

Natural psychology

The EEA and the structure of cognition

Edward H. Hagen

Institute for Theoretical Biology
Humboldt University, Berlin
e.hagen@biologie.hu-berlin.de

Donald Symons

Department of Anthropology
University of California, Santa Barbara
symons@anth.ucsb.edu

The modern materialist conception of nature was born in the first half of the 17th century with major works by Bacon, Harvey, Galileo and Descartes. In its current form, the universe comprises fundamental particles and forces that obey precise laws; more complex entities like nuclei, atoms, molecules, gases, stars and galaxies are explicable, it is believed, solely in terms of these fundamental particles and forces. Given a precise description of the state of even a very complex system at one point in time, its properties at any future point in time are determined by the operation of physical law. The universe, in short, is a big machine. (Quantum mechanics does not really change this view, nor do recent ideas on chaos, complexity and emergent properties; see, e.g., Bricmont, 2004).

If materialism is correct, everything in the universe, including life, brains, thoughts and feelings, has a material explanation. Providing these explanations has been a formidable and ongoing challenge. Two challenges are particularly important to cognitive science: the origins and nature of life, and, of course, cognition itself. Here we sketch an idealized history of the successful surmounting of the first challenge, and the current state of efforts to surmount the second. We see these two challenges as essentially one and the same. Evolutionary psychology is an attempt to apply to the brain the model that has worked so well for the rest of the body. Yet it has failed to fully embrace key lessons from anatomy and physiology.

Following Harvey's discovery that the heart is a pump, there was an explosion of research in anatomy and physiology that adopted, not merely a materialist, but a distinctly functional approach; bodies were increasingly understood as

machines. This idea, however, is fundamentally different from the idea of the universe as a machine. Unlike non-living systems, hearts, lungs and eyes have a purpose or function. Like human artifacts, they show clear evidence of design – of having been engineered to perform specific functions that benefit the organism. Body parts, then, have two properties: (1) they are physical systems that obey physical laws and (2) they are functional. The latter property raised one of the most important questions ever asked in science: Who or what designed the functions evident in living organisms?

We are not sure when the critical distinction between living systems as functional, and non-living systems as non-functional, was first appreciated (aspects of the idea trace back to at least Aristotle; Ogle, 1882). It is clear, however, that natural theology, brilliantly synthesized in William Paley’s book of the same name, played a decisive role in framing this distinction as a core problem for Darwin. Whereas revealed theology was based on scripture and religious experience, natural theology sought evidence for God in the natural world – God is not merely a matter of faith, but can be demonstrated using logic and commonly observed facts. That “things of different natures [fall] into harmonious order, not rarely and fortuitously, but always or for the most part” was for Aquinas evidence of “some Power by whose providence the world is governed; and that we call God.” In this form, natural theology would have been of little use to Darwin. Much of the order and harmony of the physical world was rapidly being explained in materialist terms, and in any case Darwin was not a physicist.

Paley’s *Natural Theology*, however, is rich with keen observations of the living world. In the structure of organisms, unlike most of the physical world, Paley saw not only order, but purpose or function.¹ An organism was a “cluster of contrivances” “for nourishment for generation,” each “contrivance” exquisitely matched to the organism’s environment. Darwin took from Paley a superbly well-defined problem, which he and Wallace then solved. Their theory of natural selection explained in materialist terms how such “contrivances” could arise without a designer, why their purposes would be limited to those that could be linked to the reproduction of the organism, and why they would closely reflect the organism’s environment.

The successful explication of most of the body’s “contrivances” is a pinnacle of science. Remarkably, reaching this pinnacle has required little, if any, Darwinian theory. The simple, almost a-theoretical, heuristic that body functions serve survival or reproduction captures much of the content of the theory of natural selection, usually rendering a formal appeal to the theory unnecessary.

Despite the amazing achievements of physiology, no materialist theory of thoughts, feelings and consciousness – which we will refer to as *cognition* – has produced anything approaching a scientific consensus. Although it has long been recognized that cognition is somehow a product of the brain, forging each link in the chain from brain to cognition has been extremely difficult. Some early,

¹In his chapter on astronomy (Ch. 22) Paley does argue that the order of the heavens is evidence for a designer.

influential psychologists like Watson and Skinner even believed that behavior must be explained without reference to cognitive properties like mental events, states or processes. This so-called *behaviorism*, popular during the first half of the twentieth century, rapidly collapsed when Chomsky showed that language could be only explained with recourse to mental states and processes.

Equally important in behaviorism's demise was the mid-century invention and commercialization of the electronic computer, a machine with properties heretofore only possessed by brains. Computers could do things, like playing chess, that required something like 'thought,' and this behavior could only be explained with reference to the computer's internal states – its program and memory. Chomsky's critique of behaviorism, his views on language, and the invention of the computer launched the cognitive revolution: Mental states cause behavior and can be scientifically studied by making inferences from that behavior, and these states can be rigorously modeled as the states of one or more computational devices.

Recognizing that the brain could be modeled as a computer was a tremendous step towards a materialist explanation of cognition. In-and-of themselves, however, computers are far too general machines to serve as useful models of nervous systems. The state of a computer's memory can characterize just about any physical system; sequences of computer instructions (algorithms) can transform this state into any other state. Thus, computers can model almost anything, including the weather, fires, automobiles and the postal service. There is nothing in the idea of a computer *per se* that is specific to nervous systems. In order to create a computational model of nervous systems in general, and the human nervous system in particular, additional principles are needed.

Our current model of body organs and tissues is that (1) they are machines (or parts thereof), and (2) these machines serve survival or reproductive functions. The computer model of cognition, on the other hand, claims only that the brain comprises one or more computational devices, akin to (1). But there is no part (2), no explicit requirement that these computational devices serve the survival or reproduction of the organism! It's as if scientists were demonstrating how body parts could be conceptualized as machines – a lever-arm here, a fulcrum there – but had little idea what kinds of machines they were a part of, or what these machines were for. Cognitive science has mostly focused on how the brain could support computation (as we noted, a much too general model), but it has paid too little attention to what, exactly, should be computed (the popular idea that the brain is simply a general learning machine is a non-starter; see, e.g., Gallistel, 1999; Pinker, 2002).

The prime contribution that EP has made to the cognitive revolution is to provide key principles that were missing from the computational model. The brain is not merely a collection of one or more computational devices, but a collection of computational devices that evolved to facilitate or enable reproduction in ancestral environments by manipulating aspects of those environments. The aspects of the environment that a mechanism evolved to manipulate are referred to as the EEA of that mechanism (although the EEA is adaptation-specific, as short-hand the term is also used to refer to the EEAs of all a species' adapta-

tions – see Salmon and Symons, 2001; Tooby and Cosmides, 1990; Hagen, 2005, for more detail). Embedded in any functional hypothesis for a body structure is a hypothesis about the environment that is manipulated by that structure. The hypothesis that the immune system identifies and eliminates pathogens from the body, for example, entails numerous assumptions about the nature of pathogens.

EP has, in essence, aligned the computational model of the brain with the functional model used for all other body tissues and organs. But instead of just adding the simple heuristic that brain mechanisms serve survival or reproduction, EP has brought the full power of evolutionary theory to bear – cognitive mechanisms are adaptations.

Research in many domains of psychology and neuroscience were already in line with research on other body functions, of course. Researchers studying vision and the other senses would certainly agree that the senses serve survival or reproductive functions by enabling the organism to obtain a more or less accurate model of its physical surroundings. Further, in order to understand these mechanisms, these researchers paid extremely close attention to the properties of their EEA: the nature of sunlight and acoustic vibrations, for example. Yet this has been more the exception than the rule in the various cognitive sciences. Too many cognitive science research programs, including EP, have focused almost all their attention on cognitive mechanisms, and virtually none on the structure of the environment those mechanisms interact with.

Understanding the design and function of the eye requires a deep understanding of the properties of light and its interaction with matter, as well as a precise description of how the eye should transform incident light. Our understanding of the immune system is founded on the truly massive research effort that has revealed the nature of infections and proteins, as well as the recognition that the goal of the immune system is to kill and remove pathogens from the body. An understanding of the logic of any mechanism almost always requires a thorough knowledge of the physical system that the mechanism was designed to manipulate and the ways in which it should be manipulated.

Although EP has long argued that evolved functions can only be understood in relation to their EEA (e.g., Symons, 1979), by adopting the traditional methods of cognitive and social psychology EP has inherited some of the intrinsic limits of these methods. These methods were designed to investigate cognitive mechanisms, not the properties of the mechanisms' EEA. As the examples of the senses and immune system make clear, however, it may be extremely difficult to elucidate cognitive mechanisms without a detailed understanding of the EEA. Imagine trying to investigate the structure of the eye with only a vague understanding of optics.

An important exception to the foregoing is what has come to be known as *ecological rationality* (e.g., Gigerenzer and Todd, 1999; Simon, 1956), an approach in psychology that emphasizes that decision-making heuristics will correspond closely to the information structure of the environment, and that actively investigates this information structure. Not surprisingly, EP and the ecological rationality school have become closely aligned.

The EEA concept is central to the scientific study of organism structure. If one knew the theory of natural selection, but *nothing else*, one could say little, if anything, about the nature of organisms. Organisms evolved to reproduce in a particular environment; if nothing is known about that environment, almost nothing can be said about what it takes to reproduce in it. The structure of the organism itself, of course, contains much information about its EEA. Via natural selection, a gene pool gradually accumulates information on how to transform its EEA. Functional organism structures (i.e., adaptations), as products of the genome, thus reflect this accumulated information in intricate detail. Adaptations can often be recognized, in fact, by the information they contain about their target EEA. The eye contains tremendous amounts of information about light, and how to transform it to the organism's benefit. The embodiment by one system – the adaptation – of detailed information about useful transformations of another system – the target EEA – serves as a clear marker of natural selection.

One of the most famous such examples is the star-of-Bethlehem orchid, whose nectar-producing organ lies 30 cm inside it. Darwin predicted that an insect with a proboscis at least 30 cm long would be discovered that pollinated the orchid. In 1903, 21 years after Darwin's death, a moth with a proboscis 30-35 cm in length was discovered that pollinated the orchid. It was christened *Xanthopan morgani praedicta*, in honor of Darwin's prediction.

Interpreting the information exhibited by adaptations about their EEA, however, can be a formidable challenge. Without many background facts, it will often be difficult, if not impossible, to correctly infer adaptations' functions. Darwin's prediction required considerable knowledge of plant pollination and the role of insects therein. Elucidating adaptations and their EEAs is an iterative process. The more that is known about one, the more that can be known about the other.

It follows, then, that EP must pay as close attention to the EEA of each psychological mechanism as physiology and anatomy do to the EEA of non-psychological mechanisms. Most EP studies use powerful, abstract concepts like reciprocal altruism and parental investment to predict cognitive structure. Yet virtually all collect data *only* on cognitive structure; almost none collect data on the putative EEA of that structure. Countless EP studies, for example, have examined mate choice cognition, yet almost none have investigated patterns of mate choice in the EEA. Arranged marriages are one of the most well-documented and important aspects of mating in the small-scale traditional societies that are most likely to resemble EEA societies. The close involvement of parents and other family members in many marriages implies, at the very least, constraints on individual mate choice, and evolved mating psychology should reflect this.

EP has provided the principles lacking in the computation model of cognition: like other body mechanisms, cognitive mechanisms evolved to manipulate specific aspects of the EEA, enabling and facilitating reproduction. With EP, cognitive science has almost, but not quite, all of the conceptual tools that guaranteed the success of anatomy and physiology. The next steps, we believe, will

involve detailed studies not only of cognitive mechanisms but also of the EEA of those mechanisms.

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