THE NEW COGNITIVE NEUROSCIENCES

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Introduction

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Most cognitive neuroscientists recognize the need for reliable sources of theoretical guidance. Many have taken a bottom-up approach, turning to cellular and molecular neurobiology. But there also is a top-down approach, which can be equally or more informative. Knowledge of evolved function can be used to identify functional units within the brain and mind and to guide investigation into their designs. Despite their sustained record of success in other areas of biology, evolutionary methods are only beginning to be understood or applied in the cognitive neurosciences. This section outlines this approach and illustrates its use.

Dissection implies function

When anatomists dissect an organism, they do not cut it randomly. Dissection–whether done by a real scalpel or a conceptual one–implies the search for functional units. Because the brain's function is to process information, correctly dissecting its neural architecture into functional units depends on correctly dissecting its cognitive architecture into corresponding, functionally meaningful computational units. Because human and nonhuman brains were constructed by the evolutionary process, these units were organized according to an underlying evolutionary logic–a logic that must be grasped if this process of dissection is to be successful. Because knowledge of adaptive problems and models of evolved functions provides the functional engineering specifications to which human and nonhuman brains were built to conform, evolutionary biology and psychology can help researchers to isolate, identify, activate, and map the important, functional design features of the cognitive architecture that otherwise would be lost among the maze of functionally irrelevant physical concomitants in which they are embedded (see chapter 80 for an overview of issues).

The cross-species diversity of brain architectures

Advocates of the bottom-up approach argue that the findings of neuroscience will place strong constraints on theory formation at the cognitive level. Such knowledge is very valuable, and it undoubtedly will contribute a great deal to theory formation in the long run. But one reason why many neglect the analysis of evolved function is because they believe that neural constraints will be sufficient for developing cognitive theories. This cannot be true.

Consider the fact that there are bird species that navigate by the stars or by the Earth's magnetic field, bats that echolocate and engage in reciprocal blood sharing, bees that compute the variance of flower patches and discriminate classes of kin, spiders that spin webs and extract social information from web movement, ant species that farm or defend host trees or dead reckon, elephant seals that forage hundreds of feet underwater, monogamous gibbons, polygynous gorillas, polyandrous seahorses, sex-changing coral reef fish, mole rats that form social-insect-like colonies, and so on. There are millions of animal species on earth, each with a different set of cognitive programs–programs that often are radically different from each other, even in closely related species. The same basic neural tissue embodies all of these programs, and it could support innumerable others as well. Facts about the properties of neurons, neurotransmitters, and cellular development cannot tell you which of these billions of programs will develop reliably in the human (or, e.g., the rhesus) mind.

Even if all neural computation turned out to be the expression of universally shared processes at the cellular level, it is the higher-order arrangement of neurons–into birdsong templates or web-spinning programs or facial emotion display programs–that matters computationally. The idea that low-level neuroscience unassisted can produce models of cognitive mechanisms is a physicalist expression of the ethologically naïve associationist doctrine that all animal brains are essentially the same (see chapter 81 [associationism] and chapter 84 and Preuss, 1995 [comparative neuroanatomy]). A related assumption–that a few computational principles underlie most mechanisms in the brains of animal species–organizes the thinking of neoassociationists and connectionists (e.g., Quartz and Sejnowski, 1997). If this were true, then the adaptive problems encountered by species ancestrally would indeed be irrelevant: The neoassociationist assumption is that evolution selected for general-purpose brains that solved most or all problems using methods applicable to the broadest and most general class of problems. In this view, brains lack specializations reflecting the specific demands of a species' particular way of life. A logical corollary of this view is that all information necessary to solve problems must be acquirable ontogenetically, through the senses, because it is not being supplied phylogenetically, in the form of evolutionarily organized specializations.

The challenge from evolutionary biology

It is difficult to reconcile this view with the mass of data accumulated by behavioral ecologists and evolutionarily oriented psychologists about behavioral diversity and the array of problems that organisms are known to solve. By using theories of adaptive function to guide their investigations, behavioral ecologists have been able to document a range of animal behavior that is breathtaking in its adaptive problem-solving sophistication and whose generation often requires information that could not be supplied ontogenetically or perceptually. There is, for example, no perceptual data in the ontogenetic environment that specifies that a male langur monkey who has taken over a troop should kill all the infants born within the following several months whereas a titi monkey should not; or that a female ground squirrel should give more alarm calls when the neighboring ground squirrels are her sisters than when they are not, and so on. These rules must be in the adaptations, because they are not in stimuli.

Equally important, specialization of circuitry often greatly increases computational efficiency, and endows architectures with the capacity to solve problems that could not be solved at all by general-purpose methods, making architectures that operate primarily through general-purpose methods uncompetitive and unlikely to evolve. These and many other converging lines of evidence and argument collectively contradict the view that a few general-purpose computational principles could explain known behavioral phenomena or be capable of solving many of the adaptive problems that humans and other species faced during their evolutionary histories (Tooby and Cosmides, 1992). As Gallistel shows (chapter 81), even in the case of animal learning–the set of phenomena that associationism was explicitly developed to handle–associationistic theories are theoretical and empirical failures, incapable of being made consistent with the data, much less of accounting for it.

To free theorizing in cognitive neuroscience from the Procrustean bed of a one-solution-fits-all-problems approach, and to clear the ground for a new generation of theories of heterogeneous functional specializations, it would be helpful if cognitive neuroscientists became aware of the truly diverse nature of adaptive problems organisms solve. Toward this end, this section includes several chapters about nonhumans to give a textured feel for the kinds of adaptive tasks that other animals' minds are able to solve quickly and efficiently. These include the chapters by Fernald and White (chapter 82) on the social behavior of territorial fish, by Sherry (chapter 83) on the spatial cognition of parasitic cowbirds, polygynous meadow voles and monogamous pine voles, and by Gallistel (chapter 81) on dead-reckoning in ants, computation of the solar ephemeris by bees, and classical conditioning in pigeons and rats (see also Gaulin, 1995; Daly and Wilson, 1995). In every case in which the computational processes are known in any detail, they have turned out to be narrowly tailored to the demands of solving specific adaptive problems.

Constraints on hypotheses

Because efficient computational designs will almost always be specialized to fit the particular nature of the problems they solve, an investigation into the nature of adaptive problems is a very productive research strategy. For any given adaptive problem, only a highly restricted class of candidate program designs has the properties required to solve it. Thus, knowledge of the structure of the adaptive problem informs the researcher about large numbers of probable design features, greatly facilitating the construction of experiments that can probe for their presence.

For this reason, cognitive neuroscientists stand to profit greatly from formally describing the problems that the human cognitive architecture evolved to solve. The intuitive conceptions of function that are widely used instead—such as "learning" and "memory"—are simply too broad to be useful. As Gallistel (chapter 81) points out:

> It is odd but true that most past and contemporary theorizing about learning does not assume that learning mechanisms are adaptively specialized for the solution of particular kinds of problems. Most theorizing assumes that there is a general purpose learning process in the brain, a process adapted only to solving the problem of learning. There is no attempt to formalize what the problem of learning is and thereby determine whether it can in fact be conceived of as a single or uniform problem. From a biological perspective, this assumption is equivalent to assuming that there is a general purpose sensory organ, which solves the problem of sensing.

In his chapter, Gallistel analyzes various learning problems solved by desert ants, bees, pigeons, and other animals, showing that (1) they are incommensurate; (2) each is solved by a different computational machine that is specialized for that task; and (3) associative theories of learning are incapable of explaining the animal learning data. According to Gallistel, there is no evidence in any species supporting the existence of the associative bond. If he is correct, then neuroscientists who hope to unlock the secrets of learning and memory by looking for the neural basis of the associative bond have had their time wasted by evolutionarily uninformed models of natural computational systems. This underlines how good research at the neural level depends on having a correct characterization of the computational level, which in turn depends on understanding the evolutionary principles responsible for organic design.

Humans also evolved

The chapters dealing with humans (chapters 83 and 85–87) also take a top-down approach. Although the hypothesis that there might be cognitive specializations for navigating the social world was once considered intuitively implausible by many, the adaptive problems posed by social life are both complex and have enormous fitness consequences. This led evolutionarily informed researchers to research the hypothesis that human brains—like those of other animals—contain a number of cognitive adaptations for understanding and negotiating social life. Following this logic, Baron-Cohen, Cosmides and Tooby, and Leslie have been finding evidence for domain-specific mechanisms specialized for reasoning about the contents of other minds and about cooperation. This research not only illuminates the computational structure of social cognitive adaptations, but it also illuminates the nature of neurological disorders, such as autism, which appear to involve selective deficits in particular computational subcomponents of social adaptations.

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