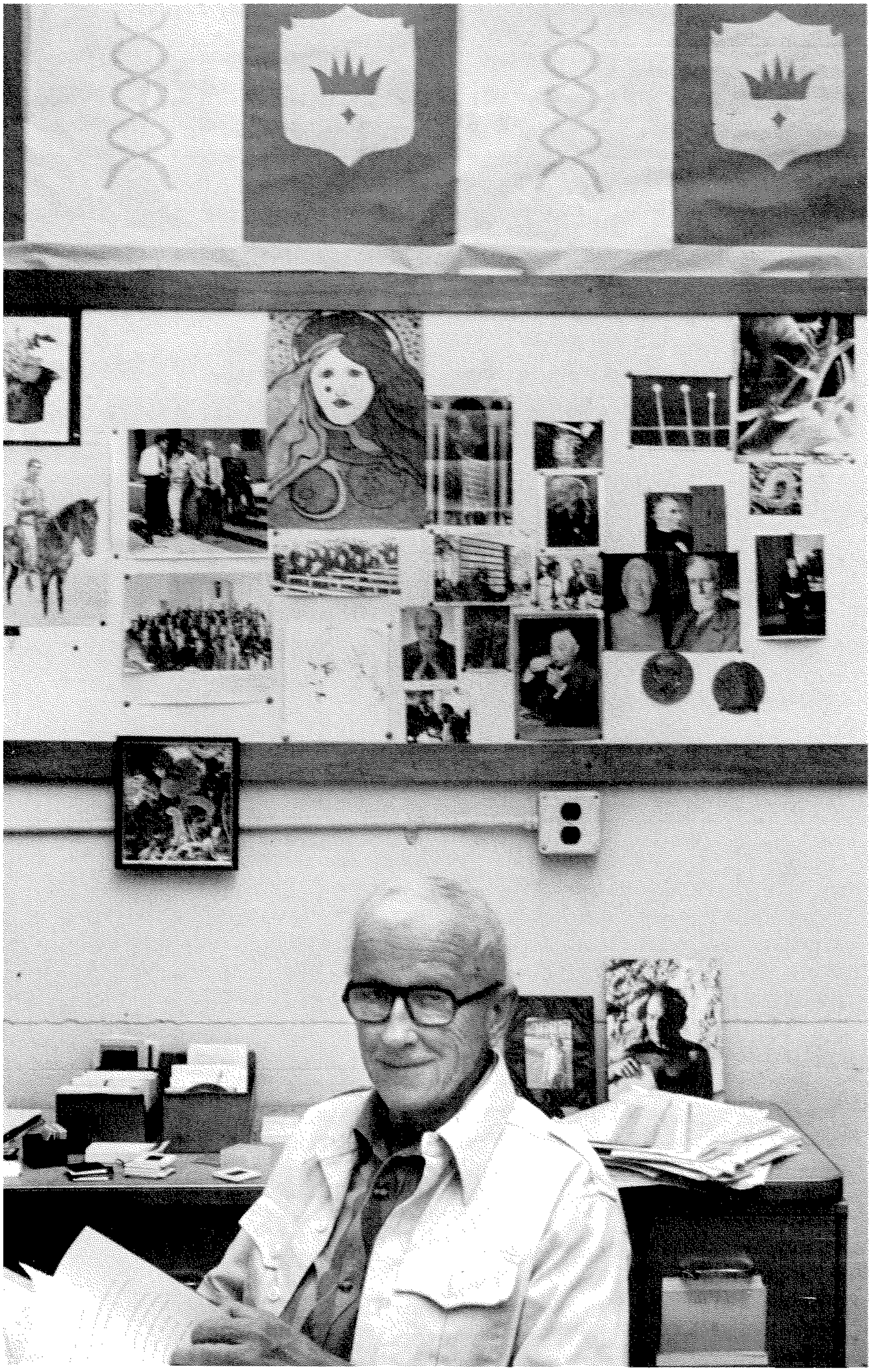

Max Delbrück poses in his Caltech office about the time of the "Mind From Matter?" lectures. These lectures were published in November by Blackwell Scientific Publications, Inc.; this chapter appears in the book.

The Cartesian

by Max Delbrück

IN 1932, WHEN NIELS BOHR conjectured that there might exist a mutual exclusion between experiments that would provide a description of an organism in terms of atomic physics and experiments that would provide a description in terms of genetics, physiology, and embryology, these three biological disciplines were already well developed. The phenomena they addressed seemed to be unique to living matter, transcending what physical chemists were able to account for in terms of the kinetics and thermodynamics of chemical reactions. At least it appeared so at that time, when there were many biologists who embraced the view of "vitalism." According to that view, living matter owes its characteristic properties to a "vital force" not present in nonliving matter.

Vitalist biologists insisted that the features of living systems that seem to defy the laws of physics and chemistry are attributable to special drives and forces. For example, the evolutionary increase in organismic complexity, which appears to run counter to the second law of thermodynamics (whose basic prediction of a loss of capacity of a system to do future work is equivalent to predicting a decrease of order or an increase in entropy in the system over time) was explained by an "anti-entropic principle." Other biologists, especially those approaching living systems from the biochemical or physiological point of view, were strongly opposed to such vitalist notions. They insisted that it is quite unacceptable to have a picture of the world in which matter is viewed as subject to addi-

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tional, "unphysical" forces as soon as it forms part of a living organism. They held that the comportment of living matter is also governed wholly by the laws of physics and chemistry.

Bohr's contribution to this controversy was to point out that the invocation of special laws that transcend the laws of physics to account for the comportment of living matter is not necessarily in irreconcilable conflict with the notion that there is no essential difference between the atoms of which living and nonliving matter are composed. In line with his general complementarity argument, Bohr suggested that, just as quantum physics managed to construct a rational theory of matter in which its wave and particle aspects coexist harmoniously, so might biology manage to provide a rational account of living matter by accepting the coexistence of seemingly conflicting notions about the laws that govern its behavior. Bohr thought that the two types of mutually exclusive observations arise from the fact that it is necessary to kill an organism if one wants to examine it closely enough to locate its atoms, a situation equivalent to the necessity of changing the state of an atom in order to locate its electrons.

The fate of Bohr's proposal regarding the role of complementarity in biology was different from that which it had been accorded in atomic physics. It was not necessary to invoke any mutual exclusion of observational arrangements in biology to account for living matter. Instead, the development of systems theory, especially of cybernetics, has shown that many of the life processes that seemed miraculous 50 years ago can, in fact, be simulated by machines. In 1948 John von Neumann showed that a self-reproducing machine, or automaton, is feasible in principle. In the following excerpt from a lecture by von Neumann (published posthumously in 1966), the designations now used by molecular biologists for the parts of the cellular apparatus of self-reproduction are indicated in brackets for the components of the automaton listed by von Neumann.

> . . . a self-reproducing automaton must have four separate components with the following functions: Component A is an automatic factory, an automaton which collects raw materials and processes them into an output, specified by a written instruction, which must be supplied from the outside. [Component A corresponds to the enzymatic apparatus of the cell that catalyzes the synthesis of building blocks of macromolecules, such as amino acids (for proteins) and nucleotides (for nucleic acids) from foodstuff, as well as the ribosomes and other accessories of protein synthesis, such as tRNA and tRNA-aminoacyl synthetases. The "written instruction" corresponds primarily to the nucleotide sequence embodied in the DNA, and secondarily to its mRNA transcript.] Component B is a duplicator, an automaton which takes the written instruction and copies it. [Component B corresponds to DNA polymerase and other enzymes directly associated with the process of DNA replication.] Component C is a controller, an automaton hooked up to both A and B. When C is given an instruction, it first passes the instruction to B for duplication, then passes it to A for action, and finally supplies the copied

instruction to the output of A while keeping the original itself. [Component C corresponds to (1) the apparatus that governs the initiation of DNA replication, (2) RNA-polymerase and other enzymes responsible for DNA transcription and synthesis of mRNA, and (3) the mitotic spindle (or its equivalent in prokaryotes), which assures that each of the two sister cells resulting from the activity of component A receives one of the DNA replicas generated by component B.] Component D is a written instruction containing the complete specifications which cause A to manufacture the combined system, "A plus B plus C." [Component D corresponds to the genome or the entire DNA complement, which encodes the set of mRNA's that specify the set of enzyme molecules that catalyze the synthesis of the cellular components.]

Von Neumann's automaton was conceived to be a minimal one. It describes a self-reproducing system different from that represented by living cells in not interposing an intermediate messenger (mRNA) between the master tape (DNA) and its realization (protein); rather it envisages a direct translation of the DNA nucleotide sequence into the protein amino acid sequence. However, some viruses that contain RNA rather than DNA as their genetic material do resemble von Neumann's minimal scheme: for instance, the genetic material of the poliovirus serves as its own mRNA in directing the synthesis of poliovirus proteins, as well as replicating directly. Viruses, however, are simpler than von Neumann's system, in that they relegate function A of his automaton, the production of the output, to the apparatus for synthesis of building blocks and proteins of the host cell.

The existence proof of self-reproducing automatons is not the only, or even the most significant, accomplishment of cybernetic systems theory, especially since no such automaton has actually been built. The most significant accomplishment of cybernetics is probably its demolition of the old prejudices that machines cannot adapt to novel situations, cannot learn from experience, and cannot interact with human beings in any meaningful way. For it turned out to be possible to design and construct machines that refute these claims. Some of these machines will be discussed in these final chapters.

Let us now recapitulate our assessment of how the progress of science has managed to denature the old concepts of object, number, time, topological space, projective space, metric space, and causality. What has happened to all those concepts that constituted our naive view of external reality? What has happened to this evolutionary acquisition, of immense adaptive value, that enables us to cope with the world? It is ironic that science has pulled the rug out from under this conceptual structure. The special relativity theory has replaced the concrete space-time frame with an abstract one, in which one twin may go on a trip and return a younger person than the stay-at-home twin — a claim that is irreconcilable with our concrete mental operations regarding space and time. The general relativity theory tells us of "singularities in space," black holes with an "event horizon" from which no signals can emerge, and finite but not bounded space — concepts that we can learn to manipulate in a formal way but cannot visualize. Quantum theory, the worst offender, does away with object identity and trajectory of objects (electrons do not revolve in orbits). It proclaims a conspiracy of nature that forces us to choose, to make either/or decisions between various aspects of reality that in any observational act are mutually exclusive. Is this a Kierkegaardian notion, with every observation becoming an existential act? Have physicists become religious thinkers? Einstein was unwilling to accept this conspiracy. His attitude is reflected in such remarks as "The Good Lord may be cunning, but malicious He is not" and "God does not play dice with the universe." Whether God is malicious or not, no satisfactory assimilative alternative to accommodate (in Piaget's sense) to this conspiracy has been found, and as Bohr's analysis made clear, none is likely to be found.

No, physicists have not become religious thinkers, since the either/or choice they are forced to make is not an ethical one, not even the choice of an individual observer, but one that concerns collective observations on, say, light quanta: pass them through an analyzer that permits statements about their circular polarization (clockwise or counterclockwise) or through an analyzer that permits statements about their plane polarization (vertical or horizontal). We make this choice, and our choices materially exclude each other, because any one quantum, once it is observed — that is, recorded by a counter — is irreversibly gone. Such is the individuality, the quantum nature, of any atomic interaction involved in constructing an object world. It always leaves this object world with a residue of uncertainty and limits us to statistical predictions.

This bizarre dialectical situation goes to the heart of the concept of the reality of the physical world, so basic to the evolution of the human mind. For a million years or so we have been animals that know the dichotomies: actor-observer, I and the world, mind versus reality, a confrontation between an inner world of thoughts, volitions, and emotions and an outer world of objects. The poet Rainer Maria Rilke commented on the regrettable loss of existential wholeness brought about by this turn of our evolutionary history, which less evolved creatures have been spared.

O Seligkeit der *kleinen* Kreatur,
die immer *bleibt* im Schosse der sie austrug;
O Glück der Mücke die noch *innen* hüpft,
selbst wenn sie Hochzeit hat: . . .
. . . .
Wer hat uns also umgedreht, dass wir,
was wir auch tun, in jener Haltung sind
von einem welcher fortgeht? . . .

Oh bliss of *tiny* creatures that *remain*
forever in the womb that brought them forth!
Joy of the gnat that still can leap *within*,
even on its wedding day: . . .
. . . .
Who's turned us round like this, so that we always,
do what we may, retain the attitude
of someone who's departing? . . .

From Rilke, "The eighth elegy," in Duino Elegies, *trans. J. B. Leishmann and S. Spender (New York: Norton & Co. 1939).*

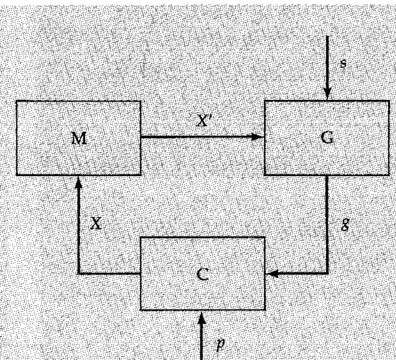
From these dichotomies springs the Cartesian cut — the separation of the world into two distinct substances — *res cogitans* (mind) and *res extensa* (matter) — which has been the stance of science for 300 years, ever since its eponymous champion René Descartes clearly formulated it in his *Passions of the Soul.* The Cartesian cut has been the bane of psychologists, whose job it is to cope with both aspects of existence and to tie both substances together in some fashion. Is the tree I see in front of me the same as the object that is out there, or are the two things distinct? On the one hand, when we consider that the retinal image of the tree is processed not only in the neural network of the retina itself, but also in the lateral geniculate nucleus, in the visual cortex, and in yet other cortical areas, we realize that what consciousness sees, that is, the tree in here as a percept, is literally worlds apart from the tree out there as an object. On the other hand, does it make sense to take the object and its percept apart in this way? Is there not but one reality: the act of seeing what our language makes us call an "object"? These are the opposing positions of the dualist and the monist. Battalions of philosophers have manned the barricades in defense of either position.

We form the notion of the objective reality of the external world, independent of the observer, in earliest infancy, and we form it with the aid of mental equipment evolved over millions of years of adaptive evolution. It is a notion that has been necessary for survival, not only in the cave, but also up in the trees before moving into the cave. It is also the notion that has been most solidified, hardened, and codified, by the development of the classical physical sciences, into the "physical laws." It has been claimed, indeed it is commonly believed, that physical laws describe the external world in an objective way and that they reduce this description to numerical relations. Let us look at this claim more closely, and dissect it in the manner proposed by the psychologist Norbert Bischof. He invites us to examine the relation $S = gt^2/2$. It is indeed a relation between numbers. However, to make it a law of physics we need to know that S is a distance, t a duration, and g an acceleration. The numerical relation as such does not express a physical law. A law is expressed only if we understand that the numbers are measures of a quality of the thing measured: a spatial length represents something completely different in quality from a duration or an acceleration. In addition to the qualities of the quantities measured, we need to know where and what to measure. We need to know the class of actual situations to which the law refers. In fact, a physical law, far from existing totally detached from the observed object, refers explicitly to situations actually or potentially experienced by an observer and to nothing else. This is true, let us add parenthetically, even if we make statements about the big bang origin of the universe — even though there could not have been an observer present to observe it. It would be an illusion to think that physical laws describe an external world independent of the observer.

In what sense, then, are the findings of the physical sciences objective? We say they are objective in being "reproducible" for each observer, and "the same" for different observers. These two criteria are the pride of the physical sciences, and they are indeed met. Information stored in enormous handbooks of physics and chemistry and the solid core of theories presented in the textbooks of these disciplines give vivid testimony to their objectivity. One might characterize the physical sciences as domains of knowledge for which explicit connection to actual experience constitutes an annoying constraint from which they are ever more trying to liberate themselves.

Physical law is supposed to refer to larger and larger classes of experiences. The infant's first construction of space-time frames and notions of persistent objects and of causal connections between events constitute giant steps in this direction. Nevertheless, the fact remains that the physical sciences represent the actual or potential experiences and observations of individuals, in however abstract a form, and as such are as psychic as any emotion or sensation. Both the blue of a summer sky and the 4,400-angstrom wavelength of its light refer to experiential acts, differing principally in the affective components accompanying these acts and in their expressions. The statement is often made that "blue" is a private sensation that cannot be identified with another person's sensation because it is subjective. But the same is true for the size of a table. How do I know how large you see it? Indeed, your impression must be different from mine, if you are farther away from it.

A cybernetic circuit uses feedback from the external environment to help maintain a desired internal state. Here such a circuit is applied to the control of torpedo depth and to the production of handwriting.



Torpedo		Writing
Depth of torpedo below surface	X = Controlled variable	Actual script
Water pressure gauge	M = Monitor of X	Seeing of writing
Pressure gauge dial position	X' = M's measure of X	Seen script
Control element	G = Governor	Mental comparison
Setting of G	s = Setting of governor	Guiding mental picture
Rudder position	g = Governor output	Command to hand
Water waves, etc.	p = Perturbing input	Rough paper, worn pen
Depth control	C = Control point	Hand motion

p & s	Free inputs
X→X'	Rigidly coupled
X'→X	Feedback loop

So we measure it with a ruler. But measurements of length — noting coincidences of marks on the ruler with edges of the table — are private acts too, being intersubjective, and hence comparable only to the extent that we have linguistic expressions for them.

It is the parsimony of the number of elements singled out for attention that makes the notion of duality of observer and observed so successful and gives the illusion in physics that the object is totally distinct from the observer. This distinctness is true in the sense that we do not mention the observer when we say, for instance, that the present temperature of the blackbody radiation left over from the big bang is 3 K, or that a supernova exploded 10^9 years ago. However, any such statement is linguistic in the first place and, as such, is meaningful only within the framework of the total scientific discourse, which reflects individual and collective experiences and acts.

Norbert Bischof pointed out that modern cybernetic machines, which are able to "observe," or take note of external reality, and "interpret," or adjust their internal reality adaptively, can be called on to demystify the relation between the Cartesian *res cogitans* and *res extensa.* Bischof asks us to consider a cybernetic circuit designed to maintain a present constant internal state in the face of a fluctuating external environment as shown in the figure at left. In this circuit a quantity x is measured by a monitor M. The monitor provides its measurement of x as signal x' to the governor G, which is set to maintain a level s. G compares x' with s, and gives an output g, either as an off-on or a graded signal. That signal acts at control point C to control the value of x which must be controlled because the system is subject to an external source of perturbation p. This circuit can be applied to a variety of situations, and Bischof considers the example of a torpedo that is to travel to its target beneath the surface of water at a preset depth. Let x be the actual depth of the torpedo, M the water pressure gauge, x' the reading from the gauge, s the setting of the depth control governor G, g the angle made by the rudder with the horizontal plane, C the control point for the depth control, and p the water waves. The perturbation p and the setting of the governor s are independent inputs into the circuit, while x and x' are physically coupled. The important point made by Bischof in presenting this example is not so much that the torpedo can be said to have a mind but that the same cybernetic circuit can also be used to control processes obviously involving "real" mental activity, for instance handwriting. When the circuit is applied to handwriting, x is the actual script and x' the seen script. Here there is a mental image of what is to be written, which the governor G compares with the seen script. The perturbation arises from rough paper and a worn pen. The lesson of this comparison is that in the case of the torpedo, we deal exclusively with physical quantities, while in the case of the writing, mental elements come into play, namely the perceived output of the pen doing the writing and the internal image with which the script is compared. Another application of such a cybernetic circuit to mental activity would be a tennis player's hand-eye coordination when trying to hit the ball. The eye sees the ball coming, the brain commands the arms and legs to make appropriate motions, the eye and proprioceptive apparatus contain the monitor M and correct this output by comparing it with an internal image in the governor G of what should happen — a feedback loop containing a conscious visual image as part of an interactive network.

Are we comparing processes that are not, in principle, comparable? I think not, because the difference between the mental and the physical is not at all a radical one, but one merely of degree. The depth of the torpedo, the reading from the water pressure gauge, the angle of the rudder, and so on refer to our spatial perceptions and as such include object and observer in their definitions. It is true that meter readings and settings lend themselves to quantification more easily than the mental images of an intended piece of writing or of hitting the tennis ball, and for that reason are more conveniently communicated either in ordinary or in mathematical language. In principle, however, all three are mental and all three are physical phenomena. The links in the cybernetic circuit are equally applicable to them, although when the circuit elements are not easily quantified they are less easily modeled. But modeling must be performed if we are to discover how valid an understanding of a situation is provided by a particular cybernetic circuit.

The distinction between external and internal reality — between subject and object — seems especially confusing when we consider phenomena in which the object is the

Delbrück uses his own cybernetic circuit to hit a tennis ball.

consciousness of ourselves or that of another person. Say you are thirsty. In what sense does your conscious sensation of thirst correspond to a physical quantity? In the sense that whatever thirst may be, it is something of which you can have more or less. In principle, therefore, thirst is measurable, either by behavioral tests or by physiological correlates. Admittedly, it may be useful to make a practical distinction between conscious and nonconscious phenomena. But as Bischof has pointed out, in the *res cogitans*, just as in the *res extensa*, some quantity a acts on another quantity b in a manner that augments, diminishes, or otherwise alters the influence of a third quantity c, which normally has this or that mental effect. We can take this for granted, even if we are unable to specify any procedure for measuring the quantities a, b, and c: they are defined simply by the cause-effect relation that links them to each other and to further, directly observable quantities. That is to say, they are defined by their position within the cybernetic circuit.

The resistance to considering consciousness on a par with physical phenomena seems to arise from our fear of the encroachment of science on the human person, an encroachment that would stifle and depersonalize us and thus open the way to our being used in inhuman ways. This resistance is a defensive stance often encountered in the humanities, where those who oppose the development of a science of man are afraid that the mind might be shown to be no more than a machine. Yet as we have seen, the antithesis of external and internal reality is merely an illusion: there is only one reality. Quantum mechanics has simply reminded us of this fact, which seems to have gotten lost in the abstractions of the physical sciences.

Do I deny, then, that there is any difference between knowing something — about animals in particular and humans most particularly — by extrospection from the outside and by introspection (direct in myself, or by empathy in others) from the inside? There certainly is a difference, but the gulf between the machinery of the brain, target of observations from the outside, and the mind, target of introspection from the inside, is not unbridgeable. If brain surgery is performed under local anesthesia, it is possible to converse with the patient while carrying out experimental procedures on the patient's brain. Wilder Penfield conducted many such experiments, in which he stimulated specific areas of the patient's brain by focal passage of electrical currents. In one case, a single stimulation of a particular area, and only that area, of the patient's cerebral cortex evoked the conscious recall of a particular memory, all the while the patient was consciously aware of being in the operating room. In another case, passage of current through one of the cortical areas dedicated to the production of speech made the patient unable to recall the names of certain familiar objects; when passage of the current ceased, the patient immediately regained the capacity to recall those names. These results show that the content of the conscious mind can be altered in a predictable way by direct manipulation of the brain from the outside. Moreover, quite unexpectedly they also show that such a crude interference with brain function as passage of electrical current through an area of cerebral cortex containing thousands of nerve cells can evoke enormously complex and highly organized mental events, rather than simply causing chaos as an analogous manipulation would do in a computer.

To summarize, the Cartesian cut between observer and observed, between inner and external reality, between mind and body, is based on the illusion that the physical world has no subjective component. This illusion arises from the high degree of quantitative reliability of scientific statements about the outer, physical world. Their quantitative reliability makes us forget that these statements are as related to subjective experiences as statements about the inner, mental world. In experiencing the physical world, we limit our attention to a narrowly circumscribed set of perceptions, such as those resulting from the reading of dials of instruments that measure such quantities as time, distance, or force. But in experiencing the mental world we include a wider repertoire of perceptions, not only primitive perceptions such as color, sound, and smell, but also higher level, complex perceptions of visual space in general and of gestures made by other human beings — their smiles, vocal or facial expressions of threat or fear or affection — in particular. While these higher level perceptions about mental states are less easily quantified than perceptions about physical states, they nevertheless fit into the same kind of cybernetic network of interactions. □