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BOOK REVIEWS

Mind from Matter? An Essay on Evolutionary Epistemology, Max Delbruck. Blackwell Scientific Publications, Palo Alto, CA, 1986. U.S.$29.95 ($19.95 paperback), 316 pp.

What is Life? Max Delbruck remarked in a Cal. Tech. course lecture 14 years ago, "When I was a student in Gdttingen, there appeared a story in the newspaper about a rabbit that had been frozen and then brought back to life. Although the report of this cryogenic feat was probably a sensationalist fabrication, someone was inspired by this story to ask various people what they would ask about if they had been frozen for 500 years and then revived" (p. 159). My own priorities come to mind with crashing immediacy: "Has a machine yet been made that has awareness, a synthetic consciousness? Is there any agreed-upon way yet to detect and measure the quality, or even the existence, of an object's consciousness?"

So far as I can tell, our science simply has no handle whatever on the most conspicuous and immediate reality of our lives: that we are aware. We experience music, seasickness, orgasm, the thrill of athletic competition, dental pain, or good dreams in ways that we imagine a plant or a machine does not. But we cannot verify that a plant or a machine does not, nor even can a lover verify that his/her partner shares the same joy or even any inner light whatever. Who would know where to begin thinking about the design of a 'consciousness meter' that would go off scale at one end when pointed into a battlefield hospital, or at the other during a monk's satori, and might hover about neutral when pointed at copulating butterflies-or might not.

Life as awareness is one focus of the query atop Erwin Schroedinger's 1944 essay. Another is Life as heritable replication-this is the one that developed wonderfully between 1944 and the present. Like many other distinguished physicists of his generation, Max Delbruck thought on both riddles. He learned quantum mechanics and associated problems in the Copenhagen school and became one of the most influential biologists of all time largely through his catalysis of the ferment in molecular biology. He was an experimentalist and he also liked to think deeply on the fundamental puzzles of Life.

Delbruck's title for this book may have been wryly chosen after Schroedinger's later essay, "Mind and Matter" (1958). Those three words conjure up a distinction that many consider spurious (see chapter on The Cartesian Cut). Can mind arise in matter? Plainly it does, but how?; and what is 'mind', anyway, that it should be regarded as utterly distinct from matter? Delbruck's

subtitle "An Essay on Evolutionary Epistemology" reveals more about the contents, not answering those ageless philosophical questions, but encyclopedically summarizing the main advances in our century toward understanding how life itself and the human brain in particular evolved, how brains work and how they relate to language and to mathematics, and to the world in which brains, language, and mathematics evolved.

Delbruck's central purpose seems to have been to outline the main ideas of evolutionary epistemology in terms meaningful to scientists: most of his examples are from neurophysiology, physics and mathematics. [For a similar, and shorter, essay, posed mainly for students of philosophy, see Gerhard Vollmer's (1984) article.] 'Evolutionary epistemology' is quite a mouthful, needing discursive explanation; but in a nutshell the term denotes a research program for inquiring into the nature of consciousness by emphasizing that much of the content of consciousness consists of something we call 'truth'-a kind of interpretive understanding of experience-and that these interpretations are made by a machine that evolved toward that ability by neoDarwinian natural selection applied to biochemical materials. In one way this is the viewpoint of Eugene Wigner (1960): he reflects on our ability to be conscious of mathematical truth, and its uncanny utility for understanding the natural world, as though mathematics is a mode of operation of brains that, having evolved in the natural world, has captured something of its regularities. In one way this is the viewpoint of Julian Jaynes (1977): he discusses the evolution of consciousness in terms of the recent historical evolution of brains to manipulate symbols linguistically. In one way this is the viewpoint of Patricia Churchland (1986): she discusses the mechanism of consciousness in terms of what little we know about the evolved mechanisms of human neurophysiology.

Mind from Matter? has 20 short chapters, originally lectures at the California Institute of Technology in winter 19741975, on topics already foreseen in Delbruck's 1969 Nobel Address. He had intended to make a book of them but his illness limited him to condensing the lot to a single essay published in 1977. After Delbruck's death in 1981, Gunther Stent and colleagues persevered with his notes, emending as required and affixing more recent citations, sending the 260-page book to press in 1983 for eventual 1986 publication. Stent's 18-page "Introduction and Overview" is among the best chapters.

As a beginning graduate student at Cold Spring Harbor Laboratory a decade before these lectures, I was lucky enough to be Delbruck's 'lab partner' for a while, and ignorant enough of his greatness that I was not too intimidated to engage him in long conversations with intent to grasp his vision of the basic riddles of life. I failed and, worse, I decided that the real mysteries are not even approachable now. I am still haunted daily by the same old riddle: What is awareness and why has it still no place whatever in quantitative science? Delbruck's lectures don't answer that question but they provide a breath-

taking panorama of related investigations that must somehow be pertinent. The panorama presents a curious spectacle, as though we stand in the centre of an intellectual clearing watching paths diverge and dwindle in all directions, vanishing into impenetrable jungle. Might all be going to the same place? Many have thought so, not only Delbruck.

For two billion years matter on the surface of this planet has reshuffled its arrangements to optimize procreation locally. At a very recent stage the mammalian cerebral cortex evolved and, very recently indeed, its variants in our own species have been intensively selected for ability to handle language. Julian Jaynes of Princeton argues that because of this last development, as recently as 3,000 years ago, consciousness emerged in adult humans (babies today still lacking it). Humans now sort phenotypes by verbal skills at time of mating; because there is huge variance in the same and in their cortical determinants and in their heritable genetic determinants, this must still be an area of rapid evolution. By such reckoning, it is an exciting time.

Others suppose that consciousness has a longer pedigree, reaching back in progressively more attenuated form perhaps hundreds of millions of years. At the extreme (panpsychist) end of a continuum of opinion, some degree of consciousness is an innate feature of all matter: Francis Bacon remarked, "I had rather believe all the fables in the legends of the Talmud and Al Koran than that this universal frame is without a mind".

There is a deep problem here, so deep that almost any position on this spectrum of opinion is as defensible (or indefensible) as any other: we simply do not know. Without using the modern jargon, Delbruck bypasses arguments about dualism and materialist or idealist monism to implicitly embrace the 'psychoneural identity' viewpoint, according to which consciousness is the subjective side of electrical and chemical activity in the brain. (For a wonderfully readable and informative recent account of all this, read Patricia Churchland's 1986 book ***Neurophilosophy.)*** We do not know what consciousness is in terms of any of the other concepts of our science. Obviously we know what it is subjectively; one might even say it is the only thing we know with immediate certainty. But we cannot yet quantitatively relate it to mathematics or physics or chemistry or even to neurophysiology except in the trivial sense that we know it depends on the brain because we know how to derange a brain so that consciousness vanishes-anyhow we ***suppose*** it was there and that now it isn't, but only if the experimenter operates on himself does he/she actually ***know.*** And even in that case he cannot be sure later, given that he has only his own memory, possibly misleading.

I think one can imagine a helpful device, without imagining even vaguely how it might work. Its input can be focused to a range of time and location that might contain myself, another person, a dog, an advanced 'computer', or a stone. Its output powers a light bulb to shine brightly if and only if the object in

the focus supports a vivid consciousness. It would double its brightness if a second person or a perfect replica of the first comes within the focus, and would dim if the object falls into dreamless sleep or breathes an anaesthetic. With such a detector one could begin to ask what material equipment is needed to support consciousness. One approach to the engineering of such a detector might be to first discover what is the physical difference between a brain awake and asleep or anaesthetized. But I suspect this would only reveal permissive conditions for awareness, rather than allowing detection of awareness itself, much as temperature (above or below the Curie point) determines whether a ferromagnetic material can support a magnetic field, without answering whether or not it in fact does, or with what direction or strength.

There are two possible positions to take about the contemporary non-existence of this detector: (i) (my choice) it just hasn't been built yet because no-one has yet got around to figuring out how; there are surely lots of devices in this category, and since we don't know clearly what consciousness is, it is hard to be sure that a consciousness detector is not among them; or (ii) it doesn't exist now because in principle it cannot exist. This second position implies that the phenomena of consciousness are so entirely unlike anything else yet encountered that there is no connection at all between them: consciousness is something apart, maybe a consequence of matter and fields, maybe not, but anyway it does nothing at all to matter or fields, or nothing distinguishable from what other matter and fields do. There is, then, no way to detect it anywhere but in yourself, only by being yourself. I cannot adopt this stance.

For want of a calibrated detector, most scientific investigations in this area are stopped dead before they ever started. That has not stopped people from puzzling over consciousness; the field of psychology originally took root in this soil. The puzzle is not just that we do not know what physical mechanisms are necessary and sufficient to support consciousness, or even how to find out; but worse, we cannot even imagine any that might do, so there is nothing to test. James Clerk Maxwell thought long on this with little satisfaction, remarking that he found the field "strewn with the bones of former explorers and abhorred by every man of science". In the absence of experiments it is possible consistently to think diverse wonderful thoughts. John Wheeler suggests that the laws of nature appear as they are because of the possibility of consciousness. Freeman Dyson (1979) concludes that the existence of consciousness may completely reshape the end of the Universe. These are not frivolous fantasies, but the conclusions of deep thinkers whose inquiries are constrained by all that is known in contemporary physics (which we assume is pertinent).

The constraints of biology loom larger still: even without carrying investigations beyond personal introspection, we already face a major problem in imagining how and why such a phenomenon could have evolved. As physicist Erich Harth puts it in Windows on the *Mind* (1982), and as

psychologist Julian Jaynes might have done: "Consciousness appears not as a necessary concomitant of sensory signals received, but as something additional, a sensory extravaganza we could perhaps do without". This riddle has vexed many individuals renowned for their clever investigations of other riddles. Alfred Russel Wallace worried in a letter to Charles Darwin that 'Natural selection could only have endowed the savage with a brain a little superior to that of an ape, whereas he actually possesses one but very little inferior to that of the average member of our learned societies ... An instrument has been developed in advance of the needs of its possessor." This might today be rephrased in several respects, but the antiquity of the underlying concern is clear (Harth again): "The crucial point is, that in creating the human brain, evolution has wildly overshot the mark." This aberration tantalizes Delbruck, as it did many distinguished physicists before him.

If you regard mathematics as a secretion of the human brain akin to language, you will probably enjoy Eugene Wigner's (1960) essay on "The Unreasonable Effectiveness of Mathematics in the Natural Sciences". He wonders if we may someday formulate a theory of the phenomena of consciousness and considers it "hard to believe that our reasoning power was brought by Darwin's process of natural selection, to the perfection which it seems to possess." Celebrating this undeserved power under the title "the empirical law of epistemology", Wigner observes that some laws of nature can be guessed in mathematical terms and turn out to be much more accurate than they have any excuse to be, given the limited information used to guide the guesswork. It appears that "we got something out of the equations that we did not put in ... *we* do not know why our theories work so well".

Delbruck dwells long on this sort of riddle. In fact, in dealing with mind and awareness, he emphasizes mind as truth-knowing entity (by which he largely means mathematical truth, a *la* Bertrand Russell and Kurt Godel) more than mind as vibrant awareness (of music, of pain, of orgasm). With either emphasis, one equally wonders what selective advantage it confers; but there is lots more to say in the former area that Delbruck chose to emphasize (mind/mathematics) than in the latter area of my helpless curiosity (mind/feeling). Still there is no less need of caution: Delbruck's concern is that we frequently misconceive some basic aspect of the Reality we try to define, by initially neglecting that our concepts arise in a special kind of instrument (brain) that is built to certain specifications (prescribed by available mutations and natural selection under pressure for differential reproduction on a certain scale of size, speeds and masses.) He endeavours throughout to portray contemporary awareness as the outcome of biological evolution selecting for ability to function in the world as discovered by mathematicians and physicists. There is some discussion of logical self-reference [celebrated by Douglas Hofstadter (1980) a few years later] and of general relativity, quantum mechanics, complementarity, and the

Einstein-Rosen-Podolsky-Bell conundrum, mainly to say that it is miraculous that our brains can handle such matters correctly, and no surprise that it does so uncomfortably, because such phenomena lie outside the range of experience that moulded the brain.

My own interpretation of Kurt Godel's finding in number theory, if it applies to science, is that we will never have a finite system of axiomatic 'laws of nature' from which all observed phenomena can be derived as theorems: there will always be one more unanticipated phenomenon, like Goldbach's Conjecture, that will have to be assimilated in the status of a new axiom. The fact of consciousness might thus evade the 'promissory materialism' (Popper's phrase) of contemporary reductionists who naively depend on the authority of 19th century physics and mathematics. Hopefully it will also evade the mystical obscurantism of contemporary popularizers of 20th century physics and mathematics. Delbruck sets a firm course between these rocks.

At the end of reading all the mentioned books and essays in connection with this review, the stubborn fact persists that I cannot reconcile my personal experience with what I have learned about matter, energy, information, time and space. I am sometimes more keenly and vibrantly aware than at other times, so I know that the degree and quality of consciousness can vary. I imagine that its degree and quality are always poorer in a cadaver or in a stone than they sometimes are in my personal experience. Yet our science provides absolutely no way to assay awareness, no way to inform us whether a futuristic computer experiences that inner light, nor even to guide the quantitative decisions that we must and do take daily. Without any distinct method we weigh against one another the degrees of happiness or misery traded back and forth by necessary decisions affecting an embryo and a pregnant young woman, a stroke victim and those maintaining his body, a pig in line for slaughter and people in line to buy pig meat, the families of Japanese fishermen and a porpoise caught with tuna, a pet snake and the live mouse I bring for its meal, my aesthetic sense about my kitchen and an offending colony of ants. We all have ethical opinions and we act on them. But opinions differ more radically than the facts they refer to possibly could.

Did we explain how mind evolved from no mind? Did we find out why so much more was delivered than was ordered? Not at all. Max Delbruck assembled a light plane for us high in the mountains, and cleared a runway pointed toward a snow-covered peak far ahead; Gunther Stent's Introduction shoved the throttle fully in, and we accelerated thrillingly across the sandy hot plain. But it is too hot and the air is too thin and the runway too short and here we are again stuck in the sand at the far end. The scenery up here is gorgeous, and even more tantalizing from this end of the runway. But we still need a longer runway.

Having read the review, don't now neglect to read the book. My literary

allusions include none of Delbruck's, which constitute an incredible treasure-trove of fact and thought.

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LITERATURE

Churchland, P. S. 1986. Neurophilosophy. Cambridge: The MIT Press.

Delbruck, M. 1970. "A Physicist's Renewed Look at Biology: Twenty Years Later". ***Science*** 168, 1312-1315.

Dyson, F. 1979. "Time Without End: Physics and Biology in an Open Universe". ***Rev. Modern Phys.*** 51, 445-461.

Harth, E. 1982. ***Windows on the Mind: Reflections on the Physical Basis of Consciousness. New*** York: Morrow.

Hofstadter, D. R. 1980. ***Godel, Escher, and Bach: An Eternal Golden Braid. New*** York: Vintage.

Jaynes, J. 1977. ***The Origin of Consciousness in the Breakdown ojthe Bicameral Mind.*** Boston: Houghton Mifflin.

Schroedinger, E. 1967. In What is Life and Mind and Matter. Cambridge: Cambridge University Press.

Vollmer, G. 1984. "Mesocosm and Objective Knowledge". In ***Concepts and Approaches in Evolutionary Epistemology,*** F. M. Wuketits (Ed.), pp. 69-121. Dordrecht, The Netherlands: D. Reidel.

Wallace, A. R. 1869. "Geological Climates and the Origin of Species". ***Quarterly*** Review 126, 359-394.

Wigner, E. 1960. "The Unreasonable Effectiveness of Mathematics in the Natural Sciences." Commun. ***pure appl. Math. 13(1).***