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Mental modularity, metaphors, and the marriage of evolutionary and cognitive sciences

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Abstract - As evolutionary approaches in the behavioral sciences become increasingly prominent, issues arising from the proposition that the mind is a collection of modular adaptations (the multi-modular mind thesis) become even more pressing. One purpose of this paper is to help clarify some valid issues raised by this thesis and clarify why other issues are not as critical. An aspect of the cognitive sciences that appears to both promote and impair progress on this issue (in different ways) is the use of metaphors for understanding the mind. Utilizing different metaphors can yield different perspectives and advancement in our understanding of the nature of the human mind. A second purpose of this paper is to outline the kindred natures of cognitive science and evolutionary psychology, both of which cut across traditional academic divisions and engage in functional analyses of problems.

Key words: Evolutionary Theory, Cognitive Science, Modularity, Metaphors

Evolutionary approaches in the behavioral sciences have begun to influence a wide range of fields, from cognitive neuroscience (e.g., Gazzaniga, 1998), to clinical psychology (e.g., Baron-Cohen, 1997; McGuire and Troisi, 1998), to literary theory (e.g., Carroll, 1999). At the same time, however, there are ongoing debates about the details of what exactly an evolutionary approach – often called evolutionary psychology— entails (Holcomb, 2001). Some of these debates are based on confusions of terminology, implicit arguments, or misunderstandings – things that can in principle be resolved by clarifying current ideas. Other issues are more sub-stantial. Dealing with these later issues (as well as resolving the former) becomes increasingly important as the sphere of influence for evolutionary ideas expands.

One of the most influential and dramatic of the evolutionary claims is that the mind is a collection of cognitive adaptations, or modules, that have been naturally selected over evolutionary history in response to specific adaptive problems faced by our ancestors. This view of a *multi-modular mind* is at once somewhat mundane and yet quite radical. It is, mundanely, true that different parts of the brain/mind perform diverse things to solve specific problems. For example, there are visual processing areas, sensory-motor areas, and language areas in the

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brain/mind. The radical part is that evolutionary psychologists hold the mind is all or nearly all comprised of such domain-specific cognitive adaptations; there is (at least in the traditional sense) no central processor, no general problem solver, no mental model space, and no content-independent "learning".

The idea of a multi-modular mind is beset both by issues stemming from confusions and by issues based on some valid debates. One purpose of this paper is to help clear off some the former confusions and bring into better focus some of the later issues. A second purpose of this paper is to outline how and why cognitive science is, in many ways, a kindred discipline to evolutionary psychology.

Modularity as a concept

Modern ideas about mental modularity typically use Fodor (1983) as a key touchstone. Fodor took an explicit step away from behavioristic ideas of the mind as a unitary "black box" (Figure 1a) and built a convincing case for a certain level of modularity (Figure 1b). Specifically, Fodor's modules existed at the interfaces between the mind and the external world (i.e. in the form of sensory input mechanisms and of motor control [output] systems). The rest of the mind, in Fodor's view, remained a general information processor of some sort. A different perspective of modularity came from Tooby and Cosmides (1992; Cosmides and Tooby, 1994a, 1994b), who argued for a much more extensive mental modularity, based on evolutionary considerations (Figure 1c).

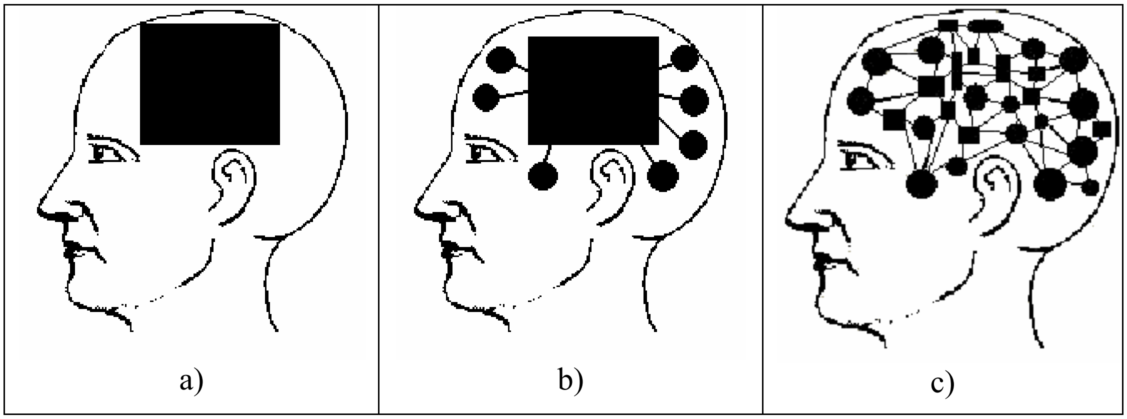

Fig. 1a-c. Different views of the mind: a) Behaviorism's "black box" view of the mind, (b) the Fodorian modular peripherals and central processor view of the mind, and (c) the multi-modular view of the mind.

The essential logic of this more extensive modularity position is a multi-sided argument that: 1) natural selection would favor the development of many, distinct modules; 2) it is implausible that a general central processing-type mind could evolve at all; and 3) it is very unlikely that a general central processing-type mind would work at all if it did exist. This first point is based on the principle that evolution by natural selection is driven by specific selection pressures (i.e., not to "survive" or "reproduce", but rather pressures that existed because of specific aspects of the environment like "avoiding dangerous predators" or "eating things that are nutritious"). One can think of each selection pressure as an adaptive problem that organisms of a particular species faced, and natural selection may have generated a solution to that problem. But there are no higher order objectives to guide this process, no foresight, no teleology, no mechanism consolidations, or spring cleanings. There is only –at a lower level— the changing of gene frequencies within the population. So there are reasons to anticipate modularity. The second point of this argument is against non-modularity, and it is a point that has been made repeatedly in science. Chomsky made this point in referring to the "poverty of the stimulus" in relation to language development; the information in the environment is simply insufficient to build complex human language. Therefore, there must be some kind of pre-built system with which people acquire language – the modular language acquisition device. This same point has been demonstrated repeatedly in computer science, where it is called the frame problem – that a problem has to be "framed" into a particular domain in order to be soluble. It is also known as the problem of indeterminancy – it is not possible to determine the correct course of action without further guidance, and the need for "constraints" in developmental psychology. Finally, if we gloss over this second point and magically endow an individual with a monolithic, non-modular type of mind, this individual will not work. That is, such a mind will not be able to solve any practical, specific problem because of either computational paralysis (insufficient information to start) or combinatorial explosion (vastly too many results to be useful). The only way to make this poor fictional creature work is to put into it's mind specific programs, routines, and subroutines - in other words, create specific, modular abilities within the system (see Tooby and Cosmides, 1992 for more on these arguments).

Taken together, these points all lead compellingly to a modularity in the mind that is akin to the modularity found within the rest of the body (e.g., the circularly, repiratory, nervous, and endocrine systems; the circulatory system is divided into a pump (the heart) a filter (kidneys), a distribution system, etc.). This position of multi-modularity (called "modularity gone mad" by Fodor [1987, p. 27]) was crystalized and refined particularly well by Sperber (1994, p. 40), who offered the following definition:

> A cognitive module is a genetically specified computational device in the mind/brain (henceforth: the mind) that works pretty much on its own on inputs pertaining to some specific cognitive domain and provided by other parts of the nervous system (e.g., sensory receptors or other modules).

In other words, a module is an information processing mechanism that is constructed such that: a) it accepts particular types of informational input (often defined in terms of a specific conceptual domain); b) it performs characteristic transformations of that information, and; c) it results in outputs that can be directed to other modules or be final outcomes. Like most definitions of sophisticated concepts, several aspects of this definition deserve some elaboration. The following are some of these important aspects of modularity:

A) *Modules are content dependent*

Specific modules are designed to take specific types of information as input. For a clear illustration, consider what is probably one of the least controversial examples of a modular cognitive ability, the line orientation detectors in the visual cortex. These detectors only take into account a very narrow range of all information in the world (properties of visual stimuli that indicate lines), and nothing else. In other words, the presence of a particular category of information invokes that module.

Suppose for now that the mind is composed of a large number of modules. There is, at the moment, some ambiguity about how modules get selectively and accurately invoked. The dilemma is to avoid a humunculus in the head that does the directing of information and activating of modules – a dilemma that can be called the *allocation problem* (Brase, 2003; Samuels, Stich, and Tremoulet, 1999). One could propose that each module is in some way hard-wired to particular input sources, but this creates other problems (e.g., flexibility, adaptability, and –in particular— encapsulation, as we will see). A more feasible possibility is that information is managed through a system that can be conceptualized as a signal detection-style mechanisms (Brase, 2003; see also the description of “demons” in Cosmides and Tooby, 2000). A suggestion by Barrett (2002; discussed below), also could help resolve this issue.

B) *Modules are domain specific*

The scope of application of a module – which is often determined by the type of information acceptable and required for input – forms a conceptual domain for that module. Whereas the property of being content dependent (above) is focussed on the nature of the input information, being domain specific refers to the aspects of the world (as a group) in which the particular module is applied. For example, line orientation detectors serve the domain of “lines” in the visual world. It should be noted that there is nothing necessarily in the associated neurons or in that region of the brain that says “lines”, or is line-like, or relates to the domain of lines in any way other than the functional outcome of that module. The concept of “lines” is something we have invented to aid us in describing the world, and if there is also a cognitive module for “line-detection” it means that the process of natural selection similarly happened to hit upon something like this useful concept as well.

Much has been made of the “domain-specific” nature of evolved modules. Naturally, if there are proposed to be a greater – rather than lesser – number of modules that make up the mind, each of those modules must encompass a smaller domain, but this terminology masks some implicit assumptions. Content dependency and domain specificity are relative terms: Dependent and specific compared to what standard of independence and generality? A monolithic black box of a mind (Figure 1a) is incredibly content-independent and domain-general (or one could say it contains exactly one domain). Compared to that standard, any division is content-dependent and domain-specific. Most models of the mind have a number of divisions into specific areas that do specific things (e.g., vision, memory, language, reasoning, etc.), so all these models can be called content-dependent and domain-specific. The issue, then, is actually one of how narrowly parsed the contents and domains are, not if there is parsing or not. In fact, even within the evolutionary, multi-modular mind, there should be systems that vary in relative specificity or generality.

Although the domain-general versus domain-specific arguments *per se* can be vacuous, there is an underlying issue that is genuine. How does one define the scope of all these different modules? If we grant for the moment that there are a large number of cognitive modules in the mind, and that these are all specific to particular domains, at what level should we divide up the mind into "domains"? For instance, there are line detectors (and motion detectors, color detectors, etc.) – are these all modules? If so, then is object recognition another module that partially subsumes these other modules, or is it something else? (meso-modules?) Further up, there is scene perception, perception of the whole visual context -- are these domains (meta-modules) as well? Atkinson and Wheeler (2001; also see Sterelny and Griffiths, 1999) have called this the *grain problem*: the issue is whether to look at adaptive problems and their subsequent cognitive adaptations at a fairly fine-grained level or at a more coarse-grained level. At the moment there seem be some gaps in our terminological –and possibly conceptual—tools to deal with this issue head-on. The most prevalent approach at the moment appears to be one of putting the problem off in the hopes that as more details of various modular abilities in the mind emerge they will eventually provide some guidance for resolving the grain problem.

C) *Modules are functionally specialized*

The conceptual domain of a module maps onto an evolutionary selection pressure, such that one can think of the module as being "designed for" accomplishing some particular function (i.e., solving a specific adaptive problem). The function of line orientation detectors is to provide a particular element of visual information to higher visual processing areas (which themselves might be considered as modules in turn), and the design of these detectors is tailored for accomplishing this objective. Another example is that of learned taste aversion (Garcia and Koeling, 1966). Rats (and humans) avoid novel foods that were ingested during an extended window of time prior to their getting sick. This functions as a mechanism for avoiding the ingestion of toxic substances and getting sick again.

It is worth pausing at this point to make an important point about these first three aspects of modularity (content dependency, domain-specificity, and functional specialization). Critics of evolutionary multi-modularity have sometimes over-extended these principles to construct an extremist view of "pan-adaptationism" (e.g., Gould and Lewontin, 1979), in which every aspect of behavior is purported to form its own domain and its own module. This caricature of modularity is used to generate claims that there would be adaptations (including cognitive modules) for everything from driving a car to ears ringing after a very loud noise, to the shape of earlobes. This is actually a straw-man version of modularity, designed to be attacked rather than seriously considered. One could simply point out the basic fact that trying to understand all aspects of behavior (a goal of behavioral science, generally) is not the same as claiming that all aspects of behavior are adaptations.

But, more specifically, there are at least three obstacles to any trait or behavior being seriously established as an adaptation. Should a trait or behavior fail to meet the criteria for overcoming these obstacles, then it is usually rejected as being an adaptation (even though it certainly continues to exist in the real world as a trait or behavior).

A first obstacle for any trait (physical or cognitive) to be considered an adaptation is that adaptations generally have characteristics that non-adaptations lack (Williams, 1966; Tooby and Cosmides, 1992; Andrews, Gangestad, Matthews, in press). Adaptations, including cognitive modules, tend to recur among related species in similar environments, tend to have effects that would have been beneficial (e.g., increasing inclusive fitness) in the species ancestral environment, tend to be well (even optimally) designed relative to all other solutions given the constraints (i.e., as optimal as possible within limits of developmental processes and co-existence with other adaptations), and tend to exhibit evidence of special design (e.g., specificity, proficiency, precision, efficiency, economy, reliability of development, complexity of design, etc.). Like most issues involving the truth of scientific theories, the ultimate decision is not black and white, but rather based on a measured evaluation: Which explanation does the preponderance of the evidence favor?

A second obstacle for meeting the criteria of being an adaptation is that it must be shown that the trait in question is not better explained as either a byproduct of some other adaptation (a characteristic that is a committed covariant of something else that is actually an adaptation) or as random noise (Tooby and Cosmides, 1992). For example, human vision tends to decrease in accuracy with age. Rather than claiming this as an adaptation, it is generally explained as a byproduct (e.g., of looking disproportionately at very close objects, such as books and computer screens) or as noise (e.g., degradation with age of the visual system).

A third obstacle for meeting the criteria of being an adaptation, particularly in the case of cognitive modules, is demonstrating that the trait or behavior in question falls within the *proper domain* of a module, rather than merely within the *actual domain* of a module (Sperber, 1994). The proper domain of a module is the set of information and circumstances that it is the module's evolved function to process – what it was "meant" to do. The actual domain of a module is all the sets of information and circumstances that are sufficiently close to the set making up the proper domain that they satisfy the module's input conditions, such that the module is elicited. Take again the example of line orientation detectors; their proper domain is lines and edges in the natural environment (like the edges of this paper), but these detectors are now invoked by lines and edges that are merely electronic representations (like those on a computer screen). Another example is the desire for sweet foods. The proper domain – the evolved function of this desire—was to seek out and consume ripe fruit. Refined sugars (and all the sweets made from them) fall within the actual domain, but not the proper domain, of our desire for sweet foods.

D) *Modules involve some level of genetic specification*

Most people have probably heard by now that the nature/nurture divide is a false dichotomy; we are a product of the interactions between nature (biology, genetics, innateness) and nurture (culture, environment, learning). So to say that a trait or behavior is "innate" or "genetic" is usually either a nod to the mundane fact that there must be some biological component involved (e.g., such that natural selection could operate upon it) or it is a red herring designed to get people's attention and provoke some kind of response. The first of these possibilities (recognizing genetic influences) is sometimes used simply to note that, for evolution by natural selection to operate, the trait in question must be to some extent biologically inherited. This is usually a quite plausible assertion, as work in behavioral genetics has demonstrated that there is heritability for cognitive traits as diverse as intelligence test scores, personality traits, handedness, mental disorders, and behavioral mannerisms (e.g., Bouchard, Lykken, McGue, Segal, and Tellegen, 1990; Bouchard, Lykken, Tellegen, and McGue, 1996).

There are genuine issues about the specific roles and patterns of interactions between nature and nurture (e.g., Tooby and Cosmides, 1992; Karmiloff-Smith, 1998; Cummins and Cummins, 1999), and these often take the form of establishing the minimum level of innate framework that is necessary for a particular trait or behavior to emerge (e.g., Chomsky's poverty of the stimulus argument helped establish such minimums in language; Chomsky, 1975). It would be a mistake, however, to confuse the *minimum* with the *actual*. That is, the minimum level of genetically provided cognitive infrastructure forms just that – the minimum level, upon which –by definition— there can only be a greater amount of genetically specified cognitive infrastructure in actual fact. It is ironic that debates between those who place a primacy on genetic factors and those who place a primacy on environmental factors (e.g., in language acquisition; Pinker, 1999; Saffran, Aslin, and Newport, 1996; Seidenberg, 1997) will in their resolution manage to establish only the point at which the environmental primacy advocates are guaranteed to lose.

None of this is to say that environmental and cultural factors are impotent or unimportant (indeed the notion of important versus unimportant only serves to perpetuate the old nature/nurture dichotomy). Rather, the purpose of this point is that the more productive avenue of research would be to move on to delineating patterns of genetic, cognitive and environmental interactions. Some researchers have begun to do just this. For example, Cummins and Cummins (1999) have used the concept of canalization to discuss the interaction between biological and environmental factors in the development of cognitive capacities and abilities.

Metaphors for the Mind and Modularity

Like most complicated, unobservable, and important aspects of the world, the mind has been likened to a number of other – more simple and easily seen —objects. Metaphors have been drawn between the mind and a wax tablet, a blank slate, a telephone switchboard, and –most prominently in recent years – a computer. Of course, the mind is not *actually* any of these things, and this is something that always has to be held in the back of one's mind (e.g. see Pinker (1997) on the computer metaphor versus a computational theory of the mind). Metaphors, at their best, help us to understand something by placing it within a framework that is more concrete and that we already understand. This metaphorical trick sometimes allows us to see patterns, processes, and unexplored issues more clearly. The problem with metaphors is that it is not always clear which aspects of the two comparison domains "map" onto each other and which aspects do not. For example, Gentner and Gentner (1983) found that when people were taught about how electricity works via a metaphor with flowing water some of their errors in understanding electricity reflected "overmapping" of the water metaphor (i.e., extending the metaphor to aspects of the target for which the metaphor was inappropriate). The problem we have with metaphors for the human mind is that, whereas we understand the nature of electricity quite well and can easily identify when a metaphor has been overextended, we do not have a similarly comprehensive understanding of the mind that allows us to reliably see when we have overmapped our metaphors.

Has the computer metaphor of the human mind been overextended? Certain aspects of this metaphor we know are wrong (e.g., the mind is made of neurons, whereas a computer is made of metal, plastic, and silicon), and other –particularly useful— aspects of the metaphor have been abstracted out (i.e., the computational model of the mind; the concept of the brain as the hardware instantiating an information processing system called the mind). Still other aspects of the computer metaphor are unclear, and sometimes even the fact that they are ideas derived from the metaphor can be unclear at first. Two issues related to the modularity of the mind are examples of issues that have arisen or been made prominent because of the computer metaphor: The issues of encapsulation and localization.

Encapsulation is the idea that, within a modular system, there must be strong control over the types of information taken in by each module and where the outputs of each module go (Fodor, 1983, 2000). A classic example of this is visual illusions. Even though our higher consciousness understands that the illusion is deceptive we cannot get our eyes to stop seeing the illusion; the visual system is encapsulated such that this level of control is not possible. The basic metaphorical equivalent of encapsulation is the wiring of a computer. Information travels in a computer upon pre-established routes and is unable to come from or go to other locations. There are other issues regarding encapsulation that are addressed else-where (e.g., Sperber, 2002); the point here is that ideas about how encapsulation must work, why it must exist, and how it is an issue are founded upon the computer metaphor, and the problems over encapsulation –as we will see— can disappear with a change of metaphor.

But first, the other issue: Localization. The idea of neural localization of function is derived from a long history of research in neuroanatomy and neurophysiology (Bottjer and Arnold, 1997; Kaitaro, 2001; Kertesz, 1994; Posner and Rothbart, 1994), but also fits well and is derivable within the computer metaphor. In computers, there are separate components that fit together, and if one of those components is broken or missing then the corresponding computer function is gone. Once again, the metaphor colors our understanding of the target item. This is not to say that there is no localization of function – to claim this would, after all, be perverse at this point in the development of neuroscience. Rather, there is no absolute requirement that every module must be discretely localized in one particular physical space in the brain. What is important is only that the areas that physically instantiate a module are in communication with one another (e.g., as with Brocca's area, Wernicke's area, and associated interconnections that form human language abilities).

Perhaps one reason that the computer metaphor still dominates ideas about the human mind is that no one has proposed a better metaphor. It can be hard to give up a metaphor without having something more attractive to jump into. There have been metaphors for the multi-modular mind – Swiss Army knives and toolboxes are the most commonly used—but both of these refer to relatively simple physical devices that pale in comparison to the human mind. Perhaps, though, a suitable alternative metaphor is now available. Clark Barrett (2002) has recently developed a metaphor between the human mind and the enzymatic system. As initially odd as this pairing might seem, this metaphor is apt and – most importantly— superior to the computer metaphor in several respects when struggling to understand the nature of a multi-modular mind. Consider some aspects of this metaphor. There are a variety of diverse enzymes, but they all function as catalysts — they change the form or behavior of the elements around them (substrates) into something other than what they were originally (i.e., they take something in, process it, and then output a result). These changes can embody forms of computation: for example, an enzyme can "add" one substrate to another and thereby create a new substance. Enzymes are not changed or destroyed by perfoming their functions, but rather they continue to function in the same way with new material. Enzymes are content dependent and domain-specific: They can distinguish the substrates appropriate for its particular form, and selectively bind only to them. The result, of course, is functional specialization: Each type of enzyme catalyzes a particular reaction (based on the enzymes shape) and works as if it was "designed" to do that job. There is little dispute that enzymes are produced by a process that involves some genetic specification, as specific gene sequences are known to produce particular enzymes.

Even though the enzymatic system has all these properties of a modular system, the enzymes are remarkably (and very unlike a computer) unrestricted.

The issue of encapsulation is moot; the input requirements of each enzyme (module) control the flow of substrates (information) and the output of the process is simply released into the larger system. This sudden discarding of encapuslation as a product of an overextended metaphor is truly startling, given that Fodor (2000, p. 63) held that "it's informational encapsulation… that's at the heart of modularity," and this assertion is used by Fodor to cast doubt on the viability of a multi-modular view of the mind. Fodor may simply be dead wrong on this issue. There is also no localization in the strong sense in enzymatic systems, even thought there can be functional interconnections between various processes. Furthermore, one could argue that the enzymes model of the mind is superior to many of the prior metaphors for the mind (including the computer) because both the central nervous system and the enzymatic system are biological systems and they are therefore more likely to have closer mappings with each other.

Finally, some of the known properties of the enzymatic system suggest different emphases and research avenues to pursue in the study of how the mind functions. For example:

- The specificity of an enzyme is attributed to a compatible fit between the shape of its active site and the shape of the substrate (compare to Sperber's ideas of proper domains and actual domains);
- As the substrate enters the active site, it induces the enzyme to change its shape to fit more snugly (can memory distortions, for example, be better understood as induced fits of information to modular domains?);
- In an enzymatic reaction, the substrate binds to the active site to form an enzyme-substrate complex, and, in most cases the substrate is held in the active site by weak interaction such as H-bonds and ionic bonds (once a particular set of inputs are fed into a cognitive module is that information "bound" within that module until the transformation which that module performs is completed?);
- The rate at which a given amount of enzyme converts substrate to product is partly a function of the initial concentration of substrate (can prior experiences modify the activity or activation levels of modules?).

There are interesting, and largely unexplored, questions as to if these aspects of the enzymatic system do, in fact, have analogs within the multi-modular mind.

Academic modularity

Another metaphor that can be used for the multi-modular mind is that of the modern research university. Within a university there are many different academic departments (modules) that are each content dependent and domain specific (e.g., Psychology, Anthropology, Philosophy, Biology, Sociology, Political Science, Communication, Linguistics, Mathematics, etc.). What each of these departments does, and how they go about doing it, is functionally specialized (e.g., different theoretical models, different types of analyses, different reporting styles, etc.).

A number of the issues within the topic of cognitive modularity, in fact, have analogs in the university system. Departments are typically (but not necessarily) localized, with various degrees of interconnections between the individuals and between different departments, and there can be inter-departmental allocation problems; "turf wars" about which department has priority on a particular resource, or even priority on a particular topic. Additionally, there is something like the grain problem in academia. How should a university be described? Is a university a collection of colleges (e.g., Arts and Sciences, Business, Law, Medicine, etc.)? Is a university a collection of departments (psychology, anthropology, sociology, philosophy, etc.)? Is a university an array of researchers and research labs (e.g., in memory, decision making, vision, interpersonal relations, etc.)? From this perspective, it is much easier to see (as compared to with the computer metaphor) that the grain problem is one of how to conceptualize modularity, rather than a problem with the existence of modularity itself.

Evolutionary Psychology and Cognitive Science

The university metaphor for the modular mind also promotes an understanding of one further aspect: the significant parallels between problems faced both by cognitive science and by evolutionary psychology as disciplines. Both approaches involve integrations across several traditional academic fields. For cognitive science the interdisciplinary focus is on psychology, computer science, and philosophy, while for evolutionary psychology the interdisciplinary focus is on biology, psychology, and anthropology. Additional cross-disciplinary integrations also occur in both approaches, reaching across many of the behavioral sciences. Both cognitive science and evolutionary psychology can sometimes encounter resistance because of these integrative efforts; for example, if a perspective from one discipline indicates that favored ideas or theories in another discipline are untenable for some reason.

The topics studied by researchers in both cognitive science and evolutionary psychology tend to be based much more on functional considerations of what is the (computational or adaptive) problem being faced, and what is needed for a solution. (i.e., modules defined by functional analyses of information processing problems). For example, cognitive science research groups can include people from various disciplines who are all interested in object recognition, or in speech comprehension, or in way-finding. Evolutionary-based research groups similarly include people from different disciplines who are all interested in, for example, social reasoning, or intersexual relations, or rationality in decision making. In either context the primary concern is not one's disciplinary background, but the nature of the problem at hand. Of course, because of the historical divisions within a university, cognitive science does not always follow the localization notion—people engaged in common cognitive science pursuits may be spread across the university, in different departments and even in different colleges.

Beyond the parallels, there are ways in which both cognitive science and evolutionary psychology will both be better off with more intercommunication between them. Evolutionary considerations can help cognitive science develop a more valid and rich understanding of cognitive functional designs, leading to more productive and informative research programs. Evolutionary considerations can also open up new vistas for cognitive science by indicating areas for research that would not be intuitively obvious without such evolutionary insights. For example, work on artificial intelligence may be able to usefully adopt the idea of very multi-modular computational structures (e.g., in dealing with the frame problem), and then ultimately inform psychologists in return with details of how such systems can be constructed. The nature of intelligence (Cosmides and Tooby, 2002) and of motivational systems (Kenrick, 2001) are also topics to which evolutionary considerations can make important and immediate contributions. From the other direction, cognitive science can help provide a more rigorous, experimentation-oriented focus for evolutionary psychology. Tools like computer simulations, sophisticated mathematic models, and more advanced statistical procedures are better established in cognitive science than in evolutionary psychology (for recent examples of how such integrations may look, see Gigerenzer, Todd, and The ABC Research Group, 1999; Henrich and Boyd, 1998). More fundamentally, the integration of cognitive science and evolutionary psychology would help to more decisively avoid what has been called the "Sociobiology fallacy" (Buss, 1995): The tendency for some evolutionary ideas to progress directly from gene-level descriptions to behavioral-level outcomes, bypassing the necessary step of those genes (interacting with the environment) producing the cognitive structures that generate behaviors within an environmental context.

Summary

It appears that there are two issues related to cognitive modularity that are genuine and in need of serious attention. The first of these issues is the *grain problem*: the issue of how to describe modularity as it occurs at varying levels of conceptualization. This problem is tied rather closely to two other issues – the domain-specificity versus domain-generality debates and the distinction between proper domains and actual domains. The solution to the grain problem, it seems, will also go a long way to solving these other two issues. All of these issues, however, have to do with the conceptual understanding of a multi-modular mental architecture, and not with the basic feasibility or existence of such structures. The second genuine issue, which is relevant to the existence and feasibility of a multi-modular mind, is the *allocation problem*: How do the modules work together given the fairly small number of serial inputs from the environments (i.e., the senses) that must feed into a much larger number of potential modules? Similarly, how do the outputs of these modules get competently channeled back out as essentially serial behavior?

Other issues raised within the context of modularity are, at best, recurrent but correctable problems. At worst, some of these issues have simply become red herrings that anti-modularist writers may use in attempting to sway naïve audiences. For instance, the *naturalistic fallacy* (the idea that anything "natural" – or "genetic" or "biological"— is therefore good) is not only a false inferential process in and of itself, but it also flies in the face of what has become almost universally accepted in terms of nature/nurture interactions. The claim that evolutionary approaches in the behavioral sciences employ a form of *pan-adaptationism* (i.e., every and all traits are specific adaptations) is typically supported by either the critic's own fanciful stories or by work that is not accepted as responsible and representative by those within the evolutionary communities (instances of bad science are a problem in any field, so this would at best be an indictment of all science). It has been claimed that evolutionary approaches to understanding cognition are untenable because of difficulties in reconstructing the EEA (environment of evolutionary adaptation) for a trait and modeling the resultant selection pressures, a claim I call the *Lewontin fallacy* (after Lewontin, 1990). Others have addressed this fallacy quite thoroughly (e.g., Crawford, 1998; Tooby and Cosmides, 1992), but the short answer is to note that many aspects of an EEA can actually be inferred from what is known in anthropology, archeaology, biology, physics, and geology. There are more specific issues and points of ambiguity in EEA reconstructions, but the notion that these constitute a blanket refutation of evolutionary accounts (e.g., Johnson-Laird, Legrenzi, Girotto, Legrenzi and Caverni, 1999) is simply false (see Brase, 2002).

The *sociobiology fallacy*, as discussed above, is becoming increasingly rare and further integrations of evolutionary and cognitive science ideas should speed its eventual demise. Finally, there is the issue of *metaphor fixations*: The tendency for a field to latch upon a particular metaphor and use it beyond it's appropriate range (i.e., overmapping). Certain issues that can at times appear to be significant problems (e.g., for a multi-modular mind) can be resolved by breaking free from a particular metaphor and allowing new types of solutions to become conceivable. *Encapsulation* is one such issue. Encapsulation is a major problem when implementing large-scale modularity within a device like a computer or a telephone switchboard (Fodor, 2000). But the mind is neither of those devices, and solutions to the concerns raised by the encapsulation issue – information input and output gating – can be found once a new metaphor is overlaid (e.g., the enzymatic system metaphor).

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