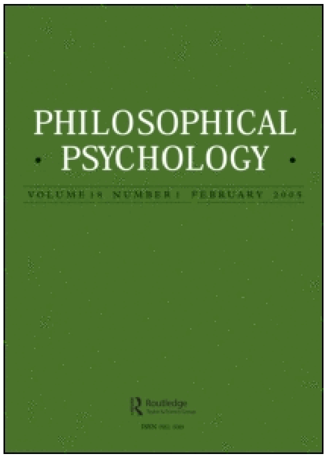

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Evolutionary Psychology Versus Fodor: Arguments For and Against the Massive Modularity Hypothesis

Willem E. Frankenhuis and Annemie Ploeger

Evolutionary psychologists tend to view the mind as a large collection of evolved, functionally specialized mechanisms, or modules. Cosmides and Tooby (1994) have presented four arguments in favor of this model of the mind: the engineering argument, the error argument, the poverty of the stimulus argument, and combinatorial explosion. Fodor (2000) has discussed each of these four arguments and rejected them all. In the present paper, we present and discuss the arguments for and against the massive modularity hypothesis. We conclude that Cosmides and Tooby's arguments have considerable force and are too easily dismissed by Fodor.

Keywords: Cognitive Architecture; Domain Specificity; Information Encapsulation; Modularity

1. Introduction

Evolutionary psychology is a relatively new approach that is "informed by the additional knowledge that evolutionary biology has to offer, in the expectation that understanding the process that designed the human mind will advance the discovery of its architecture" (Cosmides, Tooby, & Barkow, 1992, p. 3). Its central assumption is that all present-day humans have inherited from their prehistoric ancestors a standard collection of psychological mechanisms that facilitated survival and reproduction in ancestral times. Consequently, the goal of evolutionary psychology is to discover and understand the universal, or species-typical, architecture of the human mind and brain (Tooby & Cosmides, 1992).

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From its conception, evolutionary psychology has caused much controversy. Some theorists assert that contemporary knowledge of human evolution is too limited to give an evolutionary account of human cognition (Richardson, 1996), while others claim that we will never know enough about our evolutionary history to give such an account (Lewontin, 1998). Still others hold the view that even if we *would* know a lot about the history of our cognitive traits, this knowledge can never add anything to our current understanding of cognition (Davies, 1996).

In contrast, evolutionary psychologists assert that their research program has *already* contributed much to psychology, and cite a wealth of empirical findings that were generated from evolutionary perspectives (see e.g., Buss & Reeve, 2003). For example, there is now considerable evidence supporting the existence of evolved neurocognitive specializations for aspects of social exchange (Cosmides, 1989; Cosmides & Tooby, 1992, 2005), kin detection (Lieberman, Tooby, & Cosmides, 2003, 2007), face recognition (Duchaine, Yovel, Butterworth, & Nakayama, 2004; Kanwisher, 2000; McKone, Kanwisher, & Duchaine, 2006), mating strategies (Buss & Schmitt, 1993; Gangestad & Simpson, 2000), emotion detection (Williams & Mattingley, 2006), spatial abilities (McBurney, Gaulin, Devineni, & Adams, 1997; Silverman & Eals, 1992), language (Pinker, 1994; Pinker & Bloom, 1990), number (Dehaene & Cohen, 1995), and intuitive mechanics (Leslie, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992), as well as for the existence of functionally specialized food avoidance mechanisms in pregnant females to protect the developing embryo from harmful substances (Profet, 1992). From a philosophy of science perspective, it has been argued that evolutionary psychology has all the hallmarks of a currently progressive research program (Ketelaar & Ellis, 2000; see also Durrant & Haig, 2001).

Although evolutionary psychology is a fruitful approach, much theoretical and empirical work still needs to be done. In the present article, we focus on one important assumption that underlies most research in evolutionary psychology: the idea that the mind consists of a large collection of functionally specialized mechanisms, or evolved modules (Barrett & Kurzban, 2006; Tooby & Cosmides, 1992). This position is sometimes called the massive modularity hypothesis (Carruthers, 2005; Samuels, 1998; Sperber, 1994). Throughout this paper we will use a common definition of evolved modules as neurocognitive mechanisms specialized for solving particular adaptive problems that recurrently faced our hominid ancestors over evolutionary time.

The massive modularity hypothesis has been the focus of intense debate in the cognitive sciences, and has inspired the production of numerous articles, books, and edited volumes. Whereas some authors have defended the massive modularity hypothesis (Barrett & Kurzban, 2006; Carruthers, 2003, 2004, 2005; Ermer, Cosmides, & Tooby, 2007; Okasha, 2003; Pinker, 2002, 2005a; Sperber, 1994, 2001), others have criticized aspects of it (Mameli, 2001; Miller, 2000a, 2000b; Samuels, 1998, 2000), or even rejected the thesis entirely (Atkinson & Wheeler, 2003, 2004; Bechtel, 2003; Buller, 2005; Buller & Hardcastle, 2000; Fodor, 2000; Looren de Jong & Van der Steen, 1998; Panksepp & Panksepp, 2000; Shapiro & Epstein, 1998).

The present paper focuses specifically on philosopher Jerry Fodor's criticisms of the massive modularity hypothesis, as presented in his recent book *The Mind Doesn't Work That Way* (2000). *The Mind Doesn't Work That Way* is a response to Pinker's book *How the Mind Works* (1997), in which the massive modularity hypothesis is thoroughly defended. Fodor's criticisms are of particular interest in this debate, because in his earlier book *The Modularity of Mind* (1983), he famously argued for the modularity of important aspects of perception, language, and motor control. However, in the final chapter of *The Modularity of Mind*, Fodor suggested that cognitive faculties such as reasoning, inference, and belief fixation, are *not* modular, but the result of general cognitive processes. This position is developed further in *The Mind Doesn't Work That Way*, and contrasts sharply with the massive modularity hypothesis.

The article is organized as follows. First, we describe how evolutionary psychologists define psychological modules, and how this differs from the notion of modularity that Fodor (1983, 2000) advocates. Thereafter, the main body of the paper presents Cosmides and Tooby's (1994) arguments for their position that cognition is massively modular and Fodor's criticisms of these arguments. We evaluate both the evolutionary psychologists' arguments and Fodor's criticisms.

2. Evolved and Fodorian Modularity

Evolutionary psychologists view the mind as an information-processing system: a device that takes particular inputs and transforms these inputs into either data structures (i.e., mental representations) or behavioral outputs (Cosmides & Tooby, 1987, 1995). This assumption is shared by many other approaches in the cognitive sciences and, as such, is not unique to the evolutionary psychological program. Therefore, it will not be discussed in much detail here. It suffices to note that evolved modules are information-processing mechanisms.

The second feature of evolved modules is that they have been shaped by natural selection over time, that is, modules are biological adaptations. Evolutionary psychologists (Buss, 1995; Pinker, 1997, 2005a, 2005b; Tooby & Cosmides, 1992) justify this feature of modularity by asserting that modules are richly structured and functionally organized, and that natural selection is the only known evolutionary process capable of generating complex, functional design in organisms (Dawkins, 1976, 1986; Williams, 1966).

The third characteristic of evolved modules is functional specialization:

> Because natural selection is a hill-climbing process that tends to choose the best of the variant designs that actually appear, and because of the immense numbers of alternatives that appear over the vast expanse of evolutionary time, natural selection tends to cause the accumulation of increasingly and impressively functional designs. (Cosmides & Tooby, 1994, p. 88)

This, of course, does not imply that natural selection always forges perfect or optimally adapted designs. Evolution is a historical process that feeds on available variation, not an engineer in front of a clean drawing board (Jacob, 1977). The key idea is that natural selection selects cognitive structures that are well-suited to solving specific adaptive problems (such as mindreading, navigation, or social exchange), and that a detailed understanding of these adaptive problems and the processes that shaped their solutions can help unravel the architecture of the human mind and brain (Duchaine, Cosmides, & Tooby, 2001).

Readers acquainted with Fodor's (1983, 2000) work will notice directly that the evolutionary psychologists' conception of modularity differs in important respects from the well-known Fodorian conception of modularity. In the literature, however, there persists considerable confusion about the definition of modularity (Barrett, 2005; Barrett & Kurzban, 2006; Coltheart, 1999). Since the differences between evolved and Fodorian modularity play a central role in the discussion of the arguments for and against the massive modularity hypothesis, it will be worth discussing them in more detail.

In *The Modularity of Mind* (1983), Fodor ascribed nine features to psychological modules. Fodor regarded none of these features as necessary or defining of modules, noting that "I am not, in any strict sense, defining my terms . . . the notion of modularity ought to admit of degrees" (p. 37). Rather, Fodor thought these features had a high probability of co-occurring in functionally specialized cognitive systems. Fodor characterized modules as information-processing devices that operate on specific classes of information (*domain specificity*), are mandatory in their operation, and fast. Further, modules allow for little or no interference by processes outside the module (*information encapsulation*), and produce relatively shallow outputs. The development of modules exhibits a characteristic pace and sequencing, and they have regular patterns of breakdown or malfunction (Weiskopf, 2002). Finally, according to Fodor, modules are associated with a stable neural architecture (for a more extensive review of Fodorian modularity, see Fodor, 1983). In the coming paragraphs we will focus mainly on domain specificity and information encapsulation.

Many psychologists (including us) agree that it is unlikely that the mechanisms underlying complex human cognition (such as reasoning, inference, and belief fixation) satisfy most or all of Fodor's (1983) restrictive criteria. Hence, theorists who believe that evolutionary psychologists endorse the Fodorian notion of modularity usually do not consider the massive modularity hypothesis a plausible model of the mind. Fodor (2000) himself, for example, regards complex mental faculties as *non*-modular, and the result of general cognitive processes. Sperber (1994) has remarked that *The Modularity of Mind* was a paradoxical title because, according to Fodor, modularity is to be found only at the periphery of the mind.

In his recent work, *The Mind Doesn't Work That Way* (2000), Fodor characterizes modules primarily in terms of an intersection of the properties of *domain specificity* and *information encapsulation* (Collins, 2005). Information encapsulation refers to the idea that information-processing within a particular module is isolated from information flowing through the rest of the mind, such that information external to the module cannot influence the processes that go on inside that module. The information inside the module is thus cut off, or encapsulated, from other (potentially relevant) information in the mind (the mechanism is also said to be "cognitively impenetrable," Pylyshyn, 1999). For example, although we know that the lines in the Müller-Lyer illusion are of equal length, we cannot help seeing one line as longer than the other. This is because the processing of the lines is encapsulated from our knowledge that the lines are not equal in length (for a more extensive treatment of information encapsulation, see Barrett, 2005; Barrett & Kurzban, 2006).

In contrast to Fodor (2000), evolutionary psychologists do not consider information encapsulation a necessary or defining feature of modularity. Instead, they use the term modularity:

> to mean the tendency of biological systems to evolve functional specializations and the term *module* to refer to an evolved cognitive specialization, regardless of the degree to which it exists in a heavily policed informational quarantine or operates on information available to other procedures in the architecture. (Tooby, Cosmides, & Barrett, 2005, p. 309)

Hence, according to evolutionary psychologists, modules can be (and often are) highly interconnected and distributed across the brain: "Mental modules need not be tightly sealed off from one another, communicating only through a few narrow pipelines" (Pinker, 1997, p. 31). The crucial property for evolutionary psychologists is functional specialization, not isolation. For evolutionary psychologists, every module is predicted to be encapsulated with respect to some information-processing but not others, depending on the informational resources that were required for solving the adaptive problem that the mechanism evolved to solve.

However, like Fodor (1983, 2000), evolutionary psychologists *do* presume an intrinsic relation between functional specialization and domain specificity. Domain specificity refers to the notion that a given cognitive mechanism accepts, or is specialized to operate on, only a specific class of information (Barrett, 2005; Barrett & Kurzban, 2006). For instance, instead of being processed by one general vision mechanism, light that enters the human eye is parsed along various dimensions by a set of functionally distinct subsystems, such as motion detectors, shape detectors, and mechanisms for color perception (Marr, 1982). Each of these perceptual modules has its own input criteria, which determine whether or not some representation will be processed by the system. A cognitive system is thus domain specific to the extent that it is tailored to handle some particular range of inputs (Barrett, 2005).

Domain-specific mechanisms may also contain innate knowledge about the class of information they process. For example, a module involved in predicting the behavior of *animate* agents (e.g., conspecifics) may assume by default that other agents' behavior is caused by internal mental states, such as beliefs, desires, and reasons. In contrast, a module that predicts the behavior of *inanimate* entities (e.g., rocks) may have no such knowledge, but instead contain a set of assumptions about the behavior of physical objects in the world. As will become apparent in Sections 5 and 6, Fodor and evolutionary psychologists disagree over whether innate, domain-specific knowledge should be included in the definition of modularity.

Given these definitions of domain specificity, information encapsulation, and modularity, we shall look at the arguments that Cosmides and Tooby (1994) provide for their position that the mind consists of a large collection of evolved, functionally specialized modules. Four arguments will be presented and discussed: the engineering argument, the error argument, the poverty of the stimulus argument, and an argument from combinatorial explosion. Each of these arguments will be reviewed in the light of some important criticisms, most of which are derived from Fodor's book *The Mind Doesn't Work That Way* (2000).

3. The Engineering Argument

The first argument for massive modularity can be framed as the answer to an engineering problem:

> If there is an adaptive problem that can be solved either by a domain general or a domain specific mechanism, which design is the better engineering solution and, therefore, the design more likely to have been naturally selected for? (Cosmides & Tooby, 1994, p. 89)

The argument is that selection pressures can be expected to produce specialization in cognition, because:

> different adaptive problems often require different solutions and different solutions can, in most cases, be implemented by different, functionally distinct mechanisms. Speed, reliability and efficiency can be engineered into specialized mechanisms because there is no need to engineer a compromise between different task demands . . . [By contrast,] a jack of all trades is necessarily a master of none, because generality can be achieved only by sacrificing effectiveness . . .. [Therefore,] when two adaptive problems have solutions that are incompatible or simply different, a single solution will be inferior to two specialized solutions. (p. 89)

Functionally specialized mechanisms can be fine-tuned for processing particular kinds of information in a fast, efficient, and reliable manner. General mechanisms, in contrast, can only be fine-tuned for one task to the extent that there is little or no interference with its performance on other tasks. Therefore, when two adaptive problems have solutions that are incompatible or even different, two functionally specialized mechanisms will outperform one general mechanism and consequently be favored by natural selection, all else being equal.

It is important to note that the engineering argument does not imply that there has evolved a separate psychological mechanism for each and every adaptive problem, nor even that there has evolved a specialized mechanism wherever this would enhance performance. Evolutionary psychologists recognize that optimality in any biological architecture will be prevented by various kinds of constraints, such as the costs of specialization (Geary, 2005), principles of self-organization (Kauffman, 1995), and physiological constraints that prevent particular phenotypes from developing in the first place (Amundson, 1998; Hall & Olson, 2003). The optimality argument merely claims that—within these constraints—engineering considerations provide reasonable grounds for expecting domain-specific specialization in the human mind, because functionally specialized mechanisms can be fine-tuned for fast and effective processing, while domain-general mechanisms cannot.

3.1. Fodor's Comments

In contrast to Cosmides and Tooby (1994), Fodor (2000) holds the position "that there's no a priori reason why MM [massive modularity] *should* be true; that the most extreme versions of MM simply *can't* be true; and that there is, in fact, no convincing evidence that anything of the sort *is* true" (pp. 64–65). He counters the engineering argument in the following way:

> Clearly, any architecture must be a choice among virtues not all of which can be simultaneously maximized: Speed vs. accuracy, memory space vs. computing space, 'depth' of computation vs. 'spread' of computation, and so on and on. There are, of course, indefinitely many imaginable mixtures. Different ways of organizing cognition play such trade-offs differently, and presumably the relative fitness of the resulting cognitive system must depend on the details of its relation to local ecology. (p. 65)

Fodor's (2000) criticism can be decomposed into two independent claims: (1) for a given mechanism, trade-offs prevent it from being maximized along all possible design dimensions, and (2) the fitness of a cognitive system depends on the details of its relation to local ecology, therefore, a single optimal system does not exist. We will discuss the former point first.

In contrast to what Fodor (2000) claims, the engineering argument does not entail that psychological mechanisms are maximized along all fitness-relevant dimensions. Specialization does not imply maximization, and trade-offs are central to evolutionary analyses of cognition (Gallistel, 2002; Todd, Hertwig, & Hoffrage, 2005), as they are of biological systems more generally (Boyd & Silk, 2006; Dawkins, 1982). No evolutionary psychologist believes that cognitive systems are maximized along all possible design dimensions. The engineering argument claims only that cognitive specializations have likely evolved in response to different adaptive problems because speed, reliability, and efficiency can be engineered into specialized mechanisms, but not (or only to a lesser degree) into domain-general mechanisms.

The fact that the fitness of a cognitive system depends on the details of its relation to local ecology has also been emphasized by evolutionary psychologists (Tooby & DeVore, 1987). Geary (2005), for instance, predicts that:

> inherently constrained and modular brain and cognitive systems should evolve for processing information patterns associated with those social and ecological conditions that are *invariant* across generations and lifetimes, if these conditions covaried with survival or reproductive outcomes. Plastic systems are modifiable within broader inherent constraints and should evolve for processing more *variant* information patterns—specifically, information patterns that are of survival or reproductive significance but vary across and within lifetimes. (p. 8; see also Geary & Huffman, 2002)

Geary's idea is clearly not that there exists a single optimal cognitive system which is insensitive to the temporally and spatially varying details of local ecologies. Instead, his framework proposes that our neurocognitive architecture is endowed with plastic systems specifically to deal with such details.

We disagree, however, with Fodor's (2000) stronger claim that environmental variability precludes the evolution of adaptive specialization. In fact, there are many functionally specialized structures in both animals and humans that have evolved in response to ever-changing conditions (Dunbar, 1993; Krebs & Dawkins, 1984; Ridley, 1993). Co-evolved traits are a good example. Over evolutionary time, cheetahs and gazelles have been involved in an arms race for faster running speed. As a result, the legs of cheetahs and gazelles have become more and more functionally specialized for running fast. Similarly, the immune system has evolved to deal with constantly changing pathogens in the environment (Penn & Potts, 1999). Still, no one would deny that the immune system is highly specialized for combating disease. Thus, it is mistaken to suppose, as Fodor does, that variation in local environments should oppose the evolution of adaptive specialization (Machery & Barrett, 2006).

3.2. Adaptive Problems

Since the engineering argument claims that different adaptive problems require different solutions, it relies on the notion of an adaptive problem. The notion of an adaptive problem can, and has been, criticized (Atkinson & Wheeler, 2003, 2004; Buller, 2005; Lewontin, 1978; Sterelny & Griffith, 1999). For example, it could be argued that although similar adaptive problems existed across environments (e.g., avoiding predators), these problems may have been differently instantiated in concrete environments. A predator avoidance mechanism would be useless if different environments contain different predators (e.g., tigers, snakes, or crocodiles), which require very different responses (respectively, freeze, flight, or hit the nose). Although evolutionary psychologists have not actually proposed a general predator avoidance module, the issue does raise some profound questions: At exactly what level of analysis do adaptive problems exist? Are adaptive problems categories that we ourselves impose upon the world? These questions challenge not only evolutionary psychology, but the adaptationist program in biology in general.

We focus on one objection that has been raised against the notion of an adaptive problem: the claim that there are no stable, pre-existing problems "out there" in the environment "to which natural selection can grind out a solution" (Sterelny & Griffiths, 1999, p. 331; Lewontin, 1978). We have already demonstrated that the evolution of adaptive specialization does not require the stability of adaptive problems. We now discuss whether or not there are pre-existing problems 'out there' in the environment for organisms to face. Critics argue that adaptive problems depend for their existence not only on the environment, but also on the internal structures, resources, and needs of the organism that meets the environment. An example may be illuminating.

Inferring emotional states of human faces is not an adaptive problem for, say, octopuses, because an octopus gains nothing by investing its energetic resources into the development of a mechanism for human emotion detection. For mosquitoes, however, the story is slightly different. At least in some regions of the world, a mosquito *could* yield significant fitness benefits by being able to read human emotions ("he's angry, I better leave his bedroom"). Still, no one would argue that inferring human emotions is an adaptive problem for mosquitoes. This is because mosquitoes lack the cognitive resources necessary for the development of such a mechanism. At the genetic level, no variation could plausibly arise in a mosquito population that would allow for the development of a mechanism for human emotion detection. In short, adaptive problems arise in a myriad of ways from interactions between the organism and its environment. As such, their ontological status is dependent on the internal cognitive structures, resources, and needs of the organism. However, this argument poses no threat to the notion of an adaptive problem.

Suppose our early ancestors had emotions (like anger, fear, and disgust), a capacity to recognize individual faces, an ability for color perception (e.g., used for finding fruits), but no mechanism for emotion detection. Suppose also that the human physiological system was structured such that when someone got angry, his or her face would reliably turn red. Finally, suppose anger were a good predictor of outbursts of violent behavior, i.e., provided information relevant to the survival and reproductive success of people near the angry individual. Supposing all of this, we would have positive correlations between anger, an increasingly red face, and outbursts of violent behavior. If a genetic variant arose in an early hominid population that played a causal role in the production of adaptive responses to angry persons (e.g., avoidance), then this variant would have a good chance of spreading in the population. In that case, we consider it legitimate to assert that the behavior had evolved *in response to* the adaptive problem of dealing with other people's anger, because although the adaptive problem depended on the organism's environment (the octopus saw no problem) and on the internal structures and resources of the organism (the mosquito encountered a problem but could do nothing about it), *the correlations between anger, a red face, and violent behavior actually existed* '*out there*' *in the world*. This is a crucial point, because it shows that it is possible, at least in principle, to identify adaptive problems independently of the solutions that evolution may find for them.

Many highly useful concepts in biology depend essentially on interactions between organisms and their environment. For instance, niches do not exist 'out there' unless there are organisms that might potentially adopt them. Frequency-dependent selection inherently results from interactions between different types or traits in the population (McElreath & Boyd, 2007). Co-evolution depends, by definition, on interactions between organisms and their environments, including other species (Futuyma, 2005). These concepts are generally accepted in biological science and yield fruitful empirical harvest. Insofar as biologists realize that these concepts are ontologically interdependent (as they do), then their use of them isn't problematic.

Thus, although adaptive problems depend for their existence on the cognitive structures, resources, and needs of particular organisms, the concept of an adaptive problem is still a valid and useful one.

3.3. Conclusion

Fodor (2000) dismisses the engineering argument on insufficient grounds. He does not elaborate enough on the potential costs of functional specialization, and provides no positive arguments for the benefits of domain-general architectures. Also, he fails to address several issues that are central to his argument: why wouldn't trade-offs over time result in cognitive specialization? And if we shouldn't expect a cognitive structure to be highly specialized, what positive reason do we have to expect it to be more domain general? In our view, the engineering argument provides compelling grounds for expecting domain-specific specialization in the human mind.

Whereas the engineering argument claims only that psychological modules have likely evolved due to the benefits of specialization, Cosmides and Tooby (1994) also present a set of arguments that aims to show that domain-general mechanisms are, even in principle, not capable of solving "*the problems that must have been solved in ancestral environments for us to be here today*" (p. 90). Analyses that attempt to demonstrate that a particular cognitive architecture lacks the characteristics needed to solve the tasks that humans routinely perform are called solvability analyses (Tooby & Cosmides, 1992; see also Pinker & Prince, 1988). In the coming sections, we present and discuss three solvability arguments: the error argument, the poverty of the stimulus argument, and combinatorial explosion.

4. The Error Argument

Cosmides and Tooby (1994) present the error argument as follows:

> For a domain-general system to learn what to do, it must have some criterion of success and failure; trial-and-error learning requires some definition of error. But there is no domain-independent criterion of success or failure that is correlated with fitness. This is because what counts as fit behavior differs markedly from domain to domain. For example, suppose our hypothetical domain-general mechanism guiding an ancestral hunter-gatherer somehow inferred that sexual intercourse is a necessary condition for producing offspring. Should the individual, then, have sex at every opportunity? In fact, such a design would rapidly be selected out. There are large fitness costs associated with incest, to pick only a single kind of sexual error . . .. [Thus] because what counts as the wrong thing to do differs from domain to domain, there must be as many domain-specific cognitive mechanisms as there are domains in which the definitions of successful behavioral outcomes are incommensurate. (p. 91–92)

Although the error argument is really about learning rules, we will discuss it as if it is about decision rules more generally, in part because several critics of the argument have interpreted it as such. The error argument essentially states that learning processes require *some* element in the cognitive machinery that tells us whether our actions are a success or failure. For instance, in the helping domain a good rule might be: 'invest *x* amount in the relationship, and if the other person invests less than *x*, then switch to helping someone else'. This algorithm contains a specific definition of error, namely 'failure to switch when the other person invests less than *x*'. However, if this particular rule would be transferred to a different evolutionarily relevant domain, for example courtship, it may be much less adaptive. In courtship, it may be adaptive to make one's investment policy contingent on the reproductive value of the partner involved, or on other possibilities for a relationship (Buss, 1999). If so, the error in such circumstances may be either a more lenient or strict switching time depending on the other input parameters. Males that apply the same cognitive rule in both the helping and the courtship domain would be outcompeted by other males that *do* apply different algorithms in these different domains. So, because different adaptive domains require different definitions of error, it may be expected that natural selection favored specialized cognitive procedures instead of just one or a few domain-general rules.

4.1. Fodor's Comments

Fodor (2000) responds to the error argument as follows:

> It sounds like what's wrong with the putative ancestor is his not having noticed that with sex, as with so much else in life, enough is enough. If, however, you're prepared to accept that a domain-general mechanism could learn that sexual intercourse is a necessary condition for producing offspring, it's unclear to me why the same domain-general mechanism mightn't be able to learn how much is likely to suffice, and hence when to stop. (p. 66)

We think that this is a misreading of the argument. The problem is not that a domain-general mechanism cannot learn how much is likely to suffice and when to stop. The problem is that a learning rule that works well in the domain of sexual decision making need not work well in other domains, such as helping, or resource acquisition. A mating cognitive system may count expending more than 50% of one's energy budget as an error. If this same definition of error was applied to a foraging task, an ancestral human would spend less time looking for food when his/her energy budget was lower, which is clearly problematic. In the sexual domain, however, the rule may work perfectly well. Thus, because different adaptive domains require different standards of what counts as success or failure, it can be expected that natural selection has favored different cognitive rules for different evolutionarily significant domains.

4.2. Shapiro and Epstein's Comments

Shapiro and Epstein (1998) have provided a more viable counterargument. They claim that the error argument "makes the mistake of identifying cognitive processes with the tasks or goals in which cognitive processes serve" (p. 175). They illustrate their point with an analogy:

> Tightening screws requires turning them to the right. Loosening screws requires turning them to the left. Because what counts as success or error differs between the two tasks, there must be at least two different kinds of screwdrivers—one for tightening screws and one for loosening them. The conclusion doesn't follow, because the argument fails to take note of the possibility that a single screwdriver can be employed in two distinct ways: it fails to distinguish the tool from the uses to which it is put. (p. 175)

Shapiro and Epstein also raise a second point:

> We should not be surprised if natural selection has recruited extant cognitive capacities for new purposes rather than going to the trouble of developing new capacities every time a novel problem comes along. (p. 176)

Shapiro and Epstein (1998) are right in asserting that cognitive processes can be used in ways that make them valuable in the solution of different kinds of adaptive problems. A cognitive device for determining genetic relatedness could be employed in both the helping and the sexual domain, because in both these domains genetic relatedness is a factor that determines what counts as adaptive behavior (Lieberman et al., 2007). Shapiro and Epstein are also right in remarking that natural selection will not develop a new capacity for every adaptive problem that comes along: it is generally accepted in biology that natural selection may co-opt structures that originally evolved for other purposes (Gould & Lewontin, 1978; Gould & Vrba, 1982). These are both good arguments against the idea that there should exist a one-to-one relationship between adaptive problems and their solutions.

But does the error argument really claim that there has evolved a separate psychological mechanism for each and every adaptive problem? No, it leaves open the possibility that a single mechanism can sometimes be used for solving adaptive problems, as well as the possibility that existing structures are co-opted for a different function. Tooby and Cosmides (1998) themselves have responded explicitly to the screwdriver analogy:

> This [parody] hardly passes as serious discussion: cognitive explanations strive to make all aspects of a system mechanically explicit, and here the authors have separated off and excluded from analyses the decision-making machinery that determines how the screwdriver is used—an element critical to making their argument work. This machinery does, in fact must, distinguish between these two different uses (i.e., it has domain-specific elements). (p. 199)

There must be some factor that determines whether the screwdriver turns left or right, and strictly speaking, whether it even turns at all. If we pursue the proposed analogy, the intensity and directionality of the force exerted by the hand will determine whether the screwdriver turns, and if so in what direction (left or right). Additionally, different systems must be responsible for motivating the two behavioral outputs. For the loosening system, turning right is an error, whereas for the tightening system turning left is. This does not negate the fact that both systems can make use of the same screwdriver as a tool in their computation. These mechanisms qualify as domain specific in two different respects: first, they are activated only by certain kinds of inputs (force), and second, different inputs (directionality of the force) result in different functional outcomes (tightening screws and loosening them) with different error definitions.

The same physical system may be used differently by two distinct functional systems. The mouth is part of the digestive as well as the respiratory system. In each of these systems, it serves a particular role (processing food, breathing), and for each of these systems, different operations qualify as appropriate (i.e., conducive to function), or inappropriate (within the definition of error). The digestive system may motivate the mouth to start chewing when food needs to be processed, while the respiratory system may cause the mouth to open more widely as a result of lack of oxygen (e.g., in choking). However, the mouth by itself has no way of telling which of these behaviors is most appropriate at what times. This requires additional functional machinery: for example, a lack of oxygen is first identified in the brain, where it triggers a cascade of events which eventually causes the mouth to open. The point is that although a single physical system (the mouth) may be involved in two different functions (like the screwdriver), there have to be specific elements in the functional machinery that determine when the system will be used for what function, and how.

To summarize, although Shapiro and Epstein's (1998) screwdriver analogy shows that a single cognitive system can be employed for different uses, it does not demonstrate a single mechanism divorced from other cognitive structure can implement different functional outputs. In fact, the analogy can be used for illustrating the opposite: the necessity of domain-specific elements for producing distinct functional outcomes at the appropriate times. We conclude that the error argument provides reasonable grounds for predicting functional specialization in the human mind, albeit not necessarily for a separate mechanism for each and every adaptive problem.

5. The Poverty of the Stimulus Argument

Cosmides and Tooby (1994) also provide an evolutionary version of the poverty of the stimulus argument, claiming that:

> Adaptive courses of action can be neither deduced nor learned by general criteria alone because they depend on statistical relationships between features of the environment, behavior, and fitness that emerge over many generations and are, therefore, often not observable during a single lifetime. (p. 93)

This is a major problem for domain-general architectures, because domain-general mechanisms:

> are limited to knowing what can be validly derived by general processes from perceptual information. Domain-specific mechanisms are not limited in this way.... [They come instead] equipped with domain-specific procedures, representations, or representational formats prepared to exploit the unobserved. (p. 92)

Consider the problem of incest avoidance. An organism cannot learn that incest avoidance is an adaptive course of action, because to do so it would have to detect statistical relationships that cannot be observed in a single lifetime. However, natural selection *can* detect these statistical patterns. The authors elaborate:

> This is because natural selection does not work by inference or simulation. It takes the real problem, runs the experiment, and retains those design features that lead to the best available outcome. Natural selection 'counts up' the results of alternative designs operating in the real world, over millions of individuals, over thousands of generations, and weights alternatives by the statistical distribution of their consequences. (pp. 93–94)

Thus, through the blind process of testing alternative cognitive programs, selection has endowed the human mind with mechanisms for avoiding incest (Lieberman et al., 2003, 2007; Westermarck, 1921; Wilson, 1978).

An incest-avoidance mechanism may prescribe 'do not have sex with those children with whom you are raised', and because those children are usually your brothers and sisters, it enables you to learn with whom not to have sex later in life. But you cannot learn that incest avoidance *itself* is an adaptive course of action, because this is a statistical fact that emerges only over generations. How would a child learn that it should avoid mating with those individuals it is raised with? To *learn* that incest is maladaptive, one would have to run a long-term epidemiological study on the effects of inbreeding: produce large numbers of children with various related and unrelated partners, and observe which children fare well and which don't. This is of course unrealistic.

It is good to notice how this argument is different from Chomsky's (1959, 1975) classical poverty of the stimulus argument. Chomsky's seminal insight was that, *empirically*, the stimulus environment of children may be too impoverished to support the learning of certain abilities (e.g., language). This leaves open the possibility that there could be *other* environments that *are* in fact rich enough to support acquisition of these abilities. The evolutionary argument, in contrast, deals with those cases where it is *principally* impossible to learn some abilities or knowledge during a single lifetime (e.g., incest avoidance is adaptive), independently of environment, because to do so would require observing relationships that emerge only over generations.

Empirical support for evolved incest avoidance mechanisms in humans comes in part from studies that exploit unusual child-rearing conditions, such as those present in Kibbutz societies (Shepher, 1971) and in some Chinese and Taiwanese families where a female infant is adopted to become a bride for a son later in life (Wolf, 1995; Wolf & Huang, 1980). These studies show that genetically unrelated children raised together are indeed unlikely to feel sexually attracted towards each other (for a more extensive discussion of this literature, see Fessler & Navarette, 2004).

5.1. Fodor's Comments

Fodor (2000) provides two arguments against Cosmides and Tooby's (1994) version of the poverty of the stimulus argument. His first states that ''poverty of the stimulus arguments militate for innateness, not for modularity'' (p. 68). As was discussed previously, when Fodor speaks of a module, he means essentially a domain-specific, informationally encapsulated psychological mechanism. For this reason, he can legitimately argue that the "domain-specificity and encapsulation of a cognitive mechanism on the one hand, and its innateness on the other, are orthogonal properties" (pp. 68–69), because you can have "perfectly general learning mechanisms that are born knowing a lot" (p. 69). A similar argument was also put forward by Samuels (1998): "the existence of domain specific bodies of knowledge does *not* entail the existence of domain-specific computational mechanisms . . . since it is possible for a mind to contain innate, domain-specific bodies of knowledge but only contain domain-general mechanisms" (p. 583).

It is worth noting that Samuels (1998), Fodor (1983, 2000), and evolutionary psychologists agree that innate bodies of knowledge are inherently domain-specific bodies of information, insofar as they are always knowledge about a subset of things (e.g., objects, or grammar). So, why make a distinction between domain-specific knowledge and domain-specific mechanisms? It could be argued that one important difference is that knowledge (e.g., two objects cannot occupy the same place at the same time) may be true or false, while mechanisms can only do a good or bad job at accomplishing a particular task (Samuels, 1998). Another argument for distinguishing innate knowledge and specificity in cognitive programs is that programs provide a processor with instructions, while items of knowledge do not (for more arguments, see Stich & Ravenscroft, 1996). We are not convinced, however, that the distinction provides a sound rebuttal of the poverty of the stimulus argument. To see why, consider what the arguments for modularity are really arguments *against*.

Cosmides and Tooby (1994) argue against the idea that the mind could function as adaptively as it does without being richly and intricately structured. Whether this structure manifests itself as domain-specific procedures, innate domain-specific knowledge, or both, seems not to be their central concern. Consider their definition of domain generality: "A domain-general evolved architecture is defined by what it lacks: It lacks any content, *either in the form of domain-specific knowledge* [italics added] or domain-specific procedures that can guide it towards the solution of an adaptive problem" (p. 94). The implication is that innate knowledge is, or at least can be, a predicted feature of modular systems.

While it may be a computationally valid distinction, evolutionary psychologists are not concerned with the distinction between innate knowledge and domain-specific mechanisms. This is because it makes no difference from a fitness-functionalist perspective whether an organism comes equipped with innate knowledge that, say, red berries are poisonous, or with cognitive procedures that lead it to infer that small red objects are aversive. In both cases, the organism will defer from eating a potentially hazardous substance. Similarly, it does not matter for evolutionary psychologists whether humans posses innate knowledge that family members should be helped in accordance with their degree of genetic relatedness, or with psychological mechanisms that lead them to do so, because both cases would reflect specificity in cognition resulting from adaptive evolution (Barrett, personal communication).

Fodor's (2000) second argument against the evolutionary poverty of the stimulus argument is that natural selection is not necessarily more sensitive to subtle distinctions than learning, and that in some cases learning is even more sensitive to environmental subtleties than adaptation: "learning is often sensitive to phenotypic differences that are invisible to adaptation" (p. 70). In our view, Cosmides and Tooby's version of the poverty of the stimulus argument is consistent with their acceptance of both of these points.

The crux of the poverty of the stimulus argument is that there exists a set of relations relevant to the survival and reproductive success of organisms that *cannot* be detected during a single lifetime, not even in principle, because they emerge only over generations. Selection can keep track of these relationships, however, because it is inherently a transgenerational process. This argument by no means precludes the possibility of there being other relations that *can* be detected by learning (and not by natural selection), nor does it imply that learning within a single generation can sometimes be more subtle than natural selection. Thus, Fodor's (2000) arguments do not negate the poverty of the stimulus argument, since there remain adaptive problems that would necessitate specific information not available within a single generation.

6. The Combinatorial Explosion Argument

Combinatorial explosion, and the closely related frame problem, refers to the observation that "with each degree of freedom added to a system, or with each new dimension of potential variation added, or with each new successive choice in a chain of decisions, the total number of alternative possibilities faced by a computational system grows with devastating rapidity" (Tooby & Cosmides, 1992, p. 102). Domain-specific architectures can deal with this explosion of possibilities, because they contain cognitive structures that organize information, such as domain-specific databases, domain-specific decision rules, and rules that constrain the inputs into a system. A domain-general system, in contrast, lacks such structure and as a result "must evaluate all alternatives it can define. Permutations being what they are, alternatives increase exponentially as the problem complexity increases" (Cosmides & Tooby, 1994, p. 94). Consequently, combinatorial explosion will paralyze any system that is truly domain general.

This is a powerful argument for domain specificity. Tooby and Cosmides (1992) illustrate this with a mathematical example, noting that:

> If you are limited to emitting only one out of 100 alternative behaviors every successive minute, [then] after the second minute you have 10,000 different behavioral sequences from which to choose, a million by the third minute, a trillion by six minutes . . .. Every hour, each human is surrounded by a new and endless expanse of behavioral possibility. (p. 102)

These calculations are lethal, because only a very small subset of all potential organizations of information will lead to desirable (that is, adaptive) behavior. How does an organism know which combinations lead to functional outcomes?

> The system could not possibly compute the anticipated outcome of each alternative and compare the results, and so must be precluding without complete consideration of the overwhelming majority of branching pathways. What are the principles that allow us to act better than randomly? (pp. 102–103)

According to Cosmides and Tooby the answer relies on domain-specific structure, either in the form of a domain-specific knowledge, or domain-specific inference rules, or both.

6.1. Fodor's Comments

Fodor (2000) makes two remarks about the combinatorial explosion argument. His first remark is equivalent to his argument against the poverty of the stimulus argument: "there is no warranted inference from a creature's possessing a domain-neutral cognitive architecture to its lacking an innate cognitive endowment" (pp. 70–71). The creature might very well possess innate psychological structure other than modules, for instance, innate domain-specific knowledge. As we have seen, this argument does not respond adequately to Cosmides and Tooby's claim, for their notion of modularity includes domain-specific knowledge. The crucial issue for them is functional specialization, and again, functional specialization can manifest itself in a variety of forms. Consider an analogy with bodily organs: the heart is functionally specialized for pumping blood, the liver for detoxification. Still, hearts and livers are very different organs. Selection need not favor the same features in different functionally specialized organs. This is exactly why evolutionary psychologists object to the list of defining features that Fodor associates with mental modularity.

Fodor's (2000) second point is that:

> Cosmides and Tooby are wrong to suppose that massive modularity is the only alternative to combinatorial explosion. The most they have a right to is that *either* we have the kind of cognitive architecture in which massive modularity avoids an explosion of classical computation, *or* that (at least some) of our mental processes *aren't* classical computations. (pp. 70–71)

The idea that mental processes are not classical computations is interesting and may turn out to be correct, but it does not counter the combinatorial explosion argument. This is because even if our mental processes are not symbolic transformations over mental representations (as in, for example, connectionist neural networks), still large amounts of information need to be combined in a non-random fashion in order to achieve adaptive behavior (see Dennett, 1987). This is even true for ecological approaches that emphasize the effectivity of fast and frugal decision making (Todd et al., 2005). Thus, if there were no severe constraints on information processing, it seems impossible to ever transform the large amount of inputs that impinge on the senses into the tiny subset of behaviors that are actually adaptive.

Unfortunately, if Fodor (2000) has an idea about how this could work, he does not mention it. He even suggests that we might better put the problem aside until someone comes up with a good idea. Although this may sometimes be the wiser of options, we believe that sufficient progress is being made in the cognitive neurosciences to warrant a continued search for the mechanisms that support human cognition. To keep progressing, in our view, researchers should consider the possibility that the problems associated with combinatorial explosion provide reasonable grounds for expecting domain-specific specialization in the human mind.

7. Conclusion

We have presented and discussed four arguments in favor of the massive modularity hypothesis as endorsed by evolutionary psychologists: the engineering argument, the error argument, the poverty of the stimulus argument, and combinatorial explosion.

The *engineering argument* proposes that specialized mechanisms will outperform domain-general mechanisms, because speed, reliability, and efficiency can be engineered into specialized mechanisms, but not (or only to a lesser degree) into domain-general systems. Fodor (2000) countered this argument by stating that cognitive mechanisms cannot be maximized along all possible design dimensions, because of variability in local ecologies. We showed that adaptive specialization does not imply maximization, that evolutionary psychologists do not actually claim that cognitive mechanisms are optimal along all fitness-relevant dimensions, and finally, that it is mistaken to think that environmental variability precludes the evolution of adaptive specialization.

Three arguments were discussed that aim to show that domain-general mechanisms lack the characteristics needed to solve the tasks that humans routinely perform in order to survive and reproduce. The error argument asserts that because learning requires different standards of error for different adaptive domains, it can be expected that specialized procedures have evolved to deal with these different domains. In our view, Fodor (2000) misread this argument, as he wondered why a domain-general mechanism could not learn what is adaptive within a particular domain (e.g., mating or prosocial behavior). The point of the error argument is that this domain-general mechanism would have to generalize the same rule to other domains which will, in many cases, be maladaptive.

Shapiro and Epstein (1998) made two interesting comments. First, they asserted that cognitive processes can be used in ways that make them valuable in the solution of different kinds of adaptive problems, and second, that natural selection will not develop a new capacity for every adaptive problem that comes along. These are both good arguments against the idea that there exists a one-to-one mapping between adaptive problems and their solutions. However, this is not implied by the error argument. A mechanism for determining genetic relatedness can be employed in different domains (e.g., helping, courtship, and incest avoidance). The point is that such a mechanism would still require connections to other cognitive structure to produce the right functional outcomes in its respective domains at the appropriate times.

Next, Cosmides and Tooby's (1994) provided an evolutionary version of the *poverty of the stimulus argument*, which asserts that adaptive courses of action cannot be learned by an individual during its lifetime, because these courses of action depend on statistical relationships that emerge only over generations. Since general mechanisms are limited to knowing what can be derived from perceptual input, they cannot infer these relationships. Fodor (2000) countered this argument by stating that poverty of the stimulus arguments militate only for innateness, not for modularity. We showed that the distinction between innate knowledge and domain-specific modules is not a central concern for evolutionary psychologists, because from a fitness-functionalist perspective, both are forms of cognitive specificity resulting from adaptive evolution.

Fodor's (2000) second argument against the poverty of the stimulus argument was that natural selection is not necessarily more sensitive to subtle distinctions than learning, and also that learning can sometimes be more sensitive to environmental subtleties than the process of adaptive evolution. Neither of these points are denied by evolutionary psychologists, nor are they contradicted by the poverty of the stimulus argument. The poverty of the stimulus argument deals specifically with statistical patterns that emerge only over generations, and that therefore cannot be learned during a single lifetime.

The *combinatorial explosion* argument states that domain-general architectures cannot deal with the gigantic amount of possibilities in which information-elements can be organized, because they lack the right structures to privilege adaptive combinations of information over others. Fodor (2000) countered this argument (again) by stating that combinatorial explosion militates for innateness, not for modularity. Additionally, Fodor suggested that mental processes may not be classical computations. Our response to his first criticism was equivalent to our response to Fodor's rebuttal of the poverty of the stimulus argument: both innate knowledge and processing specificity are included in the evolutionary psychological conception of modularity. To his second argument we replied that even if the mind were not a computational organ, combinatorial explosion would still be a problem.

We conclude that the arguments for the massive modularity hypothesis do provide reasonable grounds for expecting functional specialization in the human mind. However, the extent to which human cognition is modularly organized will ultimately be an empirical issue. This is also true of the features that domain-specific mechanisms (insofar as they exist) will turn out to have. As Sperber (1994) has observed, whatever features are currently associated with adaptive mechanisms, their nature and properties are ultimately 'a matter of discovery, not stipulation'.

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