

MODULES, BRAIN PARTS, AND EVOLUTIONARY PSYCHOLOGY

The central focus in debates over broad evolutionary psychology is whether mental abilities can be understood as adaptive functions (Davies, 1996, p. 446). Narrow evolutionary psychology¹ further closely couples the claim that mental abilities are adaptive to a commitment to modularity of mental functions. This linkage is presented as quite direct—if the mind is comprised of discrete modules, then we can ask what are the selective factors that promoted each module. If, on the other hand, the mind is comprised of a single, fully integrated, general processor, then it would be much harder for natural selection to promote cognitive capacities individually.² And it would be much harder for us to give an explanation of the evolution of particular mental abilities. Cummins and Allen (1998, p. 3) provide a succinct account of the link between modularity and narrow evolutionary psychology:

Taking an evolutionary approach to the explanation of cognitive function follows naturally from the growing body of neuroscientific evidence showing that the mind is divisible. The picture that is emerging from both noninvasive studies of normal brain function and from clinically defined syndromes resulting from brain damage from strokes, injury, and neurodevelopmental disorders is one of different substrates subserving different cognitive functions ... The Cartesian view of a seamless whole makes it hard to see how such a whole could have come into being, except perhaps by an act of divine creation. By recognizing the modularity of mind, however, it is possible to see how human mentality might be explained by the gradual accretion of numerous special function pieces of mind.

There is little doubt that contemporary neuroscientific evidence does repudiate the holism of Cartesian accounts of mind (the kind of holism grounded in the apparent unity of

¹ EDITOR'S NOTE: In this book, the term 'narrow evolutionary psychology' signifies the approach to evolutionary psychology developed by Cosmides, Tooby, Buss, et al. This term was chosen not to imply that this approach has an inappropriately narrow point of view, but merely to suggest that the approach adopts a narrower range of assumptions than 'broad evolutionary psychology' (or, just 'evolutionary psychology'). This latter term signifies evolutionary psychology generally, practiced with any of a very broad range of assumptions possible within the general framework of evolutionary approaches to psychology. For more detail on this terminology, see the editor's introduction, p 1.

² The difficulty seems comparable to that in a standard feedforward connectionist networks where acquiring a new input-output pattern disrupts already acquired ones unless the previously acquired ones are retrained along with the new one. This is known as the problem of *catastrophic interference*. Two ways connectionists have tried to respond to this difficulty is to provide a principled means of continually retraining on previously learning examples (McClelland, McNaughton, & O'Reilly, 1995) and by building in modules (Jacobs, Jordan, & Barto, 1991).

thinking and consciousness that motivated Flourens in his rebuttals of Gall in the 19th century and Lashley and others in the first half of the 20th century). But what kind of modularity does neuroscience really support? What sort of cognitive processes are carried out by the separable components of the brain? Most advocates of narrow evolutionary psychology identify modules at a fairly coarse grain. Modules are proposed for various tasks it is thought our ancestors needed to perform — reasoning about groups and coalitions, detecting cheaters, making risk aversive decisions, or interacting with other minds. The reason why psychologists advocating narrow evolutionary psychology seek modules responsible for whole tasks humans perform is clear — they match the proposed selection forces.³ (These psychologists did not originate the search for modules at this level; the prototype of such modules is the language acquisition module advocated by Chomsky.) I will argue, however, that the sort of modules supported by neuroscience are at a far finer grain. They are involved with what Petersen and Fiez (1993, p. 513) characterize as elementary operations, not tasks:

... elementary operations, defined on the basis of information processing analyses of task performance, are localized in different regions of the brain. Because many such elementary operations are involved in any cognitive task, a set of distributed functional areas must be orchestrated in the performance of even simple cognitive tasks ... A functional area of the brain is not a task area: there is no "tennis forehand area" to be discovered. Likewise, no area of the brain is devoted to a very complex function; "attention" or "language" is not localized in a particular Brodmann area or lobe. Any task or "function" utilizes a complex and distributed set of brain areas.

Many proponents of narrow evolutionary psychology (Cosmides & Tooby, 1994; Gigerenzer, 1997; Shettleworth, 2000) simply assume that the mind/brain is modular at the relatively coarse grain at which they work and focus instead on arguing for proposals for particular modules and accounts of their evolution. Most of the arguments for modularity have originated elsewhere, especially in computer science and neuropsychology. Accordingly, I begin with a review of those arguments. I then turn to current neuroscience to argue that the units of brain organization do not correspond to modules as conceived in narrow evolutionary psychology. Neural information processing units are both far more integrated into the overall neural system and operate at a far finer grain than supports the strategies used in narrow evolutionary psychology. Consequently, the task of developing an evolutionary account of cognitive function must be construed much differently than it is by current practitioners of this approach. I will sketch the alternative in the final section.

1. MODULES: FODORIAN, COMPUTATIONAL, AND NEUROPSYCHOLOGICAL

At the center of most discussions of modularity is the account offered by Fodor (1983). For Fodor, the core mind (which he termed the *central system*, and which he construed as

³ Cf. Cummins (1998, p. 31): "Structures evolve in response to environmental demands, demands that impact on survival rates and reproductive success." (See also Shettleworth, 2000).

engaged in inference and belief fixation) was not modular.⁴ Rather, modules are found between transducers and the central system and have the task "to present the world to thought" (1983, p. 40). Although the modules for him are responsible for information processing, they do so in an automatic and autonomous manner. He characterizes the operation of the modules in terms of nine properties: they (1) are domain-specific, (2) are mandatory in their operation, (3) allow only limited central access to the computations of the modules, (4) are fast, (5) are informationally encapsulated, (6) have shallow outputs, (7) are associated with fixed neural architectures, (8) exhibit characteristic and specific breakdown patterns, and (9) exhibit a characteristic pace and sequencing in their development. Of these, Fodor places the primary emphasis on informational encapsulation, which requires that a module use only information encoded within it in its processing; in particular, a module cannot invoke information stored in other modules or in central cognition.⁵ One thing that restricting the information available to a module does is make its processing task tractable. But it also prevents what is often referred to as *top-down* processing between modules — the use of later processing of higher-level cognitive information in lower-level processing.⁶ Many accounts of perception allow top-down influences whereby what one sees is influenced by knowledge and expectations. Such accounts engender the view that perception is theory-laden and skeptical worries that we lack any independent, objective epistemic access to the world. Fodor offers it as a virtue of his approach that the output of modules are objective in the requisite sense (Fodor, 1984).

Fodor's account of modularity is extremely strong in the degree of isolation it creates between modules. One consequence of this is that processing within modules cannot exhibit much intelligence. Modules can perform complex manipulations of inputs, but because they are encapsulated and their operation is mandatory, they cannot respond flexibly by drawing upon other sources of information. Accordingly, Fodor's account does not lend itself to application to central processes. Evolutionary psychologists who draw on Fodor, however, "see cognition as modular right through from input to decision processes" (Shettleworth, 2000, p. 54). In many respects, Fodor's account of modules is the one narrow evolutionary psychology needs to embrace, since his modules are sufficiently autonomous to be potentially selected for independently. But the inability of such modules to accommodate intelligent processing would seem to make them of limited use to narrow evolutionary psychology. Fodor's is not the only account of modules narrow evolutionary

⁴ Fodor's denial of modularity for the central system is a result of his construal of thinking as isotropic and Quinean. By *isotropic* he means that anything a person knows is relevant to determining whether to believe a given proposition, and by *Quinean* he means that the degree of confirmation of a belief depends on its relation to other beliefs. One may question how isotropic and Quinean human thought really is (see Waskan & Bechtel, 1997), but a main point to emphasize is that Fodor's rejection of modularity for central systems (and his accompanying law denying the possibility of cognitive science — see 1983, p. 107) is largely a result of his very strong conditions on what constitutes a module.

⁵ Note that the notion of informational encapsulation is a strong notion. Fodor differentiates it from domain specificity, which many modular theorists employ: "Roughly, domain specificity has to do with the range of questions for which a device provides answers (the range of inputs for which it computes analyses); whereas encapsulation has to do with the range of information that the device consults in deciding what answers to provide" (1983, p. 103).

⁶ See Appelbaum (1988) for a discussion of how this presents a problem for Fodor in analyzing data about speech perception.

psychology could draw on. Other accounts are found in computer science and neuropsychology, but as we shall see, these are event less suited to narrow evolutionary psychology's construal of modules as the units of evolution.

In computer science, ideas of modularity arose in the design of computer programs. By breaking complex tasks into components and developing subroutines for each, it became more efficient both to design and revise computer programs. But Herbert Simon argued that modularity was not just a consideration for programs. He argued that our ability to understand complex systems depended on them exhibiting what he called "near decomposability."⁷ Simon imposed two conditions on near decomposability:

- (1) In a nearly decomposable system, the short-run behavior of each of the component subsystems is approximately independent of the short-run behavior of the other components;
- (2) in the long run the behavior of any one of the components depends in only an aggregate way on the behavior of the other components (Simon, 1969, p. 210)

Moreover, he advanced an argument that evolution could only have produced complex systems if the systems it produced were nearly decomposable; without the possibility of adjusting components piecemeal (and then composing them into wholes), complex structures could not have evolved in limited time. (Simon's conception of evolution also involves building complex assemblies out of nearly decomposable units. The hierarchical features of his account are not considered here. For a response to this argument, see Bechtel & Richardson, 1993.)

Another computer scientist (although originally a physiologist) who invoked a conception of modularity not just for computer programs but for the physiological systems he was modeling was David Marr (1982). He advanced a *principle of modular design* according to which the interactions between components in a system are weak and have limited effect on each other. This permits the isolation and independent study of the components. But for neither Simon nor Marr is such independence absolute. Simon speaks of *near decomposability* and Marr of organization being, to a *first approximation*, modular. Their conception of modularity is, accordingly, much weaker than Fodor's and less suited for the purposes of narrow evolutionary psychology.

With their qualifications, Simon's and Marr's conception of modular design seem entirely reasonable. Much of scientific practice since the 17th century has started by taking systems apart and attempting to understand how their parts behave (Bechtel & Richardson, 1993). This practice assumes there are parts and that they carry out operations on their own. But it is important to note that when this heuristic is adopted, it often succeeds only to a first approximation. Subsequent research frequently reveals complex modes of interaction between the components, which have the effect of severely modulating the behavior of the individual components. Second, the activities carried out by the parts of a system often do not perform functions that can be understood just from the framework of the activity of the overall system. Researchers sometimes begin by characterizing the

⁷ The linkage between the assumption of modularity and scientific practice is also emphasized by Semenza, (1996, p. 481): "the value of the modularity principle probably transcends the likelihood of the nervous system implementing cognitive functions in a modular way. It seems, in fact, to honor a longstanding scientific tradition of decomposing complex entities into their basic functional components, a method that has often been successful in the physical sciences."

behavior of the parts from such a viewpoint. For example, once physiological chemists recognized that fermentation consisted of multiple chemical reactions, they first attempted to characterize the component reactions as themselves fermentations. But only a reconceptualization of the component reactions in different terms (e.g., as oxidations, reductions, phosphorylations, transphosphorylations) allowed modern biochemistry to develop adequate mechanistic models of what components contributed and of the crucial interactions that allowed them together to carry out fermentation. I return to these considerations below, as they critically affect how we construe modular components in the mind.

Neuropsychology employs a notion of module that is closer to Simon's and Marr's than Fodor's. A major endeavor of neuropsychology has been to utilize the behavior of individuals with brain injury to make inferences about normal function. In its simplest version, one infers from a behavioral deficit in a patient that the area damaged in the patient's brain was responsible for the ability the patient has lost. Thus, Broca (1861) inferred from the Leborgne's deficit in articulate speech that an area in the frontal cortex that came to bear his name was the center of articulate speech. In the years since Broca, neuropsychologists have identified a rich, often bewildering patterns of deficit in human patients.⁸ Two important theoretical ideas began to bring order to the various findings of deficits in the mid-20th century. One was an emphasis on the association of deficits — by showing that different deficits generally appeared together, one could infer that each of the abilities in their normal manifestation depended on a common underlying process. The second was dissociation, especially double dissociations as developed and employed by Teuber (1955). The idea underlying double dissociation is that if one can find two patients or groups of patients, one of which exhibits diminishment of one capacity due to brain injury with much less or no diminishment of another capacity, and the other of which shows the reverse pattern, then the two capacities can be construed as relying, at least in part, on distinct brain processes. These dissociable components can be construed as modules (Shallice, 1988).

In the 1980s neuropsychology was partly transformed by adopting the information processing framework from cognitive psychology. Within cognitive psychology at the time information processing models were developed and evaluated almost exclusively in terms of behavioral data such as reaction times, but through sophisticated application of these techniques, psychologists began to identify component cognitive operations and develop models of how they interacted in achieving cognitive performance (Posner, 1978). The idea of processing information through different operations upon representations provided a powerful organizing principle for thinking about the deficits neuropsychologists had

⁸ Until the 1980s, neuropsychology was pursued under three broad perspectives—the localizationist approach exemplified by Broca, the connectionist approach of Wernicke and Geschwind, and the holist approach of Head, Goldstein, and Lashley. The last proved dominant during the first half of the 20th century, but gradually lost sway, especially with the influence of Geschwind, the finding of anterograde and graded retrograde amnesia in H.M. following bilateral resection of his medial temporal lobe, and the studies on split brain patients by Roger Sperry and his collaborators.

identified.⁹ Specifically, it enabled a shift into thinking about deficits from the point of view of underlying operations that were disrupted and not just localizing areas where lesions produced deficits:

Traditionally, neuropsychologists studied the localization and functional organization of *abilities*, such as speech, reading, memory, object recognition, and so forth. But few would doubt that each of these abilities depends upon an orchestrated set of *component cognitive processes*, and it seems more likely that the underlying cognitive components, rather than the task-defined abilities, are what is implemented in localized neural tissue. The theories of cognitive psychology therefore allowed neuropsychologists to pose questions about the localization and organization of the components of the cognitive architecture, a level of theoretical analysis that was more likely to yield clear and generalizable findings (Feinberg & Farah, 2000, p. 16).¹⁰

Feinberg and Farah illustrate this shift with reading impairments. There are patients who can read non-words (*rini*) but not irregularly pronounced words (*pint*), and others who show the reverse pattern. This might suggest a center for non-word reading and another for irregular word reading, but an information processing account advances a different decomposition — one relying on a lexicon of words and another on grapheme-to-phoneme transition rules (Coltheart, 1987). In normal subjects, both support fluent reading, but when one or the other is impaired, one expects the pattern actually found in patients.¹¹

For neuropsychology, then, the import of modularity is that the system is composed, at an appropriate grain, of components which can be studied in relative isolation and which carry out specific information processing operations. Thus, Shallice (1991, p. 431) describes the modularity assumptions operative in neuropsychology as follows:

1. The cognitive system being investigated contains a large set of isolable processing subsystems (in the sense of Posner, 1978) or modules (in the sense of Marr, 1982).
2. The modularity operates on a number of levels. As far as neuropsychology is concerned, however, there is a limit to the fineness of the grain of modularity.
3. Following Marr (1982), isolable processing subsystems may be viewed as having functions carried out by algorithms implemented by particular mechanisms.

The conceptions of modularity derived from computer science and especially neuropsychology already differ in a crucial respect from that operative in much of narrow evolutionary psychology. They do not offer a conception in which modules correspond to

⁹ The availability of neuropsychological evidence for cognitive psychology was also important. By showing that different capacities were lost together (perceiving and mental imagery—see Farah, 1988; Kosslyn, 1994) or that some capacities were preserved in patients in whom others were lost (implicit memory in amnesics—see Schacter, 1987), neuropsychology could provide new sources of data about the nature of the information processing components.

¹⁰ Cf., Semenza (1996, p. 481): "Without a theory of a given task, the principle of modularity applied to that task is conceptually empty and has no empirical ramification because anything may be viewed as a module."

¹¹ The dual-route model of reading has been challenged by neural network modelers who contend that a single pathway can account for reading and when lesioned generates both patterns of deficits (Plaut et al., 1996).

overall cognitive abilities that human agents possess. Rather, modules exist at a lower level, at the level of information processing operations which are recruited in various ways in realizing cognitive abilities. But the conception of modularity in neuropsychology retains the idea of relatively autonomous components. Does that square with the organization of the brain?

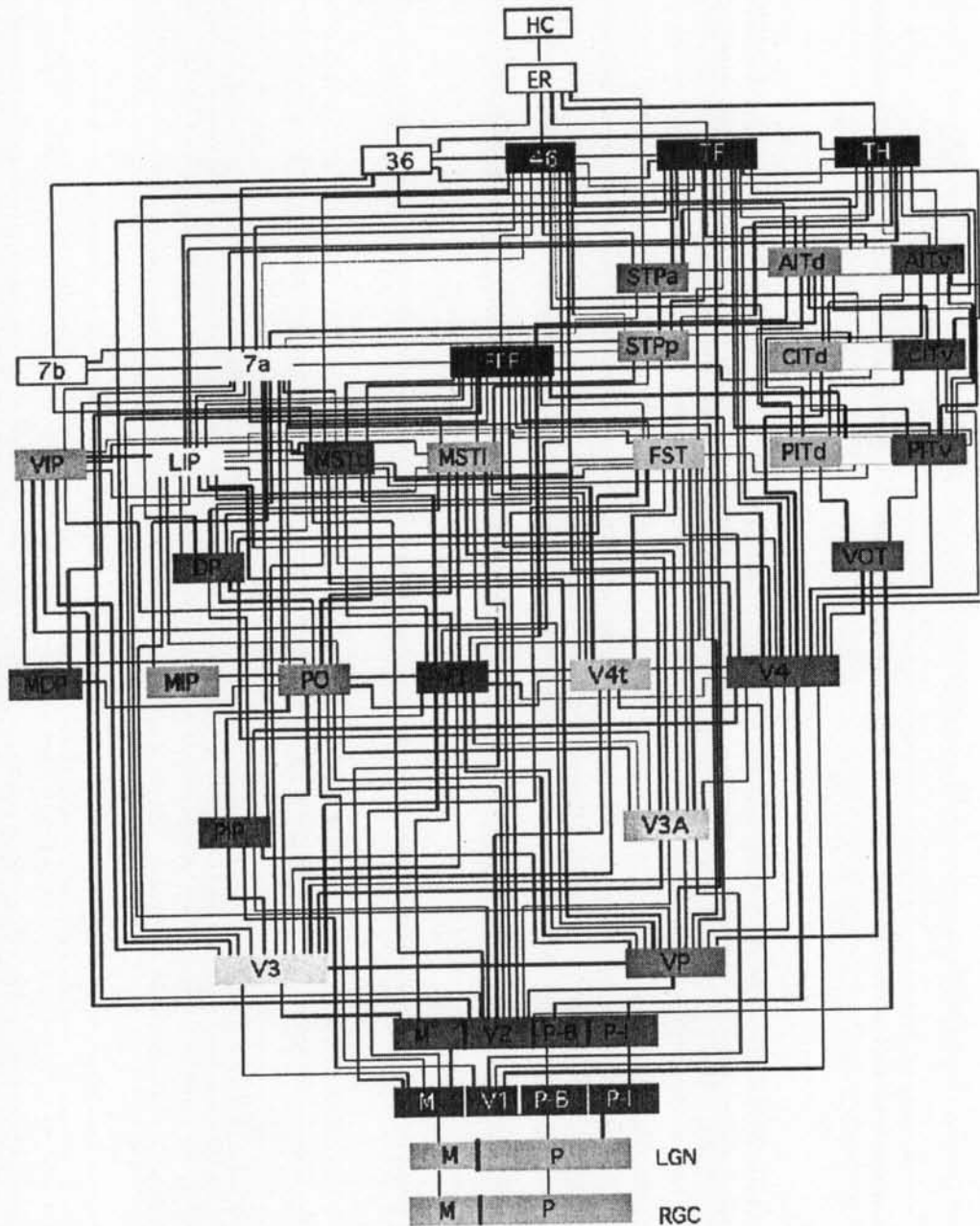


Figure 1. A Map of the Visual Processing Areas and their Interconnections in the Macaque Brain. (From van Essen, Anderson, & Felleman, 1992).

2. BRAIN CARTOGRAPHY AND MODULES

Clearly the brain is not an undifferentiated mass. Even a casual examination reveals fundamental differences. For example, it is not hard to differentiate the cerebral cortex from such other components as the brain stem, midbrain, and cerebellum. Within the cortex, major fissures mark out the four lobes. A natural assumption, and one that has guided much research, is that structural differences probably correspond to functional differences, although sometimes this heuristic may be misleading. The pattern of convolutions in the cortex is basically similar among members of a species, but it does not reliably map onto what are taken to be more basic functional units and more recent evidence suggests that it results from physical constraints on the developing brain rather than anything related to differences in function (Van Essen, 1997). The more micro-level decomposition into brain components, based on such factors as types of neurons present and their distribution between different laminae of the cortex, was begun by a number of early 20th century researchers, of whom Brodmann has had the greatest influence. The contemporary project of mapping the brain is fundamentally a continuation of Brodmann's, but carried out with additional resources. In addition to Brodmann's cytoarchitectural methods, researchers rely heavily on patterns of connectivity (as revealed, for example, through chemical tracers), the replication of topographical maps, and differences in function in delineating brain areas (Mundale, 1998). The result of this is a more fine-grained identification of brain areas and their connectivity. Although increasingly similar efforts are being made for other portions of the brain (see Carmichael & Price, 1994), the best exemplar of such brain mapping remains research on visual processing areas in the brain. Felleman and van Essen (1991) differentiate 32 visual processing areas in the macaque and 300 distinct pathways between them, yielding a picture of a complex, integrated system (see Figure 1).

For Brodmann, differentiating areas of cortex and mapping relations between them was not an end in itself. His assumption was that distinct areas would serve different functions: "It is a basic biological principle that the function of an organ is correlated with its elementary histological structure" (Brodmann, 1909/1994, p. 243). At Brodmann's time, however, the only tools for linking structures with functions were analyses of deficits after lesioning and responses to electrical stimulation. One of the most powerful tools during the 20th century in determining the function of neurons was single-cell recording. By determining the types of stimuli to which cells in different areas are responsive, researchers could begin to identify the kind of processing each was likely to be performing. While many details remain to be filled in, a basic outline of the steps in visual processing both in the ventral stream that results in object identification and in the dorsal stream that analyzes spatial relations and possibilities for action have been identified, largely on the basis of a combination of lesion studies and single cell recording studies (Bechtel, 2001).

When presented schematically, the organization of the processing streams seems to conform closely to models of information processing through sequential modules — information about wavelength, orientation, and spatial frequency is processed in the interblob areas of V1, from which the interstripe areas of V2 compute disparity and subjective contours, from which in turn V4 computes non-Cartesian patterns, and areas in

inferotemporal cortex identify objects (van Essen & Gallant, 1994). But the details reveal a much more complex system. As Figure 1 exhibits, the different areas are multiply connected, including numerous lateral connections between different processing streams. On average, each visual area has ten distinct inputs and ten distinct outputs. Van Essen and DeYoe (1995) analogize the overall organization to a possible organization of a industrial factory, and describe design for a factory with merging and splitting of processing streams:

The main disadvantage of this strategy is the need for complex links between modules. In exchange, there are two obvious advantages: It provides for efficient compartmentalization of function, insofar as each step of the manufacturing process can be assigned to a module well suited for that particular task; and it is inherently flexible, because each module can access whatever inputs it needs and can distribute its output as necessary to achieve the desired set of final products. A major thrust of this chapter will be to argue that similar principles apply to the overall design of the primate visual system (p. 384).

In the picture of cortical design van Essen espouses, the degree of autonomy of processing areas is significantly reduced. Each component still carries out its own information processing operation, but it is highly interconnected and responsive to other components.

An often noted important feature of cortical organization is that backwards projections are at least as numerous as forward projections. Nearly every forward projection has a corresponding backward projection. Although the function of the backward projections is still a matter of some dispute, one thing that is clear is that there are neuroanatomical differences between forward, backward, and lateral connections. Forward and backward projections both originate in either the superficial or deep layers,¹² but forward projections project to layer 4, whereas backward projections project to the superficial or deep layers. In contrast, lateral connections project to all layers of cortex (see Figure 2). (In large part, it was this distinctive pattern of forward and backward projections that enabled van Essen and his colleagues to place various cortical visual areas in the 10 different levels of the hierarchy shown in Figure 1.)

Although the details of brain anatomy and its relation to psychological function are best worked out in the case of vision, investigations on other brain areas suggest the same ideas apply elsewhere. The brain is comprised of different processing units, but the information processing operations they perform are at a quite micro-level of organization. Moreover, these units are highly interconnected. This description of neural organization might seem to be at odds with the popularized results of neuroimaging (to which Cummins and Allen allude in the quotation at the beginning of this paper). PET and many fMRI studies seemed to identify brain areas responsible for relatively macro-level tasks — word identification, face and object recognition, semantic processing, encoding and retrieval of semantic and episodic memories, etc. These seemed to be tasks close to the level proposed in narrow evolutionary psychology. But the identification of these tasks with one brain area is partly an artifact of the sensitivity of the instruments and the statistical measures invoked in early studies, which only revealed areas with the greatest increase in activation, and the use of the subtractive method. Employing the subtractive method, investigators used two

¹² If they originate in just one layer, though, forward projections originate in the superficial layer while backward projections originate in the deep layers.

tasks, which were thought to differ in one operation, and then subtracted the pattern of activation produced performing one task from that produced performing the other. The area(s) left after the subtraction were construed as performing the additional task. But many of the areas subtracted out might also figure in the new operation. For example, in evaluating Tulving's proposal that retrieval of episodic memories activates right prefrontal areas whereas retrieval of semantic memories activates left prefrontal areas, Buckner (1996) found that the left prefrontal areas and areas elsewhere in the brain were active above baseline in episodic retrieval as well, but camouflaged by the subtraction technique. The more common strategy in recent imaging studies is to identify networks of areas active in the performance of any task. The various components of these networks are thought to be interconnected, with each performing component subtasks of the overall cognitive activity. Increasingly, therefore, imaging is revealing highly interactive neural processing at a finer grain, a picture that coheres well with the neuroanatomy just discussed.

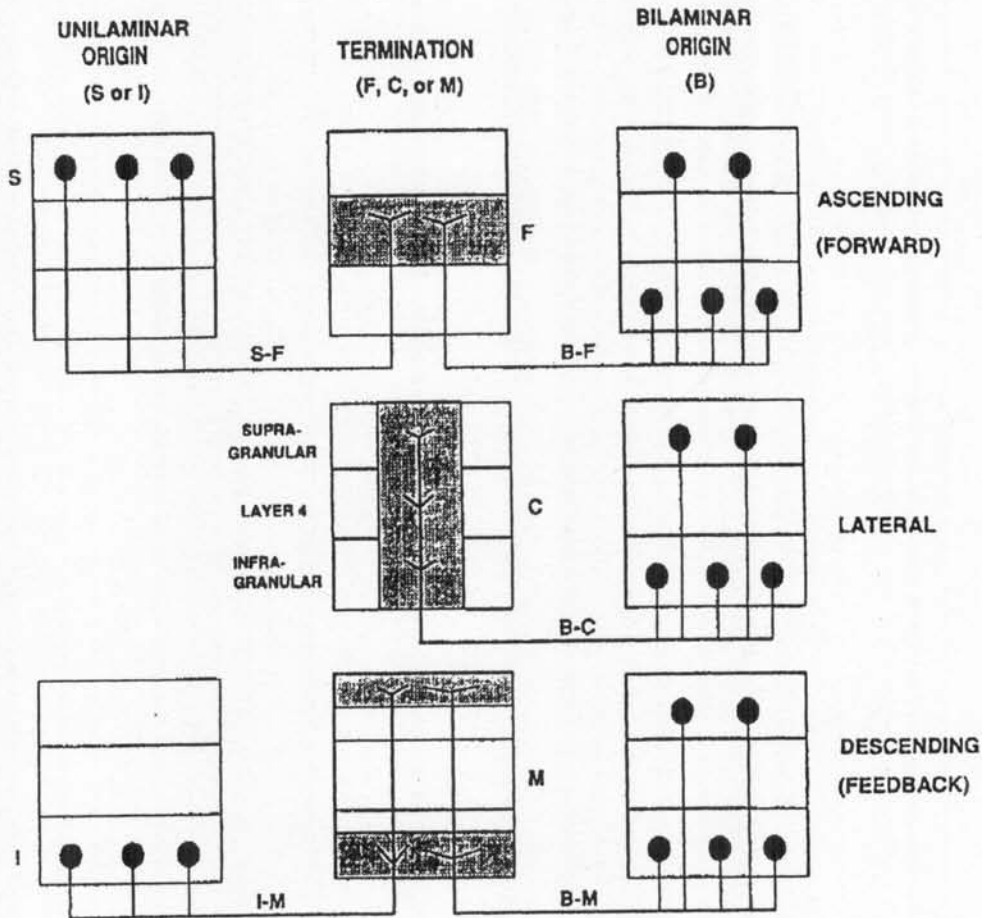


Figure 2. The Different Patterns of Connectivity Between Cortical Columns for Feedforward, Feedback, and Lateral Connections. (From Felleman & van Essen, 1991).

3. CAN NEUROPSYCHOLOGY AND NEUROSCIENCE ACCOUNTS OF MODULES BE RECONCILED?

In the previous two sections I have contrasted the accounts of modules offered by neuropsychology and neuroscience, both in terms of the grain size of modules and especially in terms of their interconnectedness. Can these be reconciled? One force for doing so has been the development of connectionist or neural network modeling frameworks in psychology. Although typically such models do not intend to ground cognition directly in actual neural processing,¹³ they do model cognitive processes at a far finer resolution than more traditional cognitive models (Smolensky, 1988). Recently, neural network modelers have simulated how neuropsychological deficits might result from lesioning such models (Hinton & Shallice, 1991; Plaut, 1995; Plaut, McClelland, Seidenberg, & Patterson, 1996). A not uncommon result is that simulated lesions at different sites in a highly interconnected network result in patterns of deficit similar to those exhibited by different patients. This suggests that the picture of highly interconnected micro-level modules resulting from neuroscience might also account for the patterns of deficits found in neuropsychology.

To show how this conception of highly interactive, fine-grained modules seems likely to gain further support in future psychological and neuropsychological research, I will focus on recent research on memory. It is common in memory research to distinguish between declarative and non-declarative memory, and, within declarative memory, to distinguish episodic and semantic memory (Cohen & Squire, 1980; Tulving, 1972). These distinctions were in large part motivated by the identification of patients who exhibited deficits in some memory abilities but not others. For example, HM, whose medial temporal lobe was resected by William Scoville in an attempt to reduce epileptic seizures, exhibits anterograde and graded retrograde amnesia for declarative memories, but retains the ability to develop non-declarative memories (e.g., exhibiting increased skill in a task with practice, with no recollection of having performed the task before — see Corkin, 1968). In contrast, KC, who became amnesic as a result of a motor cycle accident in the early 1980s, is able to develop new semantic memories, albeit with difficulty, but not episodic memories (Tulving, Heyman, & MacDonald, 1991).

One interpretation of these and other dissociations of memory capacities is that there are different systems responsible for the different types of memory (Tulving, 1984). One of the challenges faced by advocates of multiple memory systems is to clarify just what comprises a system. In Tulving's early conception, memory systems (a) are, in some sense, structurally distinct, (b) process different types of information and represent it differently, and (c) operate in accord with different principles (see also Sherry & Schacter, 1987). More recently Tulving (1999) has emphasized the type of information represented. He illustrates this idea in terms of three types of information provided when a person reads the sentence "aardvarks eat ants":

¹³ Despite the fact that the units in such models are based in general features of neurons, most modelers do not treat that linkage very seriously. Rather, the units in the models are generally thought to represent interactive components in the neural system, perhaps more at the level of neural columns.

PRS, the perceptual representation system [an additional system Tulving introduced], encodes and stores information about the features of the visual objects represented by the letter strings AARDVARKS EAT ANTS. The semantic memory system, or a set of its (presumably numerous) subsystems, encodes and stores propositional information about the feeding habits of animals named aardvarks. The episodic system integrates, registers, temporally dates, and spatially localizes the rememberer's experience of the experience of being present and witnessing the sentence appearing on and disappearing from the screen (p. 20).

This proposal of different memory systems seems to fit well with the sorts of modules advocated by psychologists following the narrow evolutionary psychology program. But there has been a competing approach to studying such memory abilities which offers a quite different conception, one that emphasizes information processing procedures rather than systems. Roediger, Buckner, and McDermott (1999) characterize this approach as follows:

The hallmark of the procedural approach, harking back to Bartlett and Neisser, was that performance on memory tasks could be described as skilled performance and that one should look to the procedures of mind to explain cognitive performances. Many experiments can be interpreted as supporting the procedural approach, including several revealing dissociations in performance on tasks that all measured recognition of words. In particular, Kolers' experiments showed that transfer from one task to another benefitted to the degree that the procedures underlying performance on the two tasks were similar (p. 42).

The processing or procedural approach also employs dissociations to separate component processes, but is open to finding multiple processes within a purported memory system (such as the episodic memory system). The version of the process approach Roediger et al. embrace is *the components of processing framework*, developed by Morris Moscovitch. In this approach, different memory tasks may draw differentially upon different information processing procedures. When tasks are dissociated, that does not show that whole systems are separated, but that at least one component procedure figures differently in the two tasks (Hintzman, 1990).

In an illustrative example, Roediger et al. (1999) use a neuroimaging study to show how a multiple process model may be developed to account for abilities that would, in the systems approach, be assigned to different systems. In the baseline condition, subjects were just asked to complete a stem like COU ____ with the first word that came to mind (a purely semantic memory task). In the other two conditions, the subjects first study a list of words. In the second condition, subjects are then given the same directions on the word stem completion task — complete the stem with the first word that comes to mind — while in the third condition, they were instructed to only complete the stem with a word they had just studied (an explicitly episodic memory task). In the first condition, word-stem completion with no previous exposure to words, increased activation was found in areas of visual cortex bilaterally, left frontal opercular cortex and supplementary motor areas, right premotor cortex and anterior cingulate. When the words were primed by prior exposure, the same areas were activated, but with reduced activations in visual areas. The researchers interpret this as evidence of incidental memory retrieval. When the instructions were added to complete the stems only with previously primed words, all the areas activated in the previous conditions were again activated, as well as two additional areas: anterior prefrontal cortex bilaterally and posterior medial parietal cortex. These are areas that have

also been activated in other studies of episodic memory, but rather than construing this as evidence for a separate system for episodic memory, Roediger et al. interpret it as evidence for multiple components of a broader memory system that are recruited when the subject is asked to evaluate whether the items were previously encountered.

The *components of processing approach* thus identifies modules at a far smaller grain than the *memory system approach*, a grain congenial to mapping onto accounts of multiple brain areas differentially activated in performing different overall tasks. Although Roediger et al.'s account, as developed to date, does not emphasize the interactivity of the components, it is certainly compatible with discovering recurrent and collateral processing within the overall system in which the components are distinguished. It thus points the way to developing an account of interactive information processing modules at a much smaller grain size than is found in narrow evolutionary psychology.

4. EVOLUTION WITHOUT FODORIAN MODULES

As I noted early in this paper, most advocates of narrow evolutionary psychology employ a notion of module that corresponds to overall abilities individuals exhibit. The claim is that these are the kinds of entities which evolution can promote. But I have been arguing that the sorts of modules neuroscientific evidence points to are at a much smaller grain size (one corresponding to information processing operations) and that these procedures are likely to be far more integrated through forward, backward, and collateral processing than those envisioned by these psychologists. Does the repudiation of these kinds of modules mean the demise of an evolutionary account of cognition? By no means, although it may spell the doom of narrow evolutionary psychology as currently practiced. I will conclude with a very brief sketch of what a broad evolutionary psychology perspective on cognition that is tied to interactive, smaller-grained modules such as are found in the brain might look like.

An important consideration is that evolution necessarily builds from what exists through small scale modifications. Sometimes the building results initially from duplicating existing parts, with each then becoming specialized for different operations that might be needed in carrying out different tasks. Other times the building results from developing new ways of relating the components that already exist. In either case, evolution begins with existing complex entities and modifies them. This is very different than a picture of developing new modules *de novo*. Moreover, it imposes an important constraint on evolutionary models — that they be grounded on information about phylogeny and the ancestral condition before the acquisition of a new ability.

Especially important for this alternative conception is the evolution of new cognitive abilities through new organization imposed upon pre-existing components. A speculative, but plausible, account of how linguistic abilities might have developed in this manner is advanced by Terrence Deacon (1997, 1998). Part of Deacon's analysis focuses on the overall character of the changes between the brains of apes and humans. The human brain is not just a general expansion of the ape brain, but a very selective expansion. The cerebral and cerebellar cortexes increase disproportionately to lower brain areas, and

within the cerebral cortex, the frontal cortex has expanded much more than more posterior areas. Expansion of an area corresponds to increased number of neurons sending out projections. The connectivity patterns in mature brains are strongly influenced by the number of cells sending projections to various areas during early development and the ensuing competition between these projections for influence on the target area. Accordingly, the differential increase in the cerebral cortex results in its exercising greater control over lower level motor nuclei than the brain stem areas and midbrain areas responsible for stereotypic mammalian calls, accounting for the diminished call repertoire of humans and greater flexible control over voicing required for speech. In addition, the disproportionate increase in forebrain areas relative to the rest of cerebral cortex results in connections from it to many areas, including the motor areas controlling speech apparatus, winning out over connections from elsewhere.

Situating the inquiry into language processing in the context of such changes in brain organization raises an intriguing prospect. One can now try to examine the kinds of information processing performed in prelinguistic creatures by the areas from which increased projections in humans stem. Although the research is still in an early stage, it suggests that some prefrontal cortical areas in monkeys play an important inhibitory function, allowing animals to suppress previously learned associations and acquire new ones (Goldman-Rakic, 1987). Deacon offers intriguing suggestions as to how this inhibitory processing might constitute a primitive form of negation and how such negation is critical to establishing a true symbolic system, in which symbols have internal relations to one another as well as referential relations to things in the world.

This example from Deacon is intended simply as an illustration of how an evolutionary psychology might be developed without invoking the kinds of modules proposed within narrow evolutionary psychology. What is key to this approach is focusing on the information processing operations different brain areas are specialized for and analyzing how they are related to each other in normal processing. An important feature of this approach to broad evolutionary psychology is that, by positioning information processing operations in a phylogenetic lineage, the evolutionary analysis becomes a tool for advancing the decomposition of the overall ability into information processing operations. Once one has identified a brain area that is recruited to perform a task, one can hope to use information about the tasks the area is recruited for in other species as a clue to the type of information processing it supports. Thus, in Deacon's example, instead of just determining that a particular area plays a role in language processing, one can ask why a component that plays a different role in other species would be recruited for language processing in humans. Especially when this investigation is integrated with the developing information about brain anatomy and connectivity, the quest for discovering phylogenetic linkages can play a major heuristic role in determining what are the basic information processing operations that underlie cognitive performances. It is thus a heuristic for developing what Richardson and I call the decomposition of the performance, an important element in the quest for a mechanistic explanation (Bechtel & Richardson, 1993).

5. CONCLUSION

I have argued that the conception of a module that figures in much narrow evolutionary psychology is not supported by what we know about brain organization and its contribution to cognition. The brain does involve differentiated components, but these components perform fine-grained information processing operations, not whole tasks like cheater detection or reasoning about other minds. These components, moreover, are highly integrated with each other, and are recruited into integrated networks to carry out the large-scale mental activities on which many evolutionary psychologists have focused. There is a motivation to link the sorts of information processing modules found in the brain to an evolutionary framework, but the emphasis is then on determining phylogenetic relations so as to utilize what is discovered about these modules in other species as clues about how they may contribute to cognitive tasks we perform.

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