The Evolution of Mind

Fundamental Questions and Controversies

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Functional Specialization and the Adaptationist Program

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The term "module" means different things to different research communities. It first arose in artificial intelligence (AI) to refer to an absurdly simple concept: a mechanism or program that is organized to perform a particular function. By interconnecting these functionally specialized mechanisms, programmers found they could assemble highly intelligent computational systems.

A great deal of confusion over the term "module" was sown by Fodor (1983), who abandoned this original and simple meaning in favor of an eccentric set of criteria that ignores adaptive function and privileges "information encapsulation" (see Barrett, 2005). But Fodor's (1983) concept of a module is neither useful nor important for evolutionary psychologists. For evolutionary psychologists, the original sense of module—a program organized to perform a particular function—is the correct one, but with an evolutionary twist on the concept of function.

Evolutionary biology places restrictions on the concept of function (Williams, 1966). In evolved systems, the function of a mechanism refers to the problem it solved—the consequences it had—that caused the propagation of its genetic basis relative to that of alternative mechanisms. Because the architecture of the human mind acquired its functional organization through the evolutionary process, theories of adaptive function are the logical foundation on which to build theories of the design of cognitive mechanisms. Evolutionarily rigorous theories of adaptive function specify what problems our cognitive mechanisms were designed by evolution to solve, thereby supplying critical information about what their design features are likely to be—information that can guide researchers to discover previously unknown mechanisms in the mind. That is the essence of the adaptationist program.

Understanding these problems in detail leads one to expect the mind to be packed with functionally specialized mechanisms—modules in the older, better sense—that interact with one another to produce adaptive behavioral responses to the kinds of problems our hunter-gatherer ancestors had to solve, generation after generation, to survive and reproduce. The design of these mechanisms should be tailored to specific adaptive problems, such as predator avoidance, cheater detection, sexual attraction, mate choice, foraging, navigation, hunting, and coalitional cooperation. This adaptive tailoring often takes the form of content-rich, domain-specialized procedures that are useful in making inferences and decisions about one problem domain, but would be useless (or even harmful) if applied to a different problem domain.

For example, the "theory of mind" system is a set of domain-specialized programs designed to infer that the behavior of people is caused by invisible mental states—beliefs and desires (Baron-Cohen, 1995). This system is activated in response to people (and certain other agents), because it has a psychophysical front end: It is activated by cues, such as contingent reactivity and self-propelled motion, which were ecologically valid predictors of the presence of an agent in ancestral environments (Johnson, Slaughter, & Carey, 1998). The theory of mind system is not typically activated by rocks, buildings, and other things that lack these cues. And this is a good thing: Inferring mental states is useful for predicting the behavior of people, but useless for predicting the behavior of a rockslide. For nonagents, we have a functionally distinct set of domain-specialized programs, an object mechanics system (Leslie, 1994).

DOMAIN-GENERAL, DOMAIN-SPECIFIC: WHAT IS AT STAKE?

During most of the 20th century, research in psychology and the social sciences was dominated by the assumptions of what we have elsewhere called

the standard social science model (Tooby & Cosmides, 1992). This model's fundamental premise is that the evolved architecture of the human mind is composed mainly of cognitive processes that are content-free, few in number and general purpose. These general purpose mechanisms fly under names such as "learning," "induction," "imitation," "reasoning," and "the capacity for culture," and are thought to explain nearly every human phenomenon. Their structure is rarely specified by more than a wave of the hand. In this view, the same mechanisms are thought to govern how one acquires a language and a gender identity, an aversion to incest and an appreciation for vistas, a desire for friends and a fear of spiders—indeed, nearly every thought and feeling of which humans are capable. By definition, these empiricist mechanisms have no inherent content built into their procedures, they are not designed to construct certain mental contents more readily than others, and they have no features specialized for processing particular kinds of content over others. In other words, they are assumed to operate uniformly, regardless of the content, subject matter, or domain of life experience on which they are operating. (For this reason, such procedures are described as *content-independent, domain-general,* or *content-free*). The premise that these mechanisms have no content to impart—that the mind is a "blank slate"—is what leads to a doctrine that was central to the behavioral and social sciences: that all of our particular mental content originated in the social and physical world, and entered through perception. As Aquinas put this empiricist tenet a millennium ago, "There is nothing in the intellect that was not first in the senses."

As we discuss, this view of central processes is difficult to reconcile with modern evolutionary biology. There are essential adaptive problems that humans must have been able to solve in order to have propagated, that cannot be solved by a small number of domain-general mechanisms. Indeed, there is a very large number of such problems, including kin-directed helping, nutritional regulation, foraging, navigation, incest avoidance, sexual jealousy, predator avoidance, social exchange, avoiding free riders—at a minimum, any kind of information-processing problem that involves motivation, and many others as well.

THE WEAKNESS OF CONTENT-INDEPENDENT ARCHITECTURES

To some it may seem as if an evolutionary perspective supports the case that our cognitive architecture consists primarily of powerful, general purpose problem solvers: inference engines that embody the content-free normative theories of mathematics and logic. After all, wouldn't an organism be better equipped and better adapted if it could solve a more general class of problems over a narrower class?

This empiricist view is difficult to reconcile with evolutionary principles for a simple reason: Content-free, general purpose problem-solving mechanisms are extraordinarily weak—or even inert—compared to specialized ones. We have developed this argument in detail elsewhere (especially Cosmides & Tooby, 1987, 1994; Tooby & Cosmides, 1992), so we won't belabor it here. Instead, we simply summarize a few of the relevant points.

1. *Functional incompatibility: The "Stoppit" problem.* There is a Gary Larson cartoon about an "all-purpose" product called "Stoppit." When sprayed from an aerosol can, Stoppit solves lots of problems: It stops faucet drips, taxis, cigarette smoking, crying babies, and charging elephants. An "all-purpose" cognitive program is no more feasible for an analogous reason: What counts as adaptive behavior differs markedly from one problem domain to the next. An architecture equipped only with content-independent mechanisms must succeed at survival and reproduction by applying the same procedures to every adaptive problem. But there is no domain-general criterion of success or failure that correlates with fitness (e.g., what counts as a "good" mate has little in common with a "good" lunch or a "good" brother). Because what counts as the wrong thing to do differs from one class of problems to the next, there must be as many domain-specific subsystems as there are domains in which the definitions of successful behavioral outcomes are incommensurate (Tooby, Cosmides, & Barrett, 2005).

2. *Combinatorial explosion.* Combinatorial explosion paralyzes even moderately domain-general systems when encountering real-world complexity. As generality is increased by adding new dimensions to a problem space or new branch points to a decision tree, the computational load increases with catastrophic rapidity. A content-independent, specialization-free architecture contains no rules of relevance, domain-specialized procedural knowledge, or content-rich privileged hypotheses to restrict its search of a problem space, and so could not solve any biological problem of routine complexity in the amount of time an organism has to solve it. The question is not "How much specialization does a general purpose system require?" but rather "How many degrees of freedom can a system tolerate—even a specialized, highly targeted one—and still compute decisions in useful, real-world time?" Combinatorics guarantees that real systems can only tolerate a small number. (Hence this problem cannot be solved by placing a few "constraints" on a general system.)

3. *Clueless environments.* Content-free architectures are limited to knowing what can be validly derived by general processes from perceptual information available during an individual's lifetime. This sharply limits the range of problems they can solve: When the environment is clueless, the mechanism will be too. Domain-specific mechanisms are not limited in this way. They can be constructed to embody clues that fill in the blanks when perceptual evidence is lacking or difficult to obtain.

Consider the following adaptive problem. Toxin-producing bacteria often colonize butchered meat, and plants foods contain an array of toxins to defend themselves against predators. Toxins the adult liver metabolizes with ease sometimes harm a developing embryo. This subtle statistical relationship among the environment, eating behavior, and fitness is ontogenetically "invisible": It cannot be observed or induced *via general purpose processes* on the basis of perceptual evidence. Women ingest thousands of compounds (including toxins) every day; embryos self-abort for many reasons; early-term abortions are often undetectable; the best trade-off between calories consumed and risk of teratogenesis is obscure. Even if a baby is born with defects, anything could, in principle, have been the cause: sex with a sibling, an injury she sustained, nutritious food she ate, seeing a water buffalo, a curse someone put on her—indeed, anything the mother experienced prior to the birth. A truly "open" mind—that is, one endowed only with content-free inference procedures—would have to evaluate all of them.

But the relation between food toxins and embryonic health can be "observed" phylogenetically, by natural selection, because selection does not work by inference or simulation. Natural selection "counts up" the actual results of alternative designs (in this case, designs regulating food choice) operating in the real world, over millions of individuals, over thousands of generations, and weights these alternatives by the statistical distribution of their consequences: Those design features that statistically lead to the best available outcome are retained. In this sense, it is omniscient: It is not limited to what could be validly deduced by one individual, based on a short period of experience; it is not limited to what is locally perceivable, and it is not confused by spurious local correlations. As a result, it can build programs, such as those that regulate food choice during pregnancy, that embody content-rich privileged hypotheses that reflect and exploit these virtually unobservable relationships in the world. For example, the embryo-toxin problem is solved by a set of functionally specialized mechanisms that adjust the threshold on the mother's normal food aversion system, lowering it when the embryo is most at risk (thereby causing the food aversions, nausea, and vomiting of early pregnancy) and raising it when caloric intake becomes a priority (Flaxman & Sherman, 2000; Profet, 1992). As a result, the mother avoids ordinarily palatable foods when they would threaten the embryo: She responds adaptively to an ontogenetically invisible relationship.

In short, functionally specialized designs endowed with content-rich, domain-specialized procedures allow organisms to solve a broad range of adaptive problems that could not be solved by a few domain-general, content-free programs. The mind probably does contain a number of functionally specialized programs that are relatively content-free and domain-general (Duchaine, Cosmides, & Tooby, 2001), but these can regulate behavior adaptively only if they work in tandem with a bevy of content-rich, domain-specialized ones that solve the aforementioned problems (Brase, Cosmides, & Tooby, 1998; Cosmides & Tooby, 2001).

HOW MUCH FUNCTIONAL SPECIALIZATION?

Some researchers accept the conclusion that the human mind cannot consist solely of content-independent machinery, but nevertheless continue to believe that the mind needs very little content-specific organization to function. Moreover, they believe that the correct null hypothesis—the parsimonious, prudent scientific stance—is to posit as few functionally specialized mechanisms as possible.

This stance ignores what is now known about the nature of the evolutionary process and the types of functional organization that it produces. Natural selection is a relentlessly hill-climbing process that tends to replace relatively less efficient designs with ones that perform better. Hence, in deciding which of two alternative designs is more likely to have evolved, their comparative performance on ancestral adaptive problems is the appropriate standard to use. AI researchers created modules because, by restricting a program's scope of operation, they did not need to engineer a trade-off between competing task demands: They realized that a jack-of-all-trades is a master of none. The same is true for naturally engineered systems. By restricting the scope of a mechanism, natural selection can produce an elegant solution to a *specific* adaptive problem, such as avoiding potentially teratogenic toxins during the first trimester of pregnancy. The solution produced—an adjustment on a food aversion system (which itself has elegant design features, eliciting disgust to smells, sights, and tastes that were ancestrally valid predictors of toxins)—is elegant. But no elegant solution is possible if the same mechanism must cause pregnancy sickness and mate choice. Or pregnancy sickness and mate choice and social exchange and . . .

Evolutionary biologists, human behavioral ecologists, paleoanthropologists, and game theorists have produced a battery of very specific analyses of many adaptive problems our ancestors faced. Take one of these problems and develop a task analysis for it. By carefully examining what, specifically, a mechanism capable of solving that problem would have to be able to do, one gets a sense of just how much functional specialization that mechanism will require to produce an elegant, good solution. For most adaptive problems we are aware of, the answer is: a lot.

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