# 4    Origins of domain specificity:
# The evolution of functional organization

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By establishing that domain-specific machinery is necessary to explain human cognitive performance, psychologists who advocate modular or domain-specific approaches have found themselves in an unanticipated situation. Metaphorically speaking, it is as if they had laboriously built a road up one side of a nearly impassable mountain range into unexplored terrain, only to find themselves met at the top by a foreign road construction crew - evolutionary functionalist researchers - who had been building a road upward to the same destination from the far side of the mountains. Quite unexpectedly, cognitive psychologists find their field intimately connected to a whole new intellectual landscape that had previously seemed remote, unfamiliar, and all but irrelevant. Yet the proliferating connections tying together the cognitive and evolutionary communities promise to transform both fields, with each supplying necessary principles, methods, and a species of rigor that the other lacks. Although the sudden conjunction of these two communities has led to the customary level of mutual misunderstanding, the long-run significance of these developments is unmistakable. From this emerging integrated perspective, the domain-specific mechanisms or modules cognitive psychologists have been studying can be readily recognized for what they are - evolved adaptations, produced by the evolutionary process acting on our hunter-gatherer ancestors (Cosmides & Tooby, 1987).

### Natural selection and ancestral environments

Viewed from a more encompassing scientific framework, the confluence of these two research communities seems inevitable (Tooby & Cosmides, 1992). The human brain did not fall out of the sky, an inscrutable artifact of unknown origin, and there is no longer any sensible reason for studying it in ignorance of the causal processes that constructed it. Rather, the reliably developing cognitive mechanisms that collectively constitute the architecture of the human mind acquired their particular functional

organization through the process of evolution. The evolutionary history leading to modern humans consisted of a step-by-step succession of designs modified across millions of generations, with two independent forces — chance and natural selection — governing at every point whether each new modification would be incorporated into our species-typical cognitive architecture.

Although chance plays a delimited role in evolution and explains the existence and distribution of many simple and trivial properties, one thing cannot be plausibly explained as the product of chance processes: complex functional design (Williams, 1966; Dawkins, 1986; Pinker & Bloom, 1990; Tooby & Cosmides, 1990a, 1990b). Random walks do not systematically build intricate and improbably functional arrangements such as the visual system, the language faculty, or motor control. The only known explanation for the existence of complex functional design in organic systems is natural selection. Therefore, the existence of any complexly functional species-typical cognitive mechanisms must be related to the cumulative operation of selection (Dawkins, 1986; Pinker & Bloom, 1990). Necessarily, then, the design or functional organization of the mechanisms present in our cognitive architecture reflects the principles and logic of natural selection. Thus, cognitive psychologists, like physiologists, are usually studying adaptations and their effects, and they can find a productive new analytic tool in a carefully reasoned adaptationist approach (e.g., Cosmides, 1989; Cosmides & Tooby, 1989, 1992; Freyd, 1987; Gallistel, 1990; Gigerenzer & Hug, in press; Jackendoff, 1992; Leslie, 1987, 1988; Marr, 1982; Pinker & Bloom, 1990; Ramachadran, 1990; Rozin, 1976; Sherry & Schacter, 1987; Shepard, 1981, 1984, 1987a, 1987b; Shiffrar & Freyd, 1990; Staddon, 1988).

Natural selection operates through the testing of alternative designs through repeated encounters with evolutionarily recurrent situations (long-enduring adaptive problems). In our evolutionary history, design changes that enhanced their own propagation relative to alternative designs were selected for — that is, they caused their own successive spread until they became universal, species-typical features of our evolved architecture.[1] The systematic contribution of a design to its own propagation was the exclusive criterion, aside from chance, that determined which design changes became incorporated into our psychological architecture and which were excluded. Cognitive psychologists need to recognize that in explaining or exploring the reliably developing organization of a cognitive mechanism, the *function* of a design refers solely to how it contributed to its own propagation in ancestral environments. It does not refer to any of the various intuitive or folk definitions of function such as "contributing to the attainment of the individual's goals," "contributing to one's well-being," or "contributing to society." These other kinds of utility may or may not exist as side-effects of a given evolved design, but they can play no role in explaining how such designs came into existence or why they have the organization that they do. The fact that sexual jealousy, for example, may not contribute to any individual's well-being or to any positive social good is irrelevant in explaining why the cognitive mechanisms that reliably produce it under certain limited conditions became part of our species-typical psychological architecture (Daly, Wilson, & Weghorst, 1982; see Tooby & Cosmides, 1990a, for a cognitive-functionalist analysis of emotions).

Evolution is a historical process, not a foresightful one. The evolved design of modern organisms was caused by events in the past without regard to the problems of the present. Natural selection is not a teleological process capable of foreseeing the future and planning ahead for it. Our evolved mechanisms were constructed and adjusted in response to the statistical composite of situations actually encountered by our species during its evolutionary history (Symons, 1992; Tooby & Cosmides, 1990a). These mechanisms were not designed to deal with modern circumstances that are evolutionarily unprecedented. By the same token, they cannot have been designed to solve all potential problems under all possible circumstances either, because our species did not encounter all problems under all circumstances. For humans, the situations our ancestors encountered as Pleistocene hunter-gatherers define the array of adaptive problems our cognitive mechanisms were *designed* to solve, although these do not, of course, exhaust the range of problems they are capable of solving. These mechanisms should be well-engineered for solving this ancestral array of problems — and not necessarily any more inclusive class.

For these reasons, there is no warrant for thinking that selection would have favored cognitive mechanisms that are well-engineered for solving classes of problems beyond those encountered by Pleistocene hunter-gatherers. The widespread prejudice among cognitive psychologists for theories positing evolved architectures that consist of nothing but general-purpose problem-solvers is therefore unjustified. The fact that a mechanism can sometimes solve novel modern problems can play no role in explaining how that mechanism came to have the design it does, because natural selection had no crystal ball. The fact that our evolved mechanisms sometimes operate successfully in changed modern circumstances is a purely secondary consequence of their Pleistocene-forged design. Moreover, well-engineered performance should be evident only under conditions that mimic relevant aspects of the ancestral environments in which these mechanisms were designed to operate.

In short, the statistically recurrent conditions encountered during hominid evolutionary history constituted a series of adaptive problems. These conditions selected for a set of cognitive mechanisms that were capable of solving the associated adaptive problems. An adaptive problem can be defined as an evolutionarily recurrent problem whose solution promoted reproduction, however long or indirect the chain of causation by which it did so. Thus, although enhanced lifetime reproduction of self or kin was the ultimate functional product of adaptations, their proximate functional product need not have been closely associated with reproduction per se. A hominid life history of successfully achieved reproduction (including kin reproduction) required

accomplishing the entire tributary network of preconditions and facilitations to reproduction in complex ecological and social environments. This entailed, of course, distinct families of specialized information gathering, inference, and decision making for our hominid ancestors. For this reason, humans are equipped with a diverse range of adaptations designed to perform a wide variety of tasks, from solicitation of assistance from one's parents, to language acquisition, to modeling the spatial distribution of local objects, to coalition formation and cooperation, to the deduction of intentions on the basis of facial expressions, to avoiding incest, to allocating effort between activities, to the interpretation of threats, to mate selection, to object recognition.

When abstracted from their ancestral hunter-gatherer contexts, such varied competences may seem (or be) disconnected from modern reproduction, and the operation of our cognitive architectures may appear instead to be a haphazard expression of activities of no particular evolutionary significance or patterning. This is an illusion produced by considering the operation of our psychological designs in isolation from their natural ancestral environments and without having developed task analyses - what Marr called computational theories - of the adaptive problems our mechanisms evolved to solve (Marr, 1982). An understanding of the nature of the problems to be solved and a model of the detailed structure of these ancestral contexts makes functional sense of the otherwise puzzling design features of our problem-solving mechanisms (for an example of such functional clarification, see Profet, 1992, on pregnancy sickness as an adaptation to the teratogenic effects of toxins present in plant foods in hunter-gatherer diets).

Of course, the design of our mechanisms should reflect the structure of the adaptive problems our ancestors faced only to the extent that natural selection is an effective process. Is it one? Evolutionary biologists since Darwin have been aware that selection does not produce perfect designs (Darwin, 1859; Williams, 1966; Dawkins, 1976, 1982; for a recent convert from the position that organisms are optimally designed to the traditional adaptationist position, see Lewontin, 1967 vs. 1978). Still, 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. The eye and visual system are collections of cognitive adaptations that are well-engineered products of the evolutionary process, and although they may not be "perfect" or "optimal" - however these somewhat vague concepts may be interpreted - they are better at vision than any human-engineered system yet developed.

In consequence, not only is natural selection the only explanation for the functional organization of our cognitive mechanisms, but these mechanisms can be expected to be relatively well-engineered for solving ancestral adaptive problems. Two related questions arise when one assesses particular hypotheses

about our cognitive architecture. The first is a learnability (or solvability) question: What kind of mechanisms are capable of solving the adaptive problems our ancestors are known to have faced and regularly solved - domain-general mechanisms or domain-specific ones? The second is an evolvability question: 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 selected for?

### What's wrong with domain-general mechanisms: An evolutionary perspective

Evolutionary biology provides a series of reasons why it is implausible and unparsimonious to assume that the human mind is an equipotential, general-purpose machine (Cosmides & Tooby, 1987; Tooby & Cosmides, 1992).

In the first place, the more important the adaptive problem, the more intensely natural selection specializes and improves the performance of the mechanism for solving it. This is because different adaptive problems often require different solutions, and different solutions can, in most cases, be implemented only 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 competing task demands. Competing task demands can, however, be handled by separate, specialized systems. This accounts for the pervasive empirical finding that natural selection tends to produce functionally distinct adaptive specializations, such as a heart to pump blood, a liver to detoxify poisons, an immune system to defeat infections. As a rule, when two adaptive problems have solutions that are incompatible or simply different, a single general solution will be inferior to two specialized solutions. In such cases, a jack of all trades is necessarily a master of none, because generality can be achieved only by sacrificing effectiveness. Consequently, domain-specific cognitive mechanisms, with design features that exploit the stable structural features of evolutionarily recurring situations, can be expected to systematically outperform (and hence preclude or replace) more general mechanisms that fail to exploit these features.

The alarm calls of vervet monkeys illustrate this point clearly. Vervets have three major predators: leopards, eagles, and snakes. Each of these predators requires different evasive action: climbing a tree (leopard), looking up in the air or diving straight into the bushes (eagle), or standing on hind legs and looking into the grass (snake). Accordingly, vervets have evolved cognitive mechanisms that produce (and respond to) a different alarm call for each of these three predators (Cheney & Seyfarth, 1990). A single, general-purpose alarm call (and response system) would be less effective because the recipients

of the call would not know which of the three different and incompatible evasive actions to take.

Simply to survive and reproduce, our Pleistocene ancestors had to be good at solving an enormously broad array of adaptive problems - problems that would defeat any modern artificial intelligence system. A small sampling includes foraging for food, navigating, selecting a mate, parenting, engaging in social exchange, dealing with aggressive threat, avoiding pathogenic contamination, avoiding predators, avoiding naturally occuring plant toxins, avoiding incest, and so on. A woman who used the same taste preference mechanisms in choosing a mate that she used to choose nutritious foods would choose a very strange mate indeed, and such a design would rapidly select itself out. These different adaptive problems are frequently incommensurate: They cannot, in principle, be solved by the same mechanism (Sherry & Schacter, 1987). Even a restricted consideration of hunter-gatherer tasks suggests that it is unlikely that any single general computational system could solve them all under ancestral conditions. (Indeed, it is difficult to imagine a domain-general computational system that could solve *any* of them.)

For this reason, the human mind can be expected to include a number of functionally distinct cognitive adaptive specializations (for discussion, see Chomsky, 1980; Cosmides & Tooby, 1987; Rozin, 1976; Rozin & Kalat, 1971; Sherry & Schacter, 1987; Tooby & Cosmides, 1992). Both empirically and theoretically, there is no more reason to expect any two cognitive mechanisms to be alike than to expect the eye and the spleen, or the pancreas and the pituitary to be alike. The argument frequently made by advocates of domain-general mechanisms - that a hypothetical and yet-to-be-described general problem-solving design would solve a larger class of unencountered or rarely encountered problems - is irrelevant: What governs the course of evolution and, therefore, the design of the human mind, is the statistical distribution of past situations that our ancestors actually encountered over evolutionary time.

In fact, we think the case can be put even more strongly. It is not simply a matter of plausibility, of efficiency, or of evolution being more likely to have produced a better system. Even simple learnability analyses show that *it is in principle impossible for a human psychology that contained nothing but domain-general mechanisms to have evolved, because such a system cannot consistently behave adaptively: It cannot solve the problems that must have been solved in ancestral environments for us to be here today.* A small number of domain-general mechanisms are inadequate in principle to account for adaptive behavior. We have developed this argument in detail elsewhere (Cosmides & Tooby, 1987; Tooby & Cosmides, 1992), so we won't belabor it here. Instead, we will summarize a few of the relevant points.

First, the ground rules for the argument:

1. To be a viable hypothesis about human cognitive architecture, the proposed design must in principle be able to solve its target problem. At a

minimum, any proposed cognitive architecture had to produce minimally adaptive behavior in ancestral environments - we know this because we are here today. Just as a hypothesized set of cognitive mechanisms underlying language must be able to account for the facts of human linguistic behavior, so too must any hypothetical domain-general cognitive architecture solve all the problems that were necessary to survival and reproduction in the Pleistocene. If it can be shown that there are essential adaptive problems that humans must have been able to solve in order to have propagated, and that domain-general mechanisms cannot solve them, then the domain-general hypothesis fails. We think there are a number of such problems, including inclusive fitness regulation, nutritional regulation, incest avoidance, sexual jealousy, predator avoidance - at a minimum, any kind of information-processing problem that involves motivation, and many others as well.

2. Because we know that the human mind evolved primarily by natural selection, hypotheses about the design of the mind gain or lose plausibility depending on whether the proposed design would have enhanced functionality under ancestral conditions - in biological terminology, whether it produced an increase in "fit" behavior. Evolutionary biology suggests that there is no principled reason for parsimony to be a design criterion for the mind, particularly when it conflicts with increased functionality. Enhanced functionality is the only criterion to which natural selection responds. (Equally, there is no reason why chance evolutionary processes would create cognitive architectures that operate according to simple, general, parsimonious principles either.)

A domain-general psychological architecture cannot guide behavior in ways that promote fitness for at least three related reasons:

1. What counts as fit behavior differs from domain to domain, so there is no domain-general criterion of success or failure that correlates with fitness.
2. Adaptive courses of action can be neither deduced nor learned by general criteria, because they depend on statistical relationships between features of the environment, behavior, and fitness that emerge over many generations and are, therefore, not observable during a single lifetime.
3. Combinatorial explosion paralyzes any truly domain-general system when encountering real-world complexity.

**Reason 1: The definition of error is domain-dependent.** 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 learning 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. Given a potential partner with a physique, personality, or resources that would normally elicit sexual desire, the information that the potential partner is a family member must inhibit sexual impulses. Now suppose that this equipotential psyche had somehow learned that avoiding sex with kin had positive fitness consequences. How then should it generalize this knowledge about kin to other domains of human activity? Should one, for instance, avoid any interaction with kin? This would be a mistake; selectively avoiding sex with kin has positive fitness consequences, but selectively avoiding helping kin has negative fitness consequences. With relatives as with so many other things, what counts as adaptive error differs from domain to domain. In the sexual domain, error = sex with kin. In the helping domain, error = not helping kin given the appropriate envelope of circumstances. In cooperative exchanges, error = being cheated, which is paying a cost without receiving the benefit to which this entitles you. When a lion is looking for lunch, error = offering yourself as an appetizer. 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. This simple point has been underappreciated because of the traditional emphasis within cognitive psychology on the acquisition of knowledge rather than on the regulation of action. The brain evolved mechanisms to acquire knowledge because knowledge was important in the regulation of successful action.

**Reason 2: Many relationships necessary to the successful regulation of action cannot be observed by any individual during his or her lifetime.** Asking the question of how a domain-general architecture could acquire all the classes of necessary domain-specific knowledge exposes a fatal weakness in domain-general systems: They are limited to knowing what can be validly derived by general processes from perceptual information. Domain-specific mechanisms are not limited in this way. The world has a statistically recurrent domain-specific structure (e.g., snakes and spiders are often venomous, objects are solid, self-propelled entities are usually animals, the person who nursed you is likely to be your mother, human speech is consistent with Universal Grammar). A domain-general system has to bring the same general procedures to bear on spiders, speech, objects, mothers, and self-propelled entities, and so cannot initially treat any of these categories differently. Its subsequent operation is limited to what can be perceptually derived based on the application of general procedures. In contrast, content-sensitive architectures can come equipped with domain-specific procedures, representations, or representational formats prepared to exploit unobserved – and indeed, individually unobservable – sequelae to membership in various domains. The individual need not observe or experience death from a snake bite to manifest a caution

around snakes, or run a long-term epidemiological study of the effects of inbreeding to manifest a distaste for sex with siblings. Chomsky's argument from the poverty of the stimuli is of this kind: Perception alone cannot supply infants with a list of constraints on the hypothesis space of potential human grammars (Chomsky, 1975; Pinker, 1984).

In its most general form, the difficulty of discovering what fitness consequences various actions or choices in knowledge representation have is fatal to any proposed domain-general system. The systematic statistical consequences of many courses of action on fitness are not stably assessable for several generations, and then only by evolutionary biologists, Divine Beings, or – and this is the essential point – natural selection. Because the promotion of fitness means differential representation of genes in subsequent generations, the time at which the consequences of an action can be assessed is remote from the time at which the action must be taken. 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.

For example, how would a general-purpose mechanism situated in an ancestral hunter-gatherer ever discover that it should regulate behavior in approximate accordance with Hamilton's kin selection equation – that X should help Y whenever $C_x < r_{xy}B_y$?[2] When an individual sees a relative, there is nothing in the stimulus array that tells her how much she should help that relative. And there is no consequence that she can observe that tells her whether, from a fitness point of view, she helped too much, not enough, or just the right amount. Even worse, there is no one in the situation from whom she could learn, because selection will have created mechanisms in her relatives that cause them to encourage her to behave in ways that violate the above equation. A design feature that causes X to help her brother will spread through the population when it causes her behavior toward her full brother to fall within the bounds dictated by $C_x < \frac{1}{2}B_{brother}$. But selection should also have designed mechanisms that cause her brother to encourage her to help him whenever $\frac{1}{2}C_x < B_{brother}$, as well as mechanisms that cause their mother to encourage her to help her brother whenever $C_x < B_{brother}$. In other words, what counts as adaptively "correct" behavior is individual-specific. Learnability theorists of language have pointed out that a learning theory is inadequate if the information required for induction is absent from the child's environment. In the case of helping kin, the information is not only absent, but other individuals in the situation should be designed to try to socialize the child into behaving in ways that are contrary to the very rule that the child must induce.

In contrast, natural selection *can* detect these statistical relationships. 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. 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. It uses the statistical foundation of the actual lives of organisms, in the actual range of environments they encounter, under the statistical regularities they experience and, using alternative developmental programs leading to alternative designs, tests for the best solution. Some statistical regularities may be picked up by some kind of inductive learning system, but many can only be detected by the feedback process of natural selection.

**Reason 3: Combinatorial explosion paralyzes any system that is truly domain-general.** A domain-general evolved architecture is defined by what it lacks: It lacks any content, either in the form of domain-specific knowledge or domain-specific procedures, that can guide it toward the solution of an adaptive problem. As a result, a domain-general system must evaluate all alternatives it can define. Permutations being what they are, alternatives increase exponentially as the problem complexity increases. By the time you analyze any biological problem of routine complexity, a mechanism that contains no domain-specific rules of relevance, procedural knowledge, or privileged hypotheses could not solve the problem in the amount of time the organism has to solve it (e.g., Carey, 1985; Cosmides & Tooby, 1987; Gallistel, Brown, Carey, Gelman, & Keil, 1991; Keil, 1989; Markman, 1989; Tooby & Cosmides, 1992). Indeed, a great deal of research on domain-specific reasoning in children has been motivated by this concern, including many of the chapters in this volume (see also Carey & Gelman, 1991; Keil, 1989; Markman, 1989; and Volume 14 of *Cognitive Science*).

In short, although some mechanisms in the cognitive architecture may be domain-general, these could not have produced fit behavior under Pleistocene conditions (and therefore could not have been selected for) unless they were embedded in a constellation of specialized mechanisms that have domain-specific procedures, or operate over domain-specific representations, or both.

### Evolutionary biology, computational theories, and learnability

An evolutionary perspective can aid research on domain specificity in cognitive development in two ways. (1) It allows one to pinpoint the important, long-enduring adaptive problems for which humans are most likely to have cognitive adaptive specializations — that is, it suggests what domains might be fruitful to investigate. (2) Evolutionary biology provides richly contentful theories and relevant data that allow one to construct detailed

computational theories or task analyses of these domains. This facilitates both the experimental investigation of the associated cognitive mechanisms and the application of learnability (or, more generally, solvability) criteria.

#### Why a theory of adaptive function is important

Many psychologists study the mind without asking what it was designed to do. Instead, they hope to uncover its structure by studying things it is *capable* of doing. Playing chess, remembering nonsense syllables or long strings of numbers, programming computers, doing college-level statistics — these are all activities that we *can* do, but they are certainly not activities that our minds were *designed* to do. It is highly unlikely that the cognitive architecture of the human mind includes procedures that are *dedicated* to solving any of these problems: The ability to solve them well would not have enhanced the survival or reproduction of the average Pleistocene hunter-gatherer, and the performance of modern humans on such tasks is generally poor and uneven. In all probability, a wide and somewhat idiosyncratic array of mechanisms and knowledge bases is mobilized when we try to solve this kind of problem, so the study of such problems is unlikely to lead us to carve nature at the joints (Marr & Nishihara, 1978).

There is a big difference between studying what a mechanism *can* do, and what it was *designed* to do. Suppose you have to figure out how an appliance works by studying some of the things it *can* do. I tell you that it can be used as a paperweight, that you can use it to warm your hands on a cold day, and that you can kill someone who is taking a bath by throwing it into the tub with him. By studying each of these uses of the appliance, you will learn a little bit about its structure — it is heavy enough to keep paper from blowing away, it generates heat, it is electrical — but you won't get a very coherent idea of what it is or how it works. It sounds like an electrical, heat-generating paperweight. Where do you go from here? Where is the heuristic value in this research strategy?

Suppose, on the other hand, that I tell you that the appliance is a mechanism that was designed to toast slices of bread — it is a "toaster." Your research strategy for discovering how it works would be completely different. Knowing its function, you would look for mechanisms that were *specially designed* for fulfilling that function; in this case, you would look for mechanisms that were specially designed for toasting bread. For example, you might hypothesize that the appliance has elements that generate heat; that it has two of these heating elements, one for each side of a slice of bread; that these elements are parallel to each other; that the distance between them is a little wider than the width of the average slice of bread; that it has a mechanism for detecting when the bread is toasted and for turning off the heat, a mechanism that allows you to retrieve the toasted bread without burning your fingers, and so on. It also tells you what features of the toaster are

functionally arbitrary; the trait, "heavy enough to use as a paperweight," is not relevant to a toaster's function - it is merely a byproduct of the fact that the toaster's functioning parts are heavier than paper.

Knowing what the appliance was designed to do - what its function is - has enormous heuristic value because it suggests what design features it is likely to have. It allows you to pinpoint the kinds of problems a toaster should be very good at solving. Although it does not tell you the exact structure of the mechanisms that solve these problems (will the toast be delivered by a pop-up mechanism or by opening a door?), it suggests sharply focused hypotheses about the structure of these design features. It allows you to develop a task analysis for that problem, or what David Marr would call a "computational theory" for that problem domain: a theory specifying what functional characteristics a mechanism for solving that problem must have (Marr & Nishihara, 1978; Marr, 1982).

### Evolvability constraints and computational theories

The most important contribution that evolutionary biology can make in the study of domain-specific mechanisms is in the development of computational theories of adaptive information-processing problems. Natural selection theory is a theory of *function:* It allows one to pinpoint adaptive information-processing problems that the human mind was selected to solve and therefore should be good at solving. Because an adaptive problem and its cognitive solution - a mechanism - need to fit together like a lock and a key, understanding adaptive problems tells one a great deal about the associated cognitive mechanisms. Natural selection shapes domain-specific mechanisms so that their structure meshes with the evolutionarily stable features of their particular problem-domains. Understanding the evolutionarily stable features of problem-domains - and what selection favored as a solution under ancestral conditions - illuminates the design of cognitive specializations. Although a computational theory of an adaptive problem cannot, by itself, tell you the exact structure of the information-processing mechanisms that solve the problem, it does suggest what design features they are likely to have and places important constraints on the family of possible mechanisms.

For example, the evolution of altruism, or helping behavior, was a puzzle for evolutionary theory. How can a new design feature spread through the population until it becomes species-typical if it causes an individual to harm its own reproductive success - the number of offspring it has - in order to increase another individual's reproductive success? The individual who has the new design feature is, by definition, selecting itself out.

In 1964, W. D. Hamilton provided an answer to this question. Using mathematical game theory, he showed that if an organism helps a kin member whenever the cost to itself (in reproductive terms) is less than the benefit to its kin member, discounted by the probability that the kin member shares the same design feature, then that helping design can spread through the

population. Any design feature that causes an individual to help more than this - or less than this - would be selected against. This constraint is completely general: It is inherent in the dynamics of natural selection, true of any species on any planet at any time.

This means that the cognitive programs of an organism that confers benefits on kin cannot violate the [Cost to self < (Benefit to kin member) x (coefficient of relatedness to kin member)] constraint of Hamilton's kin selection theory. Cognitive programs that systematically violate this constraint cannot be selected for. Cognitive programs that satisfy this constraint can be selected for. A species may lack the ability to confer benefits on kin, but if it has such an ability, then it has it by virtue of cognitive programs that produce behavior that respects this constraint. One can call theoretical constraints of this kind *evolvability constraints;* they specify the class of mechanisms that can, in principle, evolve (Tooby & Cosmides, 1992).

The specification of constraints imposed by the evolutionary process - the specification of an adaptive function - does not, in itself, constitute a complete computational theory. Evolvability constraints merely define what counts as adaptive behavior. Cognitive programs are the means by which behavior - adaptive or otherwise - is produced. The important question a computational theory must address is: What kind of cognitive programs must an organism have if it is to behave adaptively?

Evolutionary biologists do not usually think of their theories as defining information-processing problems, yet this is exactly what they do. For example, Hamilton's kin selection theory raises - and answers - questions such as: How should the information that X is your brother affect your decision to help him? How should your assessment of the cost to you of helping your brother, versus the benefit to your brother of receiving your help, affect your decision? Will the information that Y is your cousin have a different effect on your decision than if you thought Y were your brother? In general, how should information about your relatedness to X, the costs and benefits to you of what X wants you to do for him, and the costs and benefits to X of your coming to his aid, affect your decision to help X?

As these questions show, an organism's behavior cannot fall within the bounds of the constraints imposed by the evolutionary process unless it is guided by cognitive programs that can solve certain information-processing problems that are very specific. To confer benefits on kin in accordance with the evolvability constraints of kin selection theory, the organism must have cognitive programs that allow it to extract certain specific information from its environment: Who are its relatives? Which kin are close and which distant? What are the costs and benefits of an action to itself? To its kin? The organism's behavior will be random with respect to the constraints of kin selection theory unless (1) it has some means of extracting information relevant to these questions from its environment, and (2) it has well-defined decision rules that use this information in ways that instantiate the theory's constraints. We are one of the species that has evolved the ability to help

kin. Consequently, we can be expected to have evolved mechanisms that are dedicated to solving such problems, and can therefore solve them quickly, reliably, efficiently, automatically, effortlessly, and unconsciously. Trying to study domain-specific processes without a detailed computational theory that is either derived from, or at least compatible with, evolutionary biology would be like trying to study language acquisition without knowing the grammar of any human language.

The development of detailed computational theories of adaptive problems not only facilitates the experimental investigation of human cognition, but it also lays the groundwork for conducting a learnability (or, more generally, a solvability) analysis (e.g., Pinker, 1979, 1984; Tooby & Cosmides, 1992; Wexler & Culicover, 1980). The fact that many adaptive problems are of a very specialized kind suggests that many cognitive processes will be far more specific than is usually assumed, even by psychologists sympathetic to a domain-specific viewpoint. For example, evolutionary biology identifies a large number of distinct problems posed by social life that learnability analyses indicate must involve very different procedures for their solution. Rules that will cause one to accurately detect cheaters in a situation of social exchange, for example, do not map onto the rules of inference of the propositional calculus (Cosmides, 1989; Cosmides & Tooby, 1992; Gigerenzer & Hug, 1992). Nor do they map onto rules for detecting violations of aggressive threats. For example, a social contract has a different cost-benefit structure from a threat; a social contract is not in effect unless both parties agree to it, whereas a threat is a unilateral speech act; a social contract does not have a biconditional entailment structure whereas a threat does; from the point of view of a single actor, there is only one way of violating a social contract, whereas there are two ways of violating a threat, and so on. Rules of inference for detecting cheaters on social contracts cannot, in principle, detect bluffs and double-crosses in situations of threat. Different rules are required for these different domains: The "grammar" of social contracts is very different from the grammar of threat. If someone were to propose a learning mechanism that accounts for the acquisition of both social contract algorithms *and* threat algorithms, their theory would have to meet stringent learnability criteria: Given the informational environment to which a child is exposed, this same mechanism would have to induce two entirely separate sets of rules that act on very different mental representations, plus metarules for when to apply each set of rules. Developing computational theories of different social problem domains has led us to believe that it is unlikely that "social cognition" will turn out to be a unitary domain (Cosmides & Tooby, 1989, 1992).

### Domain-specific reasoning in children

Long-term, across-generation recurrence of conditions – external, internal, or their interaction – is central to the evolution of adaptations, and it is easy to see why. Transient conditions that disappear after a single or a few generations may lead to some temporary change in the frequency of designs, but the associated selection pressures will disappear or reverse as often as conditions do. Therefore, it is only those conditions that recur, statistically accumulating across large numbers of generations, that lead to the construction of complex adaptations. As a corollary, anything that is recurrently true (as a net statistical or structural matter) across large numbers of generations could potentially come to be exploited by an evolving adaptation to solve a problem, or to improve performance. For this reason, a major part of adaptationist analysis involves sifting for these environmental or organismic regularities or invariances.

For those who study cognitive adaptations, the long-enduring structure of the world provides a deeply illuminating source of knowledge about the evolved architecture of the mind. As Shepard has put it, there has been the evolution of a mesh between the principles of the mind and the regularities of the world, such that our minds reflect many properties of the world (Shepard, 1987a). Many statistical and structural relationships that endured across human evolution were "detected" by natural selection, which designed corresponding computational machinery that is specialized to use these regularities to generate knowledge and decisions that would have been adaptive in the environment in which humans evolved.

Our domain-specific cognitive adaptations can, through exploiting the world's subtle enduring statistical structure, go far beyond the information they are given, and reconstruct from fragmentary cues highly accurate models of local conditions by exploiting these relationships (e.g., a self-propelled entity is usually an animal; sharp discontinuities in reflected light intensity usually indicate the presence of an edge). This evolutionary Kantian position has already been strongly vindicated in the fields of perception and psychophysics (see, e.g., Shepard 1981, 1984, 1987a, 1992; Marr, 1982), where the representations that our evolved computational systems construct go far beyond what is "logically" warranted solely by the sensory information itself, usually settling on single preferred interpretations. Our minds can do this reliably and validly because this fragmentary information is operated on by evolved procedures that were selected precisely because they reflect the subtle relationships enduringly present in the world (e.g., shading cues indicate shape and depth, time-location relationships indicate the most probable kinematic trajectories followed by solid objects). These mechanisms supply a privileged organization to the available sense data so that the interaction of the two generates interpretations that usually correspond to actual conditions in the external world. In the absence of specialized mechanisms that assume certain relationships are characteristic of the world, recovering accurate models of the external world from sense data would be an insoluble computational problem (Marr, 1982; Poggio, Torre, & Koch, 1985).

Parallel ideas form the centerpiece of Chomskyan psycholinguistics: Children

must be equipped with specialized mechanisms ("mental organs") organized to exploit certain grammatical universals of human language, because otherwise language learning would be an unsolvable computational problem for the child (Chomsky, 1957, 1959, 1975, 1980; Pinker, 1979, 1982, 1984, 1989; Wexler & Culicover, 1980). The discovery and exploratory description of such universal subtle relationships present in the "world" of human language is a primary activity of modem linguists and psycholinguists. Proposed mechanisms for language learning that do not include specialized procedures that exploit these relationships have been repeatedly shown to be inadequate (Pinker, 1989, 1991; Pinker & Prince, 1988). As in perception, adaptations for grammar acquisition must mesh with the enduring structure of the world. But in this case, the recurrent structure to be meshed with is created by the species-typical design of other (adult) human minds, which produce grammars that manifest certain relationships and not others.

This same logic is what places the recent advances in the study of children's reasoning in the mainstream of evolutionary psychology. Indeed, the field of cognitive development has been revolutionized by the discovery that the principles of inference that infants and children bring to the tasks of learning are organized to reflect the particular recurrent structure of specific problem-domains, such as object construal and motion, the differences between artifacts and living kinds, physical causality, and so on (see, e.g., the articles in Carey & Gelman, 1991 and in this volume). These evolved, domain-specific cognitive specializations have been shown to be specialized according to topic and to develop in the absence of explicit instruction.

For example, contrary to the Piagetian notion that infants must "learn" the object concept, recent research has shown that (at least) as early as 10 weeks — an age at which the visual system has only just matured — infants already have a sensorily integrated concept of objects as entities that are continuous in space and time, solid (two objects cannot occupy the same place at the same time), rigid, bounded, cohesive, and move as a unit (e.g., Spelke, 1988, 1990, 1991). Indeed, when infants of this age are shown trick displays that violate any of these assumptions, they indicate surprise — one could almost say in such cases that the object concept embodied in their evolved mechanisms causes them to "disbelieve" the evidence of their senses (Leslie, 1988). By 27 weeks, infants already analyze the motion of inanimate objects into submovements and use this parsing to distinguish causal from noncausal relationships (Leslie, 1988; Leslie & Keeble, 1987). Needless to say, these are all relationships that accurately reflect the evolutionarily long-enduring structure of the world. A Piagetian architecture that had to laboriously discover them would be a poor and inept design compared to one that spontaneously organized its knowledge in terms of such stably true principles.

Brown (1990) has shown that early causal principles such as "no action at a distance" guide learning about tool use in children as young as 18 months; these children categorize tools for use according to functional properties (e.g.,

a hooked end for pulling) over nonfunctional properties (e.g., color). In contrast, the same children have great difficulty learning how to use a tool when its mechanism of action appears to violate one of their concepts about physical causality — concepts that mirror certain aspects of Newtonian mechanics.

The living world of plants and animals is structured into species and other more inclusive units that have large sets of properties in common — wolves resemble other wolves, mammals other mammals, and so on. This is another enduring set of relationships in the world that our minds should have evolved special design features to exploit. Ethnobiologists and cognitive anthropologists such as Atran and Berlin have shown that the principles of categorization humans spontaneously bring to this task reflect certain aspects of this enduring structure, and are the same cross-culturally (Atran, 1990; Berlin, Breedlove, & Raven, 1973).

The enduring relationships created by the existence of such "natural kinds" and of artifacts have apparently selected for additional reasoning specializations as well. To begin with, very young children make sharp distinctions between the animate and inanimate worlds. Throughout our evolutionary history, being an animal has been reliably — if imperfectly — correlated with self-generated motion, whereas inanimate objects rarely move unless acted upon by an outside force. Recent research suggests that young children use this cue to distinguish the animate from the inanimate worlds, and make very different inferences about the two (Gelman, 1990b; Premack, 1990). More generally, experiments by Keil (1989) and others indicate that the kind of inferences children spontaneously make about natural kinds, such as animals, plants, and substances, differ sharply from those they are willing to make about human-made artifacts. Artifacts are defined by how their perceptual attributes subserve their (intended) function. In contrast, natural kinds are viewed as having invisible, defining "essences" that cause their perceptual attributes. (Indeed, the species-typical genetic endowments of species, and the common ancestry of larger taxa do cause an indefinitely large set of similarities to be shared among members of a natural kind, as does a common chemical structure for different instances of a substance.)

In an important series of experiments, Gelman and Markman (1986, 1987; Markman, 1989) found that natural-kind membership is a powerful organizer of inference in young children. In general, being a member of a natural kind carries more inferential weight than being perceptually similar. In addition, children give more weight to natural-kind membership when reasoning about traits that actually are more likely to vary as a function of membership in a natural kind, such as breathing, than when reasoning about traits that are more likely to vary as a function of perceptual similarity, such as weight or visibility at night (for a summary, see Markman, 1989).

Another important set of evolutionarily long-enduring regularities is the recurrent design features of other human minds. Evolved domain-specific cognitive specializations are even more necessary in this area, not only because

other minds constitute the single most important selective force facing any individual human, but also because mental states such as beliefs, motives, intentions, and emotions cannot be directly observed. To allow a human to represent at least some of the mental states that generate others' behavior, special inferential systems must be available to bridge the gap from the observable to the unobservable. For example, if there is a reliable correlation over evolutionary time between the movement of human facial muscles and emotional state or behavioral intentions, then specialized mechanisms can evolve that infer a person's mental state from the movement of that person's facial muscles (Ekman, 1973, 1984; Fridlund, 1991). Indeed, evidence drawn from cognitive neuroscience indicates that we do have mechanisms specialized for "reading" facial expressions of emotion (Etcoff, 1983, 1986). If humans organize their understanding of each other through invoking the operation of unobservable entities such as beliefs, desires, and intentions, it cannot be because perception alone drove them to it.

An intensive research effort in the field of cognitive development has recently provided substantial support for the hypothesis that our evolved psychological architecture includes procedures that cause very young children to reliably develop models of other human minds (e.g., Astington, Harris, & Olson, 1988; Leslie, 1987, 1988; Perner, 1991; Wellman, 1990; Wimmer & Perner, 1983). Developmental psychologists have been finding that even l- and 3-year-olds make different inferences about "mental entities" (dreams, thoughts, desires, beliefs) than about "physical entities." Moreover, children typically "explain" behavior as the interaction of beliefs and desires. Such inferences appear to be generated by a domain-specific cognitive system that is sometimes called a "theory of mind" module (Leslie, 1987). This module consists of specialized computational machinery that allows one to represent the notion that *agents* can have *attitudes* toward *propositions* (thus "Mary" can "believe" that "X," "Mary" can "think" that "X," and so on). Between the ages of 3 and 5 this domain-specific inferential system develops in a characteristic pattern that has been replicated cross-culturally in North America, Europe, China (Flavell, Zhang, Zou, Dong, & Qui, 1983), Japan (Gardner, Harris, Ohmoto, & Hamazaki, 1988), and a hunter-gatherer group in Camaroon (Avis & Harris, 1991). Moreover, there is now evidence suggesting that the neurological basis of this system can be selectively damaged; indeed, autism is suspected to be caused by a selective neurological impairment of the theory of mind module (Baron-Cohen, Leslie, & Frith, 1985; Leslie, 1987, 1988; Leslie & Thaiss, 1990).

This research suggests that a panhuman theory of mind module structures the folk psychology that people develop. People in different cultures may elaborate their folk psychologies in different ways, but the computational machinery that guides the development of their folk notions will be the same, and many of the representations developed will be similar as well. It appears that humans come into the world with the tendency to organize their

understanding of the actions of others in terms of beliefs, desires, and other mental entities, just as they organize patterns in their two-dimensional retinal array under the assumption that the world is three-dimensional and that objects are permanent, bounded, and solid.

These principles can be expected to apply far beyond these few presently documented cases. The world is full of long-enduring structure — social, biological, physical, ecological, and psychological — and the mind appears to be full of corresponding mechanisms that use these stable structural features to solve a diverse array of adaptive problems. Like a key in a lock, the functional organization of each cognitive adaptation should match the evolutionarily recurrent structural features of its particular problem-domain (Shepard, 1987a; Tooby & Cosmides, 1990a). Because the enduring structure of ancestral environments *caused* the design of psychological adaptations, the careful empirical investigation of the structure of environments from a perspective that focuses on adaptive problems and outcomes can provide powerful guidance in the exploration of our cognitive mechanisms.

### The future of domain-specific research

#### Domain-specific procedures or domain-specific representations?

One of the satisfying aspects of the recent florescence of research on domain specificity in cognitive development has been its rigor relative to alternative approaches within the field. Despite its relative sophistication, however, it is important to realize that the research program is only in its beginning phases, and we are a long way from having complete models of the phenomena in question. The ultimate goal of cognitive research should be the achievement of a fully specified formal model of some cognitive mechanism, implementable — at least in principle — by automata. This requires the full specification of, for example, (1) the initial set of procedures, (2) the initial set of representations, (3) the representational formats, (4) the environment the architecture operates in, and (5) the way in which procedures create the relationship between representational inputs and outputs.

However, in reading the literature on domain-specific reasoning in children, one could come away with the impression that the study of cognition is nothing more than the study of representations. But representations are, by themselves, inert. Obviously, there must be procedures that operate on representations if the brain is to process information. So the next step for many researchers lies in discovering where the domain specificity lies — in the child's mental representations, in the procedures that operate on these representations, or in both.

The literature on domain-specific reasoning in children is often unclear on this issue. Some researchers appear to favor the notion that certain content-imbued, domain-specific representations are reliably developing aspects of

our evolved architecture, but that the procedures that operate on these representations are themselves domain-general. R. Gelman, for example, can be read as arguing that domain-specific skeletal principles (representations or procedures?) provide an initial categorization of the world, thereby determining what data gets processed, but that the processors themselves are statistical inference engines that are reasonably domain-general, able to take a wide variety of contents as inputs (R. Gelman, 1990a, 1990b). In contrast, Spelke often seems to imply that the infant's object concept is embodied in procedures that are domain-specific but modal in the sense that they can operate on both visual and tactile data (Spelke, 1988, 1990). Both procedures and representations are hypothesized to be domain-specific in Leslie's conception of the child's theory of mind module (Leslie, 1987, 1988). In yet another variation on the theme, Karmiloff-Smith argues that infants have domain-specific procedures, but that some kind of process - presumably a domain-general one - operates on these procedures in such a way that the knowledge embodied therein, is transformed into representations that can themselves be acted upon by yet other procedures, whether domain-specific or domain-general (e.g., Karmiloff-Smith, 1991).

Any of these possibilities may be correct. Indeed, all may be correct, although for different domains. Our point is that the study of domain specificity in cognitive development will advance significantly when researchers propose more precise computational models - models that attempt to specify the nature of both the representations *and* the procedures that give rise to domain-specific reasoning in children. Once such models are proposed, learnability analyses can determine whether they can, in fact, give rise to the performance they are credited with, and experimentation can explore the details of the mechanisms involved.

### From domain-specific knowledge acquisition to domain-specific behavioral regulation

The work on domain specificity in cognitive development has not been, for the most part, motivated by evolutionary considerations or, indeed, by any larger program intended to discover how the human mind regulates behavior. Instead, it was spurred by philosophical arguments that combinatorial explosion will prevent a blank slate - or its technologically modern equivalent, the general-purpose computer - from learning anything in real time (e.g., Carey, 1985; Keil, 1989; Markman, 1989). Indeed, the problem that combinatorial explosion poses for the acquisition of knowledge is certainly a sufficient justification for looking for domain-specific mechanisms. But this approach is limited in its heuristic power. The invocation of combinatorial explosion cannot, by itself, generate hypotheses about which domains we are likely to have domain-specific mechanisms for reasoning about. In contrast, by considering what adaptive problems our ancestors would have had to be

good at solving, as well as what kind of information would have been available for solving such problems under ancestral conditions, one can make many educated guesses about which domains are likely to have associated cognitive competences (for an array of examples, see the chapters in Barkow, Cosmides, & Tooby, 1992).

The origins of cognitive psychologists' interest in knowledge acquisition are well known. Cognitive psychology developed in substantial measure as an outgrowth of epistemology, and so it has inherited a preoccupation with such traditional philosophical concerns as knowledge acquisition, concept formation, language, and perception. Questions of how adaptive behavior is generated or how adaptive problems - such as mate selection - were solved have been largely ignored. Yet, from an evolutionary perspective this relative emphasis appears strangely disproportionate. Cognitive mechanisms capable of acquiring knowledge evolved solely because they subserved a larger cognitive architecture that regulated behavior. Specific knowledge acquisition mechanisms evolved only because they enhanced the system's ability to generate adaptive behavior under ancestral conditions. Surely this larger encompassing architecture with its constituent array of problem-solving specializations is equally worthy of study by cognitive psychologists. We suspect that the heavy emphasis on knowledge acquisition rather than behavioral regulation has caused many researchers to grossly underestimate the number of domain-specific mechanisms that are necessary to account for human thought and behavior. The evolvability considerations discussed earlier suggest that our species-typical architecture can be expected to contain not only a large number of domain-specific mechanisms that generate knowledge, but also a large number of domain-specific mechanisms that otherwise function to regulate and generate behavior (see, e.g., Cosmides, 1989; Cosmides & Tooby, 1989, 1992).

As a scientific matter, mechanisms describable at the cognitive level underlie and organize all of human thought and behavior - not just knowledge acquisition - and so cognitive psychology needs to broaden its scope to include them. This changes cognitive psychology into a wide-ranging discipline in which every kind of behavior or psychological phenomenon must eventually be addressed. Indeed, once cognitive psychologists begin to consider what kind of mechanisms would have been capable of generating adaptive behavior under ancestral conditions, the area of inquiry is explosively expanded. Not only should we expect to find domain-specific mechanisms that give rise to the object concept and an implicit theory of mind, but we should also find domain-specific mechanisms that give rise to incest avoidance, social exchange, aggressive threat, parenting, mate choice, disease avoidance, food aversions, predator avoidance, habitat selection, and so on (see, e.g., Buss, 1992; Cosmides & Tooby, 1992; Fernald, 1992; Mann, 1992; Orians & Heerwagen, 1992; Profet, 1992; Shepher, 1983; Symons, 1979; Wolf & Huang, 1980).

In such cases, the domain specificity may be found not in the form of

knowledge structures per se, but in the specialized way in which various procedures and cues interact to produce an adaptively appropriate behavior. Rhesus monkeys, for example, have domain-specific mechanisms specialized for learning to avoid venomous snakes. If a laboratory-reared monkey sees a snake, it exhibits no fear. It does exhibit fear toward snakes, however, if it sees another monkey emiting a fear reaction toward snakes or snake facsimiles. Yet the monkey does not become afraid of *any* stimulus toward which it sees other monkeys reacting with fear. For example, if it sees another monkey emit a fear reaction toward an artificial flower, the lab-reared monkey does not become afraid of artificial flowers (Mineka & Cook, 1988). The rhesus monkey's fear-producing mechanism is highly domain-specific, but its domain specificity lies in the way in which a precise configuration of cues activates procedures that give rise to adaptively appropriate behavior. There is evidence for a similar mechanism in humans (Cook, Hodes, & Lang, 1986).

By asking what kinds of mechanisms would have been capable of giving rise to adaptive behavior under ancestral conditions, cognitive psychologists can also determine what kind of knowledge an individual would need to acquire in order to generate the appropriate behavior. This allows one to pinpoint domains for which we should have domain-specific mechanisms governing knowledge acquisition. Thus, knowing that our ancestors must have evolved mechanisms that would have caused them to avoid incest under ancestral conditions tells one that we must have evolved mechanisms that allow us to categorize the social world into kin versus non-kin. Moreover, it tells one that these evolved mechanisms must use cues, such as coresidence at an early age, that were reliably associated with kinship during our evolutionary history (Wolf & Huang, 1980). Knowing that our ancestors must have evolved mechanisms that, under ancestral conditions, would have caused them to choose habitats that were well-suited for supporting human life tells one a great deal about the kind of habitat knowledge people can be expected to seek out, and what kind of habitats they can be expected to prefer (e.g., Kaplan, 1992; Orians & Heerwagen, 1992). Knowing what would have counted as a good mate under ancestral conditions can tell one what kinds of information about the opposite sex a person will find interesting and what kind of mates they will tend to prefer. And so on. By using evolvability criteria and remembering that our evolved mechanisms were designed not to seek truth as an end in itself, but instead to generate adaptive behavior, one can both expand and focus the search for domain-specific cognitive mechanisms.

### Evolution, domain specificity, and culture

The new research on domain-specific reasoning in cognitive development indicates that the human mind is permeated with content and organization that does not originate in the social world. This content was placed in the mind by the process of natural selection, and it is a reliably

developing feature of our cognitive architecture. At a minimum, children's cognitive mechanisms were selected over evolutionary time to "assume" that certain things tend to be true of the world and of human life (e.g., objects are solid, other humans have minds, the self-propelled are animate). The specialized procedures, representational formats, cues, and categorization systems of these mechanisms impose — out of an infinite set of potential alternatives — a detailed organization on experience that is shared by all normal members of our species. Such a conclusion radically transforms our view of culture (for an extended analysis, see Tooby & Cosmides, 1992).

Traditionally, the mind has been considered to be a general-purpose computer or blank slate, with all of its content deriving from general-purpose mechanisms operating on environmentally or socially generated content. To speak crudely, the external social world was thought to impose its content on the internal. On this view, "culture" was seen as a unitary phenomenon that can be expressed in three different ways: (1) Culture as the socially learned: It is conceived as being some kind of contingently variable informational substance that is transmitted by one generation to another. (2) Culture as adult mental content: Because the individual mind is considered to be initially content-free and general-purpose, all or nearly all adult mental organization and content is assumed to be "cultural" in origin. (3) Culture as within-group similarities: Humans everywhere show patterns of local within-group similarity in their behavior and thought, accompanied by significant intergroup differences. The existence of separate streams of transmitted information is then assumed to be the exclusive explanation for these group patterns: Cultures are these sets of similarities, and intergroup differences are unreflectively called "cultural" differences. Under the standard view, these three logically separable concepts — the socially learned, mental content, and intragroup similarities — are all seen as one and the same thing — "culture."

But if all humans share a universal highly organized architecture that is endowed with many mechanisms that are rich in content, then the equation of these three breaks down. To begin with, the socially transmitted can no longer be equated with the contentful organization of human mental life and viewed as its sole cause because evolution is another cause of reliably developing mental content. Instead of all mental content being a social product; in many cases the causality is reversed. The evolved structure of the mind itself imposes content on the social world. In this alternative view, each domain-specific cognitive adaptation is a building block in a new theory of culture, because each can be expected to impose its particular organization on its special area of human knowledge and action (Sperber, 1985, 1990; Atran, 1990; Boyer, 1990; Hirschfeld, 1989; Cosmides & Tooby, 1989, 1992; Tooby & Cosmides, 1992; Chomsky, 1980). The design of our evolved domain-specific mechanisms will themselves govern what is or can be socially transmitted (see, e.g., Sperber, 1985, 1990). Certain representations may be viewed as subsisting within individual domain-specific mechanisms, and the

programming of these mechanisms will regulate how specific representations move from individual to individual, distributing themselves in the population in response to different social and ecological conditions (Boyer, 1990; Sperber, 1990). At a deeper level, the existence of domain-specific mechanisms also means that there is a level of universal human mental content – that is, for certain things there is a single universal human "culture" (e.g., Universal Grammar, social exchange logic, object permanence, theory of mind).

In short, understanding that the human mind includes a large number of complex; evolved, domain-specific cognitive processes fundamentally changes one's view of transmitted "culture" and of the origins of mental content. At a minimum, as Sperber (1985) has cogently argued, it tells one that the equipotentiality assumption implicit in most cultural transmission theories – the assumption that mental representations with different content are equally easy to transmit – is false. Representations whose content taps into a domain for which we have specialized mechanisms will be transmitted very differently than representations whose content does not tap into such a domain. Second, it casts the strongest doubt on the notion that the individual is the passive recipient of cultural transmission. The Hamiltonian revolution in evolutionary biology has demonstrated that individuals' fitness interests were often in conflict during human evolution. One would  expect our domain-specific psychological mechanisms to reflect this fact, causing individuals to resist socialization in certain domains and under certain circumstances, and to accept it in other domains and circumstances. For example, as we discussed earlier, one would expect a child to resist attempts by her parent to socialize her into helping her sibling whenever $C_x < B_{sib}$ and behave in ways that satisfy the $C_x < 1/2\ B_{sib}$ rule (Tooby & Cosmides, 1989; Boyd & Richerson, 1985).

Finally, domain-specific mechanisms provide an alternative explanation for within-group similarities – aside from attributing them to the operation of cultural transmission. Domain-specific adaptations raise the possibility that within-group similarities (and intergroup differences) are "evoked" rather than socially learned (Tooby & Cosmides, 1989, 1992). The possibility of *evoked culture* breaks down the traditionally hypothesized equivalence between shared intragroup similarities and the socially transmitted.

Some (or all) domain-specific cognitive adaptations should be designed to respond in structured ways to inputs from local situations. As a result, humans in groups can be expected to express, in response to local conditions, organized within-group similarities that are caused not by social learning or transmission, but rather by the activation of these content-imposing mechanisms. Of course, these generated within-group similarities will simultaneously lead to systematic differences between groups that face different conditions.

To take a single example, differences in attitudes and social rules involving food sharing may be evoked by ecological variables (Cosmides & Tooby, 1992). One finding from the theoretical literature of evolutionary ecology on optimal foraging is that different kinds of sharing rules benefit individuals in

different situations. For example, when the variance in foraging success of an individual is greater than the variance for the band as a whole, bandwide food sharing buffers the variance. In essence, the individual stores food in the form of social obligations. Bandwide sharing is a "from each according to his ability to each according to his need" type of system – food is distributed relatively equally to everyone in the band, no matter who found it. In contrast, when the variance in foraging success for an individual forager is low, that individual is better off sharing just within his or her family, in accordance with kin selection principles. If everyone reliably has access to the same goods, there is no particular benefit to sharing.

Optimal foraging theory is one component of a task analysis, or, in David Marr's terms, a computational theory of the adaptive problem of foraging. It defines the nature of the problem to be solved, and thereby specifies constraints that any mechanism that evolved to solve this problem can be expected to satisfy. In this case, optimal foraging theory suggests (1) that we should have domain-specific information-processing mechanisms governing foraging and sharing, and (2) these mechanisms should be sensitive to information regarding variance in foraging success, causing us to prefer one set of sharing rules for high variance items and another set for low variance items.

Kaplan and Hill's (1985) study of the Ache, a hunter-gatherer group living in eastern Paraguay, provides a particularly elegant test of this hypothesis because it controls for "culture." Meat is a very high variance food item among the Ache: On any given day, there is a 40% chance that a hunter will come back empty-handed. Collected plant foods, in contrast, are very low variance items. Kaplan and Hill found that the Ache engage in bandwide sharing of meat, whereas they share plant food primarily within the nuclear family. Thus the same individuals, in the same "culture," engage in different patterns of sharing for different foods, depending on the variance they experience in obtaining them.

Cashdan (1980) found a very similar situation among different groups of the Kalahari San. The Kalahari San are widely cited in anthropological circles for their strict economic and political egalitarianism. For example, the !Kung San, who experience extreme variability in the availability of food and water, have very strong social sanctions that reinforce sharing, discourage hoarding (calling someone "stingy" is a terrible insult), and discourage displays of arrogance and authority. For example,

**The proper behavior of a !Kung hunter who has made a big kill is to speak of it in passing and in a deprecating manner (Lee, 1969; Draper, 1978); if an individual does not minimize or speak lightly of his own accomplishments, his friends and relatives will not hesitate to do it for him. (Cashdan, 1980: 116)**

But it turns that some San bands are more egalitarian than others, and their degree of egalitarianism is related to variance in their food supply. The //Gana San of the northeastern Kalahari are able to buffer themselves from

variability in the food and water supply in ways that other San cannot, through a small amount of food cultivation (including a kind of melon that stores water in the desert environment) and some goat husbandry. In contrast to the !Kung, the //Gana allow considerable economic inequality, they hoard more, they are more polygynous and, although they have no clear-cut authority structure, wealthy, high-status //Gana men are quick to claim that they speak for others and that they are the "headman" - behavior that would be considered unconscionable among the !Kung. Again, even though the !Kung and the //Gana are culturally similar in many ways - they share the same "memepool," so to speak - their social rules regarding sharing and economic equality differ, and these differences track the variance in their food supplies.

These phenomena are quite possibly instances of evoked culture. Rather than being the result of cultural transmission (at least in any traditional sense), they are evoked by the local situation. Because foraging and sharing are complex adaptive problems with a long evolutionary history, it is difficult to see how humans could have escaped evolving highly structured domain-specific psychological mechanisms for solving them. These mechanisms should be sensitive to local informational input, such as information regarding variance in the food supply. This input can act as a "switch," turning on and off different modes of activation of the appropriate domain-specific mechanisms. The experience of high variance in foraging success should activate rules of inference, memory retrieval cues, attentional mechanisms, and motivational mechanisms that allow bandwide sharing to occur and that make it appealing. The experience of low variance in foraging success should activate rules of inference, memory retrieval cues, attentional mechanisms, and motivational mechanisms that make within-family sharing possible and appealing. These alternative modes of activation of the domain-specific mechanisms provide the core knowledge that must be mutually manifest to the various actors for bandwide or within-family sharing to occur. This core knowledge can then organize and provide points of attachment for symbolic activities that arise in these domains.

Such alternative modes of activation can create alternative sets of complexly patterned social rules and activities. These will emerge independently, that is, in the absence of direct cultural transmission, in culture after culture when the individuals therein are exposed to the informational cues that activate these alternative modes.

In summary, cognitive psychology gains an entire new dimension of rigor when its natural relationships to the larger scientific landscape are recognized and exploited. Cognitive mechanisms are adaptations that were produced over evolutionary time by the operation of natural selection, and they acquired their particular forms as solutions to evolutionarily long-enduring adaptive problems. Indeed, the origins of domain specificity can be located in the evolutionary process, in the selective advantages conferred by functional design in adaptive problem solving.

Despite institutional histories to the contrary, anthropology and psychology cannot be seen as truly independent disciplines. The centerpiece of anthropological theory is the centerpiece of psychological theory: a description of the reliably developing architecture of the human mind, a collection of cognitive adaptations. These evolved problem solvers are the engine that link mind, culture, and the world. Domain-specific performance is the signature of these evolved mechanisms, a signature that can lead us to a comprehensive mapping of the human mind.

**Notes**

1. In certain situations two or more alternative designs can be stably maintained in a population through frequency-dependent selection, as in the case of contagion-retarding protein variation (Tooby, 1982). However, natural selection in interaction with sexual recombination tends to impose a specieswide uniformity in our complex adaptations, providing an explanation for the existence of a universally shared human nature (Tooby & Cosmides, 1990b). Nonfunctional traits can vary freely, but the developmental programs underlying our complex adaptations are constrained to be virtually species-typical.

2. In this equation, $C_i$ and $B_i$ refer to costs and benefits to individual $i$, measured as decreases and increases in $i$'s reproduction caused by the design feature in question. $r_{ij}$ — the coefficient of relatedness between individuals $i$ and $j$ — refers to the probability that $i$ and $j$ share the same design feature by virtue of common descent.

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