whatever. Low-level control systems operating in parallel must presumably communicate with each other, and with higher level control systems, if the animal or person is to act in a way that is intelligently responsive to the particularities of the environment. All this, it deserves to be noted, beautifully exemplifies rules 1 to 4, problem solving being a special case of goal pursuing. Indeed, rules 1 to 4 might almost be said to encapsulate the notion of hierarchical-parallel control, goal pursuing or problem solving. Methodology is doubly relevant to neuroscience. It is relevant to the conduct of neuroscience, and it is relevant to the actual subject matter itself of neuroscience. For the brain is itself a problem solver, designed by evolution, we may presume, to solve problems of living in a highly efficient manner—in a manner, that is, that puts into practice a rational methodology of problem solving. However, if living systems operate by means of hierarchical-parallel control, computers and robots built by artificial intelligence experts seem to work according to quite different principles. Such artefacts proceed *sequentially,* one step being performed at a time, rather than by means of *hierarchical-parallelism.* This means that the control problems tackled by artificial intelligence have been largely irrelevant from the standpoint of understanding how animal and human brains work. This, as before, is a result of artificial intelligence being pursued in a way that is dissociated from biology.

Fourth, psychology and the philosophy of mind have not seriously attempted to implement the evolutionary research programme indicated above. If our minds are the control aspect of our brains, and if this control aspect of our brains has evolved over millions of years by means of very many successive modifications produced by random variation and selected by natural selection, then all apparently distinctively human capacities—such as our capacity to experience, to be conscious, to choose freely, to communicate, to use and understand language, to produce art and science, to imagine and reason, and to love—must have evolved gradually, step by step, from early beginnings deep in our animal past. This means that no understanding of these human capacities can be adequate which does not portray them as *capable* of evolving gradually, in response to evolutionary pressures. A basic task for psychology and the philosophy of mind is to develop theories of consciousness, free will, etc., which render these things open to such evolutionary understanding—in close collaboration, of course, with the other branches of neuroscience. This task has not been given the priority it deserves.

Fifth, neuropsychology—somewhat like artificial intelligence—has failed to give priority to the problem of how the brain achieves *overall* control. Much work has been devoted to improving knowledge and understanding of subsystems of the brain—the visual cortex, the motor cortex, the cerebellum, and so on—but, as the editors of this book in effect point out in their introduction, no model of the visual cortex can ultimately be satisfactory which fails to show how the visual cortex is functionally related to the rest of the brain. Ultimately, the job of the visual cortex is to enable the animal to act successfully in its environment: visual information is processed to this end. It is this that models of the visual cortex need to describe and explain. In short, in order to understand how the visual cortex works, we need to understand how the brain achieves *overall* control. In order to solve this problem of overall control we will need to adopt the evolutionary approach advocated above.

Finally, in an attempt to put rule 4 into practice, I conclude with a crude neuropsychological speculation as to how the fundamental problem of overall control is to be solved. In mammals, including humans, overall control is to be associated with the reticular formation. Furthermore, since *consciousness* is what, for us, achieves overall control (Shallice, 1978), consciousness is to be associated with the functioning of the reticular formation in our brain. Diverse neurological processes occurring in the cerebral cortex constitute *subordinate control systems*, which become differentially activated and so more conscious and deactivated and so less conscious—as the primary control system of the reticular formation dictates—as our attention moves from one thing to another.

This reticular formation theory of overall control and consciousness has not, I suspect, been given the attention it deserves because it conflicts with the traditional view that consciousness is to be associated with the cerebral cortex. We differ from other animals in having both enhanced consciousness and an enlarged cerebral cortex. From this the conclusion is reached that consciousness is to be associated with the cerebral cortex. However this argument is invalid (MacKay, 1966). Enhancement of consciousness may well be associated with the development *of subordinate* control systems of the brain, facilitating imagination, planning, speech, and so on. The reasonable conjecture, in line with the evolutionary approach, is to associate consciousness in us with that neurological feature of our brain which most closely corresponds to that which achieves overall control in the simplest mammalian brain.

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