Cognitive Biology

Evolutionary and Developmental Perspectives on Mind, Brain and Behavior

edited by Luca Tommasi, Mary A. Peterson and Lynn Nadel

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1 Cognitive Biology: The New Cognitive Sciences

Luca Tommasi, Lynn Nadel, and Mary A. Peterson

Most who have written about the history of the cognitive sciences have conceived of the field as an interdisciplinary gathering of psychology, philosophy, computer science, linguistics, neuroscience, and anthropology. For the last fifty years it has been expected that pooling information from these disciplines would unveil the hidden secrets of the mind. Many introductory, advanced, and encyclopedic accounts of the history of the cognitive sciences have portrayed the field as a large alliance of disciplines studying cognitive phenomena in their natural and artificial manifestations, a field that is strongly interdisciplinary in nature and that pursues both basic and applied research (Gardner 1985; Bechtel et al. 1998; Nadel and Piattelli Palmarini 2003; Boden 2006).

In the past decade cognitive science has undergone a transformation that, although tangible in the everyday practice of cognitive scientists, has not yet been integrated into the definition of the field. This transition took place when the fields of developmental psychology, comparative psychology, and the neurosciences began to share and compare data obtained using similar methodologies in animals and humans, and at different stages of developmental change. As a consequence, many cognitive abilities have now been explored in a wide range of organisms and developmental stages.

Results have revealed the nature and origin of the understanding of numbers, places, values, objects, identity of other individuals, causal events, agency, intentionality, and many other instances of the cognitive life of organisms. In a growing number of cases these results have passed a “comparative check” and a “developmental check” before being further explored at the level of the nervous system. Indeed, the possibilities offered by genetics, ecology, and the neurosciences for elucidating the small- and large-scale biological mechanisms underlying these domains have greatly helped in renewing the whole field. In this introduction we intend to give a schematic but realistic portrait of these sources of change in the cognitive sciences and provide a basis for what we have chosen to call cognitive biology.

A Good Time for a Change in the Definition of Cognitive Science

In his famous book dedicated to the praiseworthy aim of advising young researchers, *Advice for a Young Investigator,* Santiago Ramón y Cajal, one of the founding fathers of the neurosciences, wrote, "It is a wonderful and fortunate thing for a scientist to be born during one of these great decisive moments in the history of ideas, when much of what has been done in the past is invalidated. Under these circumstances, it could not be easier to choose a fertile area of investigation" (Ramón y Cajal 1899, p. 14).

The cognitive sciences currently represent such an example, attracting the interest of armies of young investigators from established disciplines who are bringing their expertise and efforts to solving the conundrum of the mind. This happened in at least three waves over almost fifty years. The first wave, in the 1950s, overtook behaviorism and established the field; the crucial keyword of this wave was *information*. The second wave brought matter and energy to the fore in the 1970s; the crucial keyword of this wave was "*brain*." The third wave, the one contributing to the picture this book plans to portray, brought in evolutionary theory and developmental issues: the crucial keyword of this wave is "*change*."

Precursors of the Cognitive Sciences

Interest in the functions of the mind and its relation to the natural sciences was already in place by the time of Greek classic philosophy, and has been a matter of constant speculation, reappearing in many forms throughout the history of scientific and philosophical thinking, from Descartes to Darwin. The so-called sciences of the "three Ps," philosophy, physiology, and psychology, went through a complex reshaping process in the nineteenth century that strongly revolved around the need for an interdisciplinary approach to the study of the mind. Moreover, since the eventual birth of experimental psychology by the end of the nineteenth century, a number of general theories provided their own integrated accounts of the mind, some of them breaking interdisciplinary boundaries, at least on theoretical grounds (for example, Gestalt theory, genetic epistemology, and other theories such as those of William James and Donald Hebb).

Classical Cognitive Sciences

Cognitive science has always been by definition a hybrid field. Nonetheless, it has a quite precise manifesto: the explicit assumption that the mind can be the subject of scientific investigation that merges experimental, theoretical, and applied practices. This original manifesto, in the broadest of forms, comprised a number of disciplines, including psychology, artificial intelligence, neuroscience, philosophy, linguistics, and anthropology.

Beginning in the mid-1950s, in the cultural milieu of recently introduced ideas (such as information theory and Noam Chomsky's universal grammar), the field was initially a group of established disciplines sharing the common currency of an interest in cognition.

By the mid-1960s, the limits inherent in carrying out research that neglected the results of one or more of the other disciplines were becoming obvious. As a result of this interdisciplinary turn, new disciplines achieved an autonomous status, a striking example being cognitive neuroscience, which fruitfully exploited new techniques (neuroimaging, multiple cell recording, fast computerized processing of complex signals, and so forth) in order to understand old problems concerning the mind-brain relationship.

The New Cognitive Sciences

What has become clear in recent decades is that the cognitive sciences cannot ignore the dynamics of cognition. Such a stance is compelled by both ontogenetic and phylogenetic reasons, stemming from empirical evidence, theoretical considerations, and changes in the overall scenario of science. Cognition is the set of representations and processes crucial for dealing with the physical and biosocial world. Any organism must deal with space, time, number, objects, events, and other organisms. Therefore, developmental and evolutionary constraints must have played a role in the implementation of their cognitive counterparts, just as they played a role in determining the shape and function of a lung or a fin. Representations and processes that take place in the minds of animals depend crucially on the tuning of brain structures during specific time courses, and ultimately on the genetic instructions that code for the building of these brain structures. Genetics and developmental biology are providing compelling evidence that cognitive functions are constrained by the timing of molecular events that produce their effects at different time scales, from the protracted establishment of the "protomap" that shapes the regional anatomy of the mammalian neocortex in separated modules during corticogenesis to the rapid molecular cascades triggered by a single learning experience during hippocampal long-term potentiation.

The State of Affairs

Cognition

It might sound trivial to affirm the importance of the study of cognition in contemporary science. Cognition has become an integrated aspect of many disciplines, not only those usually associated with "cognitive sciences" or "cognitive studies." From sociology and political studies to ethnology and archaeology, medicine, and economics, the ubiquitous reference to cognition suggests the incorporation, in the scientific understanding of many complex phenomena, of explanations ascribed to the processes taking place in the mind. Methodological advances in contemporary cognitive science frequently derive from the necessity of acquiring knowledge in indirect ways, through ingenious experimentation, the invention of sophisticated statistical tools, and a strong appeal to theoretical modeling. The current state of affairs in psychology suggests an inevitable merging of the discipline with neuroscience. The convergence of methods devised to grasp the workings of mental facts with experimental rigor, together with techniques developed to show the functions of the brain, has moved forward so fast in recent decades that nowadays it is not really possible to speak about cognition without referring to the brain. Cognitive neuroscience, the investigation of the neural correlates of the mind, is a field witnessing enormous success, reflected by the ever-increasing popularization of themes connected to the mind and the brain in the mass media and in popular culture. The related field of social neuroscience—bringing the methods of cognitive neuroscience to the study of the social life of organisms—has more recently shown the same explosive growth (see, for example, Cacioppo and Berntson 2002). Although this success is fully deserved, and insights into the understanding of mental phenomena have come from brain imaging studies (and the other way around), the mind-brain coupling is subject to serious temptations: the standard cognitive neuroscience formula (mental phenomenon + imaging = fabulous discovery) has been applied quite liberally, and often incautiously, to the brain correlates of justice, beauty, and truth, to name but a few examples. Neuroimaging incursions in the most fundamental corners of human cultural complexity are literally flourishing: labels such as "neuroethics," "neuroaesthetics," "neuropolitics," or "neurotheology" increasingly populate scientific journals and academic publications, and one has the feeling that belief in the explanatory power of human neuroscience may exceed the genuine knowledge being returned by these disciplinary joint ventures. Weisberg and colleagues (2008) have recently shown that nonexperts judge explanations of psychological phenomena as more satisfying when they include neuroscientific information, even when that information is logically irrelevant. Most worrisome is the striking ability of neuroscientific information to mask bad explanations. Notwithstanding this trend, we believe that many fundamental problems will be tackled and solved by the progressive accumulation of evidence from research at the border of psychology and neuroscience (Christensen and Tommasi 2006). Moreover, one should not forget that imaging tools can be fancy toys for basic scientists, but they are also precious equipment in the hands of clinicians whose main preoccupation is human health rather than pure knowledge.

On the "applied side," it must be added that the construction of theoretical or biologically inspired models of the mind in artificial intelligence and cognitive engineering has seldom proved able to offer answers to relevant, let alone fundamental, questions about cognition. The liveliest debates generated from such endeavors, which should have constituted the core subject for interaction chiefly among psychology, neuroscience, and information science and engineering, have come from philosophers focused on research about the representational, computational, and emergent properties of the mind-brain. It is also true that cognitive engineering has successfully profited from knowledge in psychology and the neurosciences to implement intelligent systems, but apart from the recurrent inspirational reference to mental and neural functions (and their overwhelming complexity), modeling and theoretical research have involved simulation of well-known facts rather than discovery of new ones. At any rate, out of the huge territory that once delimited artificial intelligence, the fields of computational cognitive neuroscience and neuroinformatics are among the few domains likely to survive.

Evolution

Those engaged in the cognitive sciences in recent decades are quite familiar with the idea that cognitive abilities evolve and with the proposal that the study of cognitive evolution deserves special attention. The idea of evolution of cognitive abilities, suggested long ago by Charles Darwin and William James, has been at the forefront of renewed approaches to psychology and the neurosciences. The field of evolutionary cognitive neuroscience reflects a biologically oriented approach to the themes of evolutionary psychology, focusing on the evolutionary bases of the neural underpinnings of the mind (Platek, Keenan, and Shackelford 2007). This evolutionary branch of neuroscience is hardly new, given the fact that neurobiology, long before the appearance of cognitive neuroscience, faced the problem of tracing the evolutionary history of sensory and nervous systems by means of the comparative method (Striedter 2006). Ever since anatomical and physiological techniques were in place, in the late 1800s, neurobiology has gone hand in hand with evolutionary biology, and many of the topics debated today in the light of discoveries in cognitive neuroscience could be traced back to debates among evolutionary neurobiologists. Interactions among the study of mind, behavior, and evolution benefited greatly from the advent of ethology, before the mid-1900s, in the wake of a genuinely Darwinian attitude toward behavior. This stance, affirmed in particular by European ethologists, promoted the understanding of behavior as an integral aspect of the species phenotype, largely innate but conceding windows of opportunity to experiential and environmental factors. In Konrad Lorenz's words in *The Foundations of Ethology* (1981, p. 100), "Under these circumstances a microsystematist on the lookout for comparable characters can hardly fail to notice that there are behavior patterns which represent just as reliable—and often particularly conservative—characteristics of species, genera, and even larger taxonomic groups, as do any morphological characteristics."

Evolutionary neurobiology increasingly found a necessary allied force in ethology, and the field of neuroethology (and the soon-to-be-born subfield of cognitive neuroethology; see Ewert 1982) is a good example of this alliance. If the coupling of neurobiology and ethology is a story of a relatively serene marriage, the same cannot be said about the relationship between genetics and the study of behavior. During the last century, population genetics and theoretical modeling helped to clarify many aspects of evolution, from the standpoint of genes, individuals, and groups. Probably most successful with respect to the specific issue of sexual selection—which already in the work of Darwin was deemed to be one of the key loci of selection—evolutionary explanations of behavior based on genetic data also brought us the controversial field of sociobiology (Wilson 1975). This much-criticized approach to behavior has not always been attacked for the best reasons, though it pushed an overly deterministic tie between behavior (at the individual or the group level, depending on one's preference for the locus of selection) and the genes responsible for behavior (Lewontin, Rose, and Kamin 1984). On the environmental side, the advent of behavioral ecology as a subfield of ethology strongly reinforced the principle that a driving force of behavior is the necessity of organisms to maximize access to available resources while minimizing risks associated with their pursuit—thus bringing economic principles of accounting for costs and benefits to the explanation of behavioral strategies (Krebs and Davies 1997).

A rather different story must be told about the adoption of evolutionary explanations in psychology. Once dominated by the behaviorist tradition, comparative psychology followed the cognitive revolution in pursuing a new approach to the study of the animal mind (Terrace 1984). The field of animal cognition rapidly progressed in studying the variability of species-specific mental abilities in the light of the different organismal constraints and ecological requirements that must have characterized species during their evolution. There has been much debate about whether and how the study of animal cognition can provide a framework for genuine evolutionary explanations of the mind (Bekoff et al. 2002) and this has become a particularly heated subject in discussions of the evolution of language and communication in human and nonhuman species (Hauser 1997).

However, animal cognition studies have taken advantage of an increasing interest in the comparative method for understanding the origins of mental abilities, and the rise of related disciplines such as cognitive ecology (a cross-breeding of animal cognition and behavioral ecology; Dukas 1998) and the previously noted field of cognitive neuroethology nicely represent the livelihood of the field in broader biological context. Another volume in the Vienna Series in Theoretical Biology (Heyes and Huber 2000) discussed the issue of evolution of cognitive abilities in animals with a special focus on nonhuman animals, and other important efforts have targeted the relationship between cognition and evolution (see, for instance, Shettleworth 1998).

Human psychology has been touched by the appeal of evolutionary explanations in a more dramatic (and often more dramatized) way. Though one can date quite precisely the birth of evolutionary psychology (Cosmides and Tooby 1987; Barkow et al. 1992), it is nonetheless hard to judge whether this discipline has safely emerged from its infancy. It has faced numerous difficulties, due to pressures stemming from a number of academic detractors in biology, psychology, and philosophy, although it is generally admitted that the basis of the approach of evolutionary psychology is more than respectable and should be pursued with the rigor of biological methodology (Richardson 2007; Buller 2005; de Waal 2002). The adoption of the evolutionary approach in the explanation of human cognition and behavior has focused mainly on the evolution of those neural and mental modules that qualify as optimal solutions of adaptive problems faced by our ancestors in their presumed environment and social milieu. The search for such adaptive specializations has ranged from nonselective learning modules that allow for the encoding of spatial and temporal contingencies (classical and operant conditioning) to modules sensitive to specific types of content, such as those sensitive to causes and effects in the physical environment (for example, folk physics), the features by means of which we recognize conspecifics (such as perception of faces and emotions), and the active understanding of the complex web of social relationships (theory of mind and aspects connected to mate choice, moral behavior, and the like). As already noted, evolutionary explanations of human cognition and behavior have provoked a number of criticisms. These have targeted principally the idea of adaptation, deemed to be too simplistic to explain the mechanics of human cognitive evolution as satisfactorily as it applies in the case of more classic subjects in organismal biology (Lewontin 1998). Despite the divergences, however, it is widely agreed that cognition should be considered not only an object of evolutionary explanation but also one agent whose action strongly impacts evolution, through the transmission of mental abilities and cultural innovations (Jablonka and Lamb 2005; Sperber 1996).

Last but not least, the dynamical dimension of evolution has largely increased its presence in the cognitive sciences via its relevance for both abstract and applied research carried out at the peculiar intersection of cognitive engineering and the life sciences, namely in the disciplines of artificial life and evolutionary computation. Although practitioners in these fields are not necessarily interested in modeling cognition per se, they have exploited notions of variation, reproduction, and selection in implementing software (genetic algorithms) and hardware (evolutionary robotics) whose main feature is that of changing through generations, showing fitter and fitter behavior in specific problem-solving contexts. As with the more traditional approaches of artificial intelligence, evolution-inspired cognitive engineering has made good use of well-known data to provide simulations and derive predictions about artificial systems, perhaps with the advantage of being a benchmark for otherwise impossible experimentation. In fact, given that the very large-scale temporal dimension can be made tractable when the availability of appropriate computational power is assumed, the field can contribute to an understanding of some aspects of the evolution of cognition in creative ways (see, for example, Cangelosi and Parisi 2001).

Development

The relevance of the developmental dimension to both biology and cognition is clear from the very moment one considers that development paves the way for organismal form and function, and that development represents the most plastic stage during an organism's life.

Studies of development, even of cognitive development, have been for a long time a district of psychology quite detached from the aims and objectives of the cognitive sciences. Piagetian theory, which was in itself a major pioneering contribution to cognitive theory, predating the birth of the cognitive sciences (Vauclair and Perret 2003), has been a particularly influential theory about cognition in infancy and childhood, positing that the acquisition of the fundamental elements of knowledge must pass through several stages in order to be fully mastered. Piagetian theory had many merits, chiefly that of devising clever ways to test what children can and cannot understand about a large number of knowledge categories, from the physics of containment to moral thought. Moreover, Piagetian theory, empirically targeting the mastering of numerous and diverse types of tasks, reinforced a vision of the developing mind as that of one system facing a number of separable problems, and established ad hoc experimental paradigms that allowed researchers to assess each of them. It is worth noting that many of those problems involve the types of representations that the contemporary cognitive sciences seek to understand, in that they are deemed to be the building blocks of cognition.

The interest of current developmental theory has recently zoomed in from the standard controversies over nativism or modularity writ large to selected types of content that largely cut across faculties and represent fundamental life aspects in an ecology of objects, events, and other organisms. It has been shown that there is much to learn about the nature of cognition from detailed analysis of the development of functions that allow children to encode and make use of specific forms of information in given contexts, disregarding any concern about the innateness or modularity of these functions: the empirical scenario is usually complex enough to satisfy a theorist's appetite, even (and especially) when starting from very specific aspects. Our ability to "understand" facial expressions, for instance, allows for a better coordination and regulation of a number of behaviors in the social structure that includes us, and this clearly involves the development of abilities that enable us to represent and manipulate facial information across perception, learning, memory, thought, and emotion.

The way these dedicated abilities develop over time is being better understood under the lens of neuroscience (see, for example, Nelson and Luciana 2001), with an increasing attention paid to aspects of neural development that might directly act as keys in the construction of cognition (see Mareschal et al. 2007).

We believe that recent fortunate changes in the fields of psychology and neuroscience have seen both comparative and developmental psychologists take a new direction that can help to delineate the future of the cognitive sciences. The core concepts of cognition and their levels of analysis (representations, computations and their function) are more likely to be uncovered through the adoption of a truly naturalistic perspective, one that merges cross-species research at various stages of development and at various levels of detail between brain and behavior—reflecting in a way the application of Tinbergen's four questions (Tinbergen 1963) on the levels of analysis set forth by David Marr (1982). This attitude has the added effect of forcing the careful consideration of many other aspects apart from evolution and development, such as ecology and genetics, that are clearly relevant in the definition of the biology of cognition.

Cognitive Biology

The reasons behind change in the history of science are not always clear. Sometimes change is produced by transformations from within, from the everyday activities and practices of scientists; at other times it reflects the action of political and cultural forces that define science as an aspect of society. If the study of evolution and development in the cognitive sciences is to be taken seriously, with attention to the proximate mechanisms and functions that underlie mind and behavior and their environmental and genetic constraints, it is clear that the enterprise is not logically separable from that of the life sciences. One of the central tenets of biology is that development, being a locus of variability, acts on evolution (Gilbert 2006). This is crucial because plasticity and developmental change become likely candidates for attaining one or another cognitive outcome, and many are the ways this can take place in ontogeny and phylogeny (Geary and Huffman 2002).

The idea that the cognitive sciences have inherited from biology more than the mere adoption of imaging techniques, constituting what we broadly refer to as "cognitive biology," is not new: the proposal that evolution and development are driving forces of a naturalistic approach to cognition is not new, nor is a sense that an evo-devo approach is important to the cognitive sciences (Hauser and Spelke 2004; Ellis and Bjorklund 2002; Langer 2000).[1] The editors of and contributors to this book hope to make the reader more familiar with the evo-devo approach, by presenting current research in a fashion that when seen from afar will convey the general picture of "cognitive biology"—but when seen from nearby will preserve the level of detail essential to the sciences of mind, brain, and behavior.

Note

1. Some time ago the expression "cognitive biology" was used very differently (Boden and Khin Zaw 1980), to refer to an approach to biology that made use of concepts usually associated with the language developed to speak about knowledge.

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