

## **Evolutionary psychology: Conceptual foundations**

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Note. We dedicate this chapter to Irven DeVore, Professor Emeritus, Department of Anthropology, Harvard University, on the occasion of his 70<sup>th</sup> birthday.

## Intellectual origins of evolutionary psychology

The theory of evolution by natural selection has implications for understanding the design of the human mind, and Darwin himself was the first to see this. During the 20<sup>th</sup> century, many thinkers tried to work out exactly how Darwin's fundamental insights could be used as a foundation on which to build a more systematic approach to psychology. This resulted in many valuable approaches: the instinct psychology of William James and William McDougall; human ethology, which applied the framework for studying how animals behave in their natural environment, developed by Karl von Frisch, Konrad Lorenz and Niko Tinbergen; Skinnerian psychology, which looked for phylogenetic continuities in the laws of learning that would apply across species; and sociobiology, which tried to understand patterns of social behavior—differences as well as universals—in humans and other primates in light of a set of exciting and rigorous new theories then emerging about how natural selection works. Our own early training included this last approach, which was flourescing in Irven DeVore's living room where Harvard's Simian Seminar was held during the 1970s and early 1980s.

DeVore was a pioneering thinker, deeply interested in human origins, who instigated and then championed the study of primate social behavior under natural conditions and the study of modern hunter-gatherers. Eschewing the "lone anthropologist" model, in which a single individual spends time learning "the" culture of a people, DeVore and his colleague, Richard Lee, innovated a team-based approach like that found in other sciences. Their Kalahari San project brought scientists and scholars from a vast array of disciplines—anthropologists, physicians, linguists, folklorists, psychologists, ethologists, archeologists—in an attempt to document as completely as possible the lifeways of the !Kung San people in Botswana's Kalahari desert, before hunting and gathering as a way of life vanished from the planet. DeVore did not do this because he thought the San's way of life was the single prototype for our hunter-gatherer ancestors or even the best example of the biotic environment in which humans evolved—he was well aware that the San had been pushed into one of the harshest and most unforgiving biotic environments on earth by the encroachment of agricultural populations. His goal in studying the San was to provide a detailed database which, when trianguated with other similarly detailed databases drawn from other hunter-gatherer groups, would allow new and powerful inferences to be made about human origins and behavior. Behavioral ecologists would be able to test optimal foraging models by matching foraging patterns to ecological conditions. Archaeologists could better interpret patterns found at ancestral sites by seeing patterns of campfires, animal remains, tool-making debris, and midden heaps produced by the social life of living hunter-gatherers. Physicians could gain insight into "diseases of civilization" by comparing diets and conditions in industrialized countries to the diets and stressors produced by a way of life that more closely resembles the conditions in which our species evolved. Developmental psychologists could understand more about the mother-infant bond and human attachment when babies are nursed and women are gathering food. Anthropologists could learn what social conditions foster risk-pooling and food sharing, what kinds of knowledge hunter-gatherers have about animal behavior and plant life, how they use this knowledge in foraging, and how people negotiate the stresses and pleasures of social life in a tiny community of extended families (see, e.g., Lee & DeVore, 1976; Shostak, 1981). Many of these ideas and insights are commonplace now: we all know, for example, that the lean meat, high fiber, low sugar diet of hunter-gatherers protects them from tooth decay, obesity, and heart disease (Eaton, Shostak, & Konner, 1988). But these ideas were revolutionary at the time, and DeVore was a

visionary who created an intellectual community at Harvard that was lighting the intellectual world on fire.

An astonishing procession of figures in evolutionary biology, behavioral ecology, primatology, and human ethology spoke at DeVore's Simian Seminar, sometimes staying for protracted periods, among them W.D. Hamilton, George Williams, Robert Trivers, John Maynard Smith, Richard Dawkins, Ernst Mayr, Edward O. Wilson, Richard Alexander, Tim Clutton-Brock, Paul Harvey, Joseph Shepher, Lionel Tiger, Robin Fox, Diane Fosse, Jane Goodall, Richard Wrangham, Robert Hinde, Richard Leakey, Martin Daly, and Margo Wilson. Among the undergraduate and graduate students present at these seminars were Sarah Blaffer Hrdy, Robert Sapolsky, Peter Ellison, Melvin Konner, Barbara Smuts, Steve Gaulin, ourselves—John Tooby and Leda Cosmides—and this Handbook's editor, David Buss, who was a newly-minted assistant professor at the time. Present in all of our minds were the lessons of George Williams' 1966 seminal volume, *Adaptation and Natural Selection: A critique of some current evolutionary thought*, in which he had clarified the logic of natural selection at the genic level, explained that not every beneficial effect is a function,<sup>i</sup> and developed strict evidentiary standards for deciding what aspects of a species' phenotype were adaptations, side-effects of adaptations, or noise.

The proliferation of game theoretic thinking and models of how natural selection should have shaped social behavior in various species was energizing. Hamilton's kin selection theory, Trivers' theories of parental investment and sexual selection, parent-offspring conflict, and reciprocal altruism, Maynard Smith's models of animal aggression—these theories resonated with what was then known about social behavior in many species, especially our own. Everyone present could see the potential these theories might have for explaining social behavior. These component theories became fully incorporated into evolutionary biology and behavioral ecology. By the mid-1980s, they were completely mainstream, applied on a routine basis to nonhuman animals. The field that became known as human sociobiology involved tracking correspondances between social behavior in various cultures and the variables identified by these theories, often in enlightening ways. At the same time, some other, deeply flawed conceptual and empirical approaches were being pursued in the name of human sociobiology.<sup>ii</sup> The flaws were productive however: they shone light on conceptual wrong turns, in this case revealing a missing piece of the puzzle.

There was a missing level of explanation without which the application of Darwin's theory to humans could never achieve the necessary level of scientific precision. Natural selection does not operate on behavior *per se*; it operates on a *relationship* between information and behavior. Running—a behavior—is neither good nor bad: running away from a lion can promote survival and reproduction, running toward a lion will curtail both. To be adaptive, behavioral responses should be contingent on information: for example, *flee when you see a stalking lion*. But a systematic relationship between information and a behavioral response cannot occur unless some piece of organic machinery *causes* it. These causal relations between information and behavior are created by neural circuits in the brain, which function as programs that process information. By altering the neural circuitry that develops, mutations can alter the information-processing properties of these programs, creating alternative information-behavior relationships. As a result, a different configuration of information may be required to elicit the response (e.g., *flee if you see a lion* versus *flee only if you see a lion and it has seen you*) or the same information may elicit a different response (e.g., *if you see a lion and it has not seen you, hide* (rather than flee)). Selection should retain or discard alternative circuit designs from a

species' neural architecture on the basis of how well the information-behavior relationships they produce promote reproduction. Those circuit designs that promote their own reproduction will be retained and spread, becoming species-typical; those that do not will eventually disappear from the population. The human brain is packed with programs that cause intricate relationships between information and behavior, including functionally specialized learning systems, domain-specialized rules of inference, default preferences that are adjusted by experience, complex decision rules, concepts that organize our experiences and databases of knowledge, and vast databases of acquired information stored in specialized memory systems—remembered episodes from our lives, encyclopedias of plant life and animal behavior, banks of information about other people's proclivities and preferences, and so on. All of these programs and the databases they create can be called on in different combinations to elicit a dazzling variety of behavioral responses. These responses are themselves information, subsequently ingested by the same evolved programs, in endless cycles that produce complex eddies, currents, even singularities in cultural life. To get real purchase on human behavior and society, one needs to know the architecture of these evolved programs. Knowing the selection pressures will not be enough. Our behavior is not a direct response to selection pressures or to a "need" to increase our reproduction.<sup>ii</sup> Behavior in the present is a response to information the individual encounters in the present. But information-behavior relationships in the present are caused by evolved programs that acquired their design in response to selection pressures from an ancestral past. This realization was the birth of evolutionary psychology (Symons, 1979; Daly & Wilson, 1983, 1988; Tooby, 1985; Cosmides, 1985; Cosmides & Tooby, 1987; Tooby & Cosmides, 1992).

Evolutionary psychology's focus on programs—on psychological mechanisms—was motivated by new developments from a series of different fields:

- Advance #1.* The cognitive revolution was providing, for the first time in human history, a precise language for describing mental mechanisms, as programs that process information.
- Advance #2.* Advances in paleoanthropology, hunter-gatherer studies and primatology were providing data about the adaptive problems our ancestors had to solve to survive and reproduce and the environments in which they did so.
- Advance #3.* Research in animal behavior, linguistics, and neuropsychology was showing that the mind is not a blank slate, passively recording the world. Organisms come "factory-equipped" with knowledge about the world, which allows them to learn some relationships easily, and others only with great effort, if at all. Skinner's hypothesis—that there is one simple learning process governed by reward and punishment—was wrong.
- Advance #4.* Evolutionary game theory was revolutionizing evolutionary biology, placing it on a more rigorous, formal foundation of replicator dynamics. This clarified how natural selection works, what counts as an *adaptive* function, and what the criteria are for calling a trait an *adaptation*.

Ethology had brought together advances 2 and 3, sociobiology had connected advances 2 and 4, sometimes with 3. Evolutionary psychology brought all four advances together, connecting the evolutionary sciences with the cognitive revolution in the ways we describe below. The causal connections between these four advances must be made carefully and seen clearly. If done properly, we thought these new developments could be pieced together into a single integrated research framework, in a way that had not been exploited before because the connections ran

between fields rather than cleanly within them. This framework became known as *evolutionary psychology*.<sup>iii</sup>

### Evolutionary psychology

The goal of research in evolutionary psychology is to discover, understand, and map in detail the design of the human mind, as well as to explore the implications of these new discoveries for other fields. The eventual aim is to map “human nature”—that is, the species-typical information-processing architecture of the human brain.

Like all cognitive scientists, when evolutionary psychologists refer to “the mind”, they mean the set of information-processing devices, embodied in neural tissue, that are responsible for all conscious and nonconscious mental activity, and that generate all behavior. And like other psychologists, evolutionary psychologists test hypotheses about the design of these information-processing devices—these programs—using laboratory methods from experimental cognitive and social psychology, developmental psychology, experimental economics, cognitive neuroscience, and cross-cultural field work.

What allows evolutionary psychologists to go beyond traditional approaches in studying the mind is that they make active use in their research of an often overlooked fact: That the programs comprising the human mind were designed by natural selection to solve the adaptive problems faced by our hunter-gatherer ancestors—problems like finding a mate, cooperating with others, hunting, gathering, protecting children, avoiding predators, and so on. Natural selection tends to produce programs that solve problems like these reliably, quickly, and efficiently. Knowing this allows one to approach the study of the mind like an engineer. You start with a good specification of an adaptive information-processing problem, then you do a task analysis of that problem. Task analysis allows you to see what properties a program would have to have in order to solve that problem well. This approach allows you to generate hypotheses about the structure of the programs that comprise the mind, which can then be tested.

From this point of view, there are precise causal connections that link the four developments above into a coherent framework for thinking about human nature and society (Tooby & Cosmides, 1992). These connections (C-1 through C-6) are as follows:

C-1. Each organ in the body evolved to serve a function: the intestines digest, the heart pumps blood, the liver detoxifies poisons. The brain is also an organ, and its evolved function is to extract information from the environment and use that information to generate behavior and regulate physiology. From this perspective, the brain is a computer, that is, a physical system that was designed to process information (*Advance #1*). Its programs were designed not by an engineer, but by natural selection, a causal process that retains and discards design features on the basis of how well they solved problems that affected reproduction in past environments (*Advance #4*).

The fact that the brain processes information is not an accidental side-effect of some metabolic process: The brain was designed by natural selection *to be* a computer. Therefore, if you want to describe its operation in a way that captures its evolved function, you need to think of it as composed of programs that process information. The question then becomes, what programs are to be found in the human brain? What are the reliably developing, species-typical programs that, taken together, comprise the human mind?

C-2. Individual behavior is generated by this evolved computer, in response to information that it extracts from the internal and external environment (including the social environment) (*Advance #1*). To understand an individual's behavior, therefore, you need to know both the information that the person registered *and* the structure of the programs that generated his or her behavior.

C-3. The programs that comprise the human brain were sculpted over evolutionary time by the ancestral environments and selection pressures experienced by the hunter-gatherers from whom we are descended (*Advances #2 and #4*). Each evolved program exists because it produced behavior that promoted the survival and reproduction of our ancestors better than alternative programs that arose during human evolutionary history. Evolutionary psychologists emphasize hunter-gatherer life because the evolutionary process is slow—it takes thousands of years to build a program of any complexity. The industrial revolution—even the agricultural revolution—are mere eyeblinks in evolutionary time, too short to have selected for new cognitive programs of any complexity.<sup>iv</sup>

C-4. Although the behavior our evolved programs generate would, on average, have been adaptive (reproduction-promoting) in ancestral environments, there is no guarantee that it will be so now. Modern environments differ importantly from ancestral ones, particularly when it comes to social behavior. We no longer live in small, face-to-face societies, in semi-nomadic bands of 50-100 people, many of whom were close relatives. Yet our cognitive programs were designed for that social world.

C-5. Perhaps most importantly, the brain must be comprised of many different programs, each specialized for solving a different adaptive problem our ancestors faced. That is, the mind cannot be a blank slate (*Advance #3*).

In fact, the same is true of any computationally powerful, multi-tasking computer. Consider the computer in your office. So many people analyze data and write prose that most computers come factory-equipped with a spreadsheet and a text-editor. These are two separate programs, each with different computational properties. This is because number-crunching and writing prose are very different problems: the design features that make a program good at data analysis are not well-suited to writing and editing articles, and vice versa. To accomplish both tasks well, the computer has two programs, each well-designed for a specific task. The more functionally specialized programs it has, the more intelligent your computer is: the more things it can do. The same is true for people.

Our hunter-gatherer ancestors were, in effect, on a camping trip that lasted a lifetime, and they had to solve many different kinds of problems well to survive and reproduce under those conditions. Design features that make a program good at choosing nutritious foods, for example, will be ill-suited for finding a fertile mate. Different problems usually require different evolved solutions.

This can be most clearly seen by using results from evolutionary game theory (*Advance #4*) and data about ancestral environments (*Advance #2*) to define adaptive problems, and then carefully dissecting the computational requirements of any program capable of solving those problems. For example, game theoretic analyses of conditional helping show that programs designed for logical reasoning would be poorly-designed for detecting cheaters in social

exchange, and vice versa; this incommensurability selected for programs that are functionally specialized for reasoning about reciprocity or exchange (Cosmides & Tooby, this volume).

C-6. Lastly, if you want to understand human culture and society, you need to understand these domain-specific programs. The mind is not like a video camera, passively recording the world but imparting no content of its own. Domain-specific programs organize our experiences, create our inferences, inject certain recurrent concepts and motivations into our mental life, give us our passions, and provide cross-culturally universal frames of meaning that allow us to understand the actions and intentions of others. They cause us to think certain very specific thoughts; they make certain ideas, feelings, and reactions seem reasonable, interesting, and memorable. Consequently, they play a key role in determining which ideas and customs will easily spread from mind to mind, and which will not (Boyer, 2001). That is, they play a crucial role in shaping human culture.

Instincts are often thought of as the diametric opposite of reasoning, decision-making, and learning. But the reasoning, decision-making, and learning programs that evolutionary psychologists have been discovering (i) are complexly specialized for solving an adaptive problem; (ii) they reliably develop in all normal human beings; (iii) they develop without any conscious effort and in the absence of formal instruction; (iv) they are applied without any awareness of their underlying logic, and (v) they are distinct from more general abilities to process information or behave intelligently. In other words, they have all the hallmarks of what we usually think of as an instinct (Pinker, 1994). In fact, one can think of these specialized circuits as *reasoning instincts*, *decision instincts*, *learning instincts*. They make certain kinds of inferences and decisions just as easy, effortless and “natural” to us as humans as catching flies is to a frog or building nests is to a robin.

Consider this example from the work of Simon Baron-Cohen (1995), using the Charlie task. A child is shown a schematic face (“Charlie”) surrounded by four different kinds of candy. Charlie’s eyes are pointed toward the Milky Way bar (for example). The child is then asked, “Which candy does Charlie want?” Like you and me, a normal 4 year old will say that Charlie wants the Milky Way (the candy Charlie is looking at). In contrast, children with autism fail the Charlie task, producing random responses. However, when asked which candy Charlie is looking at, children with autism answer correctly. That is, children with this developmental disorder can compute eye direction correctly, *but they cannot use that information to infer what someone wants*.

We know, spontaneously and with no mental effort, that Charlie *wants* the candy he is *looking at*. This is so obvious to us that it hardly seems to require an inference at all. It is just common sense. But “common sense” is caused: it is produced by programs, cognitive mechanisms. To infer a mental state (*wanting*) from information about eye direction requires a computation. There is little inference circuit—a reasoning instinct—that produces this inference. When the circuit that does this computation is broken or fails to develop, the inference cannot be made. Those with autism fail the Charlie task because they lack this reasoning instinct.

Reasoning instincts are invisible to our intuitions, even as they generate them—no more accessible to consciousness than retinal cells and line detectors, but just as important in manufacturing our perceptions of the world. As a species, we have been blind to the existence of these instincts, not because we lack them but precisely because they work so well. Because they process information so effortlessly and automatically, their operation disappears unnoticed into

the background. These instincts structure our thought so powerfully that it can be difficult to imagine how things could be otherwise. As a result, we take normal behavior for granted: We do not realize that normal behavior needs to be explained at all.

As behavioral scientists, we need corrective lenses to overcome our instinct blindness. The brain is fantastically complex, packed with programs, most of which are currently unknown to science. Theories of adaptive function can serve as corrective lenses for psychologists, allowing us to see computational problems that are invisible to human intuition. When carefully thought out, these functional theories can lead us to look for programs in the brain that no one had previously suspected.

## **Principles of Organic Design**

### **Natural selection is an engineer that designs organic machines**

The phenomenon that Darwin was trying to explain is the presence of functional organization in living systems—the kind of organization that one finds in artifacts, such as clocks, spectacles, or carriages, that were designed by an intelligent engineer to solve a problem. Darwin realized that you can think of an organism as a *self-reproducing machine*. What distinguishes living from nonliving machines is reproduction: the presence in a machine of devices (organized components) that cause it to produce new and similarly reproducing machines. Given a population of living machines, this property—self-reproduction—drives a system of positive and negative feedback—natural selection—that can explain the remarkable fit between the design of organisms and the problems they must solve to survive and reproduce.

In contrast to human-made machines, which are designed by inventors, living machines acquire their intricate functional design over deep time, as a downstream consequence of the fact that they reproduce themselves. Indeed, modern Darwinism has an elegant deductive structure that logically follows from Darwin's initial insight that reproduction is the defining property of life, the driving force that causes species to change over time. That logic is as follows:

When an organism reproduces, replicas of its design features—its functional components—are introduced into its offspring. But the replication of the design of the parental machine is not always error-free. As a result, randomly modified designs (i.e., mutants) are introduced into populations of reproducers. Because living machines are already exactly organized so that they cause the otherwise improbable outcome of constructing offspring machines, random modifications will usually introduce disruptions into the complex sequence of actions necessary for self-reproduction. Consequently, most newly modified but now defective designs will remove themselves from the population: a case of negative feedback.

However, a small number of these random design modifications will, by chance, improve the system's machinery for causing its own reproduction. Such improved designs (by definition) cause their own increasing frequency in the population: a case of positive feedback.

This increase continues until (usually) such modified designs outreproduce and thereby replace all alternative designs in the population, leading to a new species-standard design: a new model retina or blood cell or reasoning circuit or preference ordering. After such an event, the population of reproducing machines is different from the ancestral population: The population- or species-standard design has taken a step “uphill” toward a greater degree of functional organization for reproduction than it had previously. Over the long run, down chains of descent, this feedback cycle pushes designs through state-space toward increasingly well-engineered—and increasingly improbable—functional



arrangements. These arrangements are *functional* in a specific sense: the elements are well-organized to cause their own reproduction in the environment in which the species evolved.

For example, if a mutation appeared that caused individuals to find family members sexually repugnant, then they would be less likely to conceive children incestuously. They will produce children with fewer genetic diseases, more of these children will mature and reproduce than will the children of those who are not averse to incest. Such an incest-avoiding design will produce a larger set of healthy children every generation, down the generations. By promoting the reproduction of its bearers, the incest-avoiding circuit thereby promotes its own spread over the generations, until it eventually replaces the earlier-model sexual circuitry and becomes a universal feature of that species' design. This spontaneous feedback process—natural selection—causes functional organization to emerge naturally and inevitably, without the intervention of an intelligent designer or supernatural forces.

**Genes and design.** Genes are simply the means by which design features replicate themselves from parent to offspring. They can be thought of as particles of design: elements that can be transmitted from parent to offspring, and that, together with stable features of an environment, cause the organism to develop some design features and not others. Genes have two primary ways they can propagate themselves: By increasing the probability that offspring will be produced by the organism in which they are situated, or by that organism's kin.

An individual's genetic relatives carry some of the same genes, by virtue of having received some of the same genes from a recent common ancestor. This means that a gene in an individual that causes an increase in the reproductive rate of that individual's kin will, by so doing, tend to increase its own frequency in the population. A circuit that motivates an individual to help feed her sisters and brothers, if they are starving, is an example of a program that increases kin reproduction. As Hamilton (1964) pointed out, design features that promote both direct reproduction and kin reproduction, and that make efficient trade-offs between the two, will replace those that do not (a process called *kin selection*).

**Reproduction and function.** How well a design feature systematically promotes direct and kin reproduction is the bizarre but real engineering criterion determining whether a specific design feature will be added to or discarded from a species' design. Therefore, we can understand why our brains are constructed in the way they are, rather than in other perfectly possible ways, when we see how its circuits were designed to cause behavior that, in the world of our ancestors, led to direct reproduction or kin reproduction.

The concept of *adaptive behavior* can now be defined with precision. Adaptive behavior, in the evolutionary sense, is behavior that tended to promote the net lifetime reproduction of the individual or that individual's genetic relatives. By promoting the replication of the genes that built them, circuits that—systematically, and over many generations—cause adaptive behavior become incorporated into a species' neural design. In contrast, behavior that undermines the reproduction of the individual or his or her blood relatives removes the circuits causing those behaviors from the species, by removing the genes that built those circuits. Such behavior is *maladaptive*, in the evolutionary sense.

Evolutionists analyze how design features are organized to contribute to lifetime reproduction because reproduction was the final causal pathway through which a functionally improved design feature caused itself to become more numerous with each passing generation, until it became standard equipment in all ordinary members of the species.

**Adaptive problems select for adaptations.** Darwin's detailed studies of plants and animals revealed complex structures composed of parts that appeared to be organized to

overcome reproductive obstacles (e.g. the presence of predators) or to take advantage of reproductive opportunities (e.g. the presence of fertile mates). Enduring conditions in the world that create reproductive opportunities or obstacles constitute *adaptive problems*, such as the presence of pathogens, variance in the food supply, the vulnerability of infants, or the presence of family in one's social group. Adaptive problems have two defining characteristics. First, they are conditions or cause-and-effect relationships that many or most individual ancestors encountered, reappearing again and again during the evolutionary history of the species, such that natural selection has enough time to design adaptations in response. Second, they are that subset of enduring relationships that could, in principle, be exploited by some property of an organism to increase its reproduction or the reproduction of its relatives. Alternative designs are retained or discarded by natural selection on the basis of *how well they function as solutions to adaptive problems*.

Over evolutionary time, more and more design features accumulate that fit together to form an integrated structure or device that is well-engineered to solve its particular adaptive problem. Such a structure or device is called an *adaptation*. Indeed, an organism can be thought of as a collection of adaptations. The functional subcomponents of the ear, hand, intestines, uterus, or circulatory system are examples. Each of these adaptations exists in the human design now because it contributed to the process of self and kin reproduction in the ancestral past. Adaptive problems are the only kind of problem that natural selection can design machinery for solving.

**The environment of evolutionary adaptedness.** One key to understanding how the modern mind works is to realize that its programs were not designed to solve the problems of a modern member of industrial society. Instead, they were designed to solve adaptive problems of our hunter-gatherer ancestors. The second key is to understand that the developmental processes that build each program, as well as each program in its mature state, evolved to use information and conditions that were reliably present in ancestral environments. The design of each adaptation assumes the presence of certain background conditions, and operates as a successful problem-solver only when those conditions are met. The *environment of evolutionary adaptedness*, or EEA, refers jointly to the problems hunter-gatherers had to solve and the conditions under which they solved them.

Although the hominid line is thought to have originated on the African savannahs, the EEA is not a particular place or time. After all, different groups of ancestors faced different conditions at various times and places. The EEA is an adaptation-specific concept: it is the statistical composite of all the selection pressures or cause-and-effect relationships that pushed the genes underlying an adaptation upwards in frequency until they became species-typical (as most adaptations are) (see Hagen, this volume). Because adaptations evolved and assumed their modern form at different times, and because different aspects of the environment were relevant to the design of each, the EEA for one adaptation may be somewhat different from the EEA for another. Conditions of terrestrial illumination, which form (part of) the EEA for the vertebrate eye, remained relatively constant for hundreds of millions of years—and can still be observed by turning off all artificial lights. In contrast, the social and foraging conditions that formed (part of) the EEA that selected for neural programs that cause human males to provision and care for their offspring (under certain conditions) may be less than two million years old.

When a program is operating outside the envelope of ancestral conditions that selected for its design, it may look like a kludgey, poorly engineered problem-solver. Efficient foraging, for example, requires good probability judgments, yet laboratory data suggested that people are

poor intuitive statisticians, incapable of making simple inferences about conditional probabilities (Kahneman, Slovic & Tversky, 1982). This was strange given that birds and bees solve similar problems with ease. The paradox evaporates when one considers the EEA for probability judgment. Behavioral ecologists presented birds and bees with information in ecologically valid formats; psychologists studying humans were not doing the same.

Being mindful of the EEA concept changes how research is designed and what is discovered. Giving people probability information in the form of absolute frequencies—an ecologically valid format for hunter-gatherers—reveals the presence of mechanisms that generate sound Bayesian inferences (Brase, Cosmides & Tooby, 1998; Cosmides & Tooby, 1996; Gigerenzer, 1991; Gigerenzer, Todd et al., 1999). Indeed, EEA-minded research on judgment under uncertainty is now showing that the human mind is equipped with a toolbox of “fast-and-frugal heuristics”, each designed to make well-calibrated judgments quickly on the basis of limited information (Gigerenzer, Todd, et al., 1999; Gigerenzer & Selten, 2002; Todd, this volume). These procedures are *ecologically rational*, providing good solutions when operating in the task environments for which they evolved (Tooby & Cosmides, in press).

**Knowing the past.** It is often argued that we can know nothing about the past that is relevant to psychology because behavior doesn't fossilize, and so the whole field rests on uncertain speculation or conjecture. But we know with certainty thousands of important things about our ancestors, many of which can be useful in guiding psychological research. Some of these should be obvious, although their implications may not be. For example, it is a certainty that our ancestors lived in a world in which certain principles of physics governed the motions of objects: facts that allowed Shepard (1984, 1987) to discover how the mind represents the motion of objects, both in perception and imagination. It is equally certain that hominids had eyes, looked at what interested them, and absorbed information about what they were looking at, making eye-gaze direction informative to on-lookers: facts that helped Baron-Cohen (1995) to create a subtle and far-reaching research program on mindreading, the ability to infer the mental states of others. It is certain that our ancestors, like other Old World primates, nursed, had two sexes, chose mates, had color vision calibrated to the spectral properties of sunlight, lived in a biotic environment with predatory cats, venomous snakes, and spiders, were predated upon, bled when wounded, were incapacitated from injuries, were vulnerable to a large variety of parasites and pathogens, and had deleterious recessives rendering them subject to inbreeding depression if they mated with siblings. All of these conditions are known, and all pose adaptive problems. By considering these selection pressures, a careful, intelligent thinker can develop plausible, testable theories of the adaptations that arose in response to them.

By triangulating the work of researchers in many disciplines, many other sound inferences can be made. Behavioral ecologists and evolutionary biologists have already created a library of sophisticated models of the selection pressures, strategies and trade-offs that characterize very fundamental adaptive problems (*Advance 4*), which they use in studying processes of attention, memory, decision-making and learning in non-human animals. Which model is applicable for a given species depends on certain key life-history parameters. Findings from paleoanthropology, hunter-gatherer archaeology, and studies of living hunter-gatherer populations locate humans in this theoretical landscape by filling in the critical parameter values (*Advance 2*). Ancestral hominids were ground-living primates; omnivores<sup>v</sup>, exposed to a wide variety of plant toxins and meat-borne bacteria, and having a sexual division of labor between hunting and gathering; mammals with altricial young, long periods of biparental investment in offspring, enduring male-female mateships, and an extended period of physiologically obligatory

female investment in pregnancy and lactation. They were a long-lived, low-fecundity species in which variance in male reproductive success was higher than variance in female reproductive success. They lived in small nomadic kin-based bands often of 20-100; they would rarely (if ever) have seen more than 1000 people at one time; they had little opportunity to store provisions for the future; they engaged in cooperative hunting, defense and aggressive coalitions; they made tools and engaged in extensive amounts of cooperative reciprocation. When these parameters are combined with formal models from evolutionary biology and behavioral ecology, a reasonably consistent picture of ancestral life begins to appear (e.g., Tooby & DeVore, 1987). From this, an intelligent scientist can refine theories of adaptive problems, develop models of their computational requirements, and test for the presence of mechanisms equipped with design features that satisfy these requirements. Most chapters in this volume provide examples of this process.

Many adaptive problems can be further illuminated by the use of evolutionary game theory (see Cosmides & Tooby, this volume) and/or optimal foraging models. For example, variance in the food supply can be buffered through food sharing, a method of pooling risk. But this is stable only when the variance is primarily due to luck rather than effort. Studies of modern hunter-gatherers have put quantitative estimates on how much variance there is in successfully finding different kinds of foods; for example, among the Ache of Paraguay, meat and honey are high variance foods even for skilled foragers, whereas the variance in gathering vegetable foods is low and comes from effort rather than luck. As one might predict from an analysis of the adaptive problems posed by variance in the food supply, Ache hunter-gatherers risk-pool with meat and honey by sharing widely at the band-level, but they share gathered vegetable foods only within nuclear families (Hill & Kaplan, 1985). This analysis suggests that our minds house at least two different decision rules for sharing, each creating a different sense of what is appropriate or fair, and each triggered by a different experience of variance (this, in turn, suggests that we have mechanisms sensitive to variance and its causes; e.g., Rode et al., 1999; Wang, 2002). These are very testable hypotheses.

Although behavioral scientists can be certain about a huge inventory of facts about the ancestral world that have not yet been harnessed to guide psychological research, certainty about the past is not necessary for building better hypotheses. One can derive valuable experimental hypotheses from possible rather than certain features of the ancestral world. The worst that will happen is that the hypothesis will be experimentally falsified—something that routinely happens to non-evolutionary researchers, who have no principled source from which to derive their hypotheses. There are, of course, many features of the ancestral world about which we are completely ignorant: These simply do not form the basis for experiments.

### **Psychology is reverse-engineering.**

As engineers go, natural selection is superlative. It has produced exquisitely engineered biological machines—the vertebrate eye, the four chambered heart, the liver and immune system—whose performance at solving problems is unrivaled by any machine yet designed by humans. (Consider the poor quality of machine vision compared to evolved vision, artificial pace-makers compared to the evolved system regulating the heart, pharmaceuticals with their negative side-effects compared to the body's immune and detoxification systems.)

Psychologists—evolutionary or otherwise—are engineers working in reverse. The brain/mind is a complex functional system, composed of programs whose design was engineered by natural selection to solve specific adaptive problems. Our job is to reverse-engineer the

human brain/mind: to dissect its computational architecture into functionally isolable information-processing units—programs—and to determine how these units operate, both computationally and physically. To arrive at the appropriate construal, one must conceptualize the cognitive architecture as composed of nonrandom parts that interact in such a way that they solve adaptive problems. *This requires theories of adaptive function.* These are engineering specifications, which provide analyses of what would count as good design for a particular problem. In so doing, they also provide the criteria necessary to decide whether a property of an organism is a design feature, a functionless byproduct, a kludge in the system, or noise.

**Many properties of organisms are not adaptations.** The cross-generationally recurrent design of an organism can be partitioned into (i) adaptations, which are present because they were selected for, (ii) byproducts of adaptations, which were not themselves targets of selection but are present because they are causally coupled to or produced by traits that were, and (iii) noise, which was injected by the stochastic components of evolution. Consider, for example, that all brain intact persons learn to speak (or sign) the language of their surrounding community without explicit instruction, whereas reading and writing require explicit schooling, are not mastered by every individual, and are entirely absent from some cultures. The neural programs that allow humans to acquire and use spoken language are adaptations, specialized by selection for that task (Pinker & Bloom, 1990; Pinker, 1994). But once an information-processing mechanism exists, it can be deployed in activities that are unrelated to its original function. Because we have evolved learning mechanisms that cause language acquisition, we can, through laborious study and schooling, learn to write and read. But the learning mechanisms that enable these activities were not selected for *because* they caused reading and writing. The ability to read and write are byproducts of adaptations for spoken language, enabled by their causal structure. Random evolutionary noise exists as well, an example being the gene variants that cause dyslexia—difficulties with learning to read.

Adaptations are present because of a prior history of selection. They are not defined as any ability or trait, however rare or modern, that is beneficial by virtue of enabling a particular individual to have more children. Suppose, for example, that a computer programmer were to become wealthy through writing code, and used that wealth to sire many children. This would not make computer programming, which is a very recent cultural invention, an adaptation, nor would it mean that the cognitive mechanisms that enable computer programming are adaptations designed *for producing computer programs*. The ability to write code is a beneficial side-effect of cognitive adaptations that arose to solve entirely different problems, ones that promoted reproduction in an ancestral past.<sup>vi</sup>

So, although selection creates functional organization, not all traits of organisms are functional. In fact most “parts” of an organism are not functional for a simple reason: Most ways of conceptually dissecting a species’ phenotype into parts will fail to capture functional components.<sup>vii</sup> To see the organization that exists in a complex system, one needs to be able to distinguish its functional components from the byproducts and noise.

With a well-specified theory of an adaptive problem, one can identify functional and nonfunctional parts of an organism. Of the three kinds of properties, adaptations are the most important and illuminating because they explain why a system has certain parts, why these participate in certain cause-and-effect relationships with one another, and why they interact with the world in the way that they do. Adaptations are problem-solving machines, and can be identified using design evidence: the same engineering standard one would use to test hypotheses about the function of a human-made machine.

## Design evidence

To determine a system's adaptive function, one needs to produce evidence of a fit between its design and the proposed function. This requires the application of engineering standards. As an analogy, consider the relation between design and function in human-made artifacts. A ceramic mug is made of an insulating material that does not dissolve or melt when it contacts hot drinks; its shape stably contains ~8 oz of liquid while allowing a mouth access to it; it has a heat-dissipating handle. These properties of a mug are *design features*: properties that exist *because* they are good solutions to the problem of drinking hot beverages without burning your hands.

These properties are unlikely to occur together by chance. Moreover, other uses to which mugs are put (e.g., paperweights, pencil holders) neither predict nor explain these features (paperweights need only be heavy; pencil holders must have a containing shape, but many materials will do and no handle is needed). A mug can produce many beneficial effects, but only one of these is its function, that is, the *explanation* for its design. We can tell which design explanation is correct by analyzing the fit between the mug's design and a proposed function. Mugs have many interlocking properties that are good solutions to the problem of drinking hot drinks and their properties are poorly explained by alternative theories of their function; that is how we know that they were designed *for that function*.

In the same way, design evidence is criterial for claiming that a property of an organism is an adaptation, whether that property is a knee, a heart, or a neural circuit that processes information. Does the organic machinery in question have properties that cause it to solve an adaptive problem precisely, reliably, and economically? If not, then its ability to solve the problem at issue may be incidental, a side-effect of a system that is well-designed to perform some alternative adaptive function (Williams, 1966). For example, zoologists found that nocturnal bats have a sonar system with many of the same intricate and interlocking features of human-engineered sonar and radar systems, including features that make bat sonar a good design for finding insects and avoiding obstacles at night (e.g., higher pulse rates when hunting small moving targets than when cruising; for discussion, see Dawkins, 1986.) At the same time, bat sonar is poorly suited for solving most other problems (e.g., judging the relative ripeness of fruit during the day). And there is no physical law or general metabolic process that produces bat sonar as a side-effect.

Finding and pursuing small flying food items in the dark without crashing into things poses intricate computational problems, which very few arrangements of matter can solve. The bat's sonar solves these problems well: there is a tight fit between the problems' requirements and the evolved solution. It is by virtue of this excellence in design that we recognize finding insects and avoiding obstacles at night as the adaptive function of bat sonar.

One can identify an aspect of an organism's physical, developmental, or psychological structure—its phenotype—as an adaptation by showing that (i) it has many design features that are improbably well-suited to solving an ancestral adaptive problem, (ii) these phenotypic properties are unlikely to have arisen by chance alone, and (iii) they are not better explained as the byproduct of mechanisms designed to solve some alternative adaptive problem, or some more inclusive class of adaptive problem. Finding that a reliably developing feature of the species' architecture solves an adaptive problem with reliability, precision, efficiency, and economy is *prima facie* evidence that one has located an adaptation. This is like showing that an oddly shaped piece of metal easily opens the lock on your front door: it is probably a key

designed for *your* door, because door locks are not easily opened by random bits of metal, by can-openers or candlesticks, or even by keys designed for other doors.

To show something is a byproduct, one must first establish that something else is an adaptation (e.g., blood as an oxygen transport system), and then show how the feature is a side-effect of the adaptation (e.g., the redness of blood is a side-effect of the oxygen-carrying iron in hemoglobin). Features that are uncoordinated with functional demands are evolutionary noise (e.g., the locations of freckles).

### **Theories of good design are a heuristic for discovery.**

If design evidence were important only for explaining why known properties of organisms have the form that they do (i.e., why is the lens of the eye transparent, rather than opaque), then its use in psychology would be limited. After all, most properties of the human mind are currently unknown. The concept of good design for solving an adaptive problem is important because it allows one to discover new mechanisms within the human mind. There is a systematic method for using theories of adaptive function and principles of good design for discovering new programs.

One starts with an adaptive problem encountered by human ancestors, including what information would potentially have been present in past environments for solving that problem. From this, one develops a task analysis of the kinds of computations necessary for solving that problem, concentrating on what would count as a well-designed program given the adaptive function under consideration. Based on this task analysis, one formulates hypotheses about what kind of programs might actually have evolved. Having done this, one tests for their presence experimentally, using methods from cognitive, social, and developmental psychology, cognitive neuroscience/ neuropsychology, experimental economics, cross-cultural studies—whichever methods are most appropriate for illuminating programs with the hypothesized properties. If the predicted properties are found, one also conducts tests to make sure they are not better explained by alternative hypotheses about the programs responsible. This includes tests to make sure the program in question is distributed cross-culturally in the way predicted by the theory, which may predict universality, different morphs triggered by different environmental or social conditions, or local calibration by specific circumstances.

Lieberman's work on the architecture of kin detection in humans provides an example of how this process of discovery can work (Lieberman, 2003; Lieberman, Tooby, & Cosmides, 2003, in press a-c). Avoiding the deleterious effects of inbreeding was an important adaptive problem faced by our hominid ancestors. The best way to avoid the costs of inbreeding is to avoid having sex with close blood relatives. This, in turn, requires a system for distinguishing close genetic relatives from other individuals: a kin detection system, which computes a kinship estimate for each individual with whom one lives in close association. Because genetic relatedness cannot be directly observed, one must ask what information relevant to estimating degrees of kinship would have been available to an ancestral hunter-gatherer. To be useful, kinship estimates would have to be based on cues that reliably predicted genetic relatedness in the social conditions under which our ancestors lived. For siblings, this could be duration of childhood co-residence (a good cue given that bands fission and fuse along nuclear family lines, such that full siblings stay together more than half-sibs, step-sibs, or cousins), being present when your mother gives birth to an infant (only effective for older siblings detecting younger ones), an olfactory signature indicating similarity of the major histocompatibility complex, and so on. Based on such cues, the kin detection system should compute a kinship estimate for

individuals in one's social world. This internal regulatory variable should serve as input to systems that compute the sexual value of an individual to oneself: all else equal, close blood relatives should be assigned a lower sexual value than unrelated people. This sexual value estimate—another internal regulatory variable—should regulate the motivational system that generates sexual attraction. All else equal, a low kinship estimate should upregulate sexual attraction whereas a high kinship estimate should downregulate sexual attraction, perhaps by activating disgust in response to the prospect of sex with that person. Data can be collected on the presence / absence of hypothesized cues to sibling relatedness, along with reactions to the prospect of sex with a given sibling. By determining in a quantitative way which potential cues to siblinghood predict disgust at the prospect of sex with a sibling and which do not, research can triangulate on which cues the kin detection system uses to compute a kinship estimate and how they are combined.

Note that by starting with an adaptive problem—inbreeding avoidance—and analyzing the computational requirements of a system that solves this problem, Lieberman and colleagues were led to posit a system that was previously unknown and uninvestigated by cognitive scientists, a kin detection system, including the developmental parameters it takes as input and which downstream systems its computational products should feed into. This model has guided their research; so far they have identified two cues used by the kin detection system—maternal perinatal association and duration of childhood co-residence—and shown that these cues regulate sexual disgust toward genetic relatives and kin-directed altruism as well (as predicted by Hamilton, 1964). The cues used by older siblings in detecting younger ones differ from those used by younger siblings detecting older ones. The results are incompatible with a variety of alternative theories that could be put forth to explain the results (e.g., Lieberman et al., 2003). So far, the pattern found holds in a variety of different cultural settings, consistent with the hypothesis that the kin detection system develops cross-culturally as a universal mechanism of the human mind.

It may not seem so at first glance, but notice that the kin detection system is a *learning mechanism*. Its function is to “learn” which individuals in one's environment are kin and which are not, and it is designed to make this categorization on the basis of certain cues present during development, while ignoring others. For example, one's consciously-held beliefs about who is a sibling do not predict degree of sexual aversion, once duration of childhood co-residence is controlled for (but co-residence does predict sexual aversion, controlling for beliefs about who is a sibling; Lieberman et al., 2003). The kin detection system is not, however, a *general-purpose* learning mechanism. It is highly specialized for a narrow task, and has nothing in common with mechanisms of classical and operant conditioning, the way facts are learned in school, or any other more general-purpose method of learning.<sup>viii</sup>

### **Nature and nurture: An adaptationist perspective**

To fully understand the concept of design evidence, we need to consider how evolutionary psychologists think about nature and nurture. Debates about the relative contribution (as it is misleadingly put) of genes and environment during development have been among the most contentious in psychology and in the discussion of human nature. The premises that underlie these debates are flawed, yet they are so deeply entrenched that many people, scientists and nonscientists alike, have difficulty seeing that there are better ways to think about these issues.



Rather than there being one nature-nurture issue, there are many independent issues but, unfortunately, they have become so tangled together that most discussions in psychology and the social sciences are hopelessly confused. We will try to pull the major questions apart, and look at them one by one. Some of them are conceptual confusions, whereas others are genuine scientific questions whose resolution will depend on research, rather than on clear thinking alone.

Despite widespread belief to the contrary, evolutionary psychology is not another swing of the nature/nurture pendulum. It shatters the traditional framework and the old categories entirely, rather than siding with any position within the old debate. Indeed, a defining characteristic of the field is the explicit rejection of the usual nature/nurture dichotomies—instinct versus reasoning, innate versus learned, biological versus cultural, nativist vs. environmentalist, socially determined vs. genetically determined, and so on—because they do not correspond to the actual distinctions that need to be made in the real world. Evolutionary psychologists do not see nature and nurture as in a zero sum relationship. As will become clear, nature and nurture exist in a positive sum relationship: more nature allows more nurture (Boyer, 2001).

**“Innate” is not the opposite of “learned”.** To begin with, everyone is a nativist, whether they know it or not. Even the most extreme advocates of the role of the environment in shaping human behavior, from Skinner to the post-modernists, make nativist claims about the “innate” structure of the evolved neural machinery that learns or responds to the environment. The only difference is whether they make the nature of their claims about this machinery explicit, or allow them to remain implicit, forcing the reader to deduce them from their arguments about why people act as they do.

Imagine that you are an engineer and your project is to create a brain that can learn. To be able to learn, this brain would have to have a certain kind of structure—after all, 3 pound cauliflowers do not learn, but 3 pound brains do. To get your brain to learn, you would have to arrange the neurons in particular ways: you would have to create circuits that cause learning to occur. In short, you would have to equip your brain with programs that *cause* it to learn. The same is true when natural selection is the engineer.

Even if a program that causes a particular kind of learning was itself learned, there had to be a prior program that caused that learning to occur, and so on. Logic forces us to conclude that there had to be, at some point in the causal chain, a program that caused learning but that was itself unlearned. These unlearned programs got into the brain by virtue of being part of its evolved architecture: they are programs that reliably develop across the ancestrally normal range of human environments.

This is a point on which both environmentalists and nativists must agree: Pavlov, Skinner, and Chomsky alike. They may disagree strongly about the computational structure of the evolved programs that cause learning, but not about whether evolved learning programs exist. Consider classical and operant conditioning. These are widely viewed as the simplest and most general forms of learning in humans and other animals. Yet even operant conditioning presumes the existence of evolved mechanisms that change the probability of a behavior by a certain amount, as a function of its consequences (and according to very precise equations). It also presumes that a handful of consequences—food, water, pain—are “intrinsically” reinforcing (i.e., the fact that these consequences are capable of changing the probability of a subsequent behavior is a design feature of the brain). Classical conditioning presumes the existence of a great deal of innate equipment: in addition to the programs that compute contingencies, the

animal is filled with unconditioned—that is, *unlearned*—responses, such as salivating in response to meat. Salivating in response to meat is considered to be part of the dog’s evolved architecture, and what the evolved learning program does is calculate when an arbitrary stimulus, such as a bell, predicts the appearance of the meat (Gallistel & Gibbons, 2000). So even in classical conditioning, the learned link between information and behavior—salivating to the sound of the bell—is caused by an evolved learning program, which takes as input both innate stimulus-response pairs (meat and salivation) and information from the external environment (the contingency between the sound of the bell and the appearance of meat). The only substantive disagreement between a Skinner and a Chomsky is about the structure of the evolved programs that cause learning.

Consequently, any learned behavior is the joint product of innate equipment interacting with environmental factors, and so cannot be solely attributed to the action of the environment on the organism. Thus “innate” cannot be the opposite of “learned”. It is just as mistaken to think of “evolved” as the opposite of “learned.” This is because our evolved learning programs were organized by evolution to learn some things and not others.

To say a behavior is learned in no way undermines the claim that the behavior was organized by evolution because the behavior was learned through the agency of evolved mechanisms. If natural selection had built a different set of learning mechanisms into an organism, that organism would learn a different set of behaviors in response to the very same environment. It is these evolved mechanisms that organize the relationship between the environmental input and behavioral output, and thereby pattern the behavior. For this reason, *learning is not an alternative explanation to the claim that natural selection shaped the behavior*, although many researchers assume that it is. The same goes for culture. Given that cultural ideas are absorbed via learning and inference—which is caused by evolved programs of some kind—a behavior can be, at one and the same time, “cultural”, “learned” and “evolved”. (For an excellent discussion of how evolved inference mechanisms produce and structure cultural transmission, see Boyer (2001)).

Moreover, there does not appear to be a single program that causes learning in all domains (consider kin detection, food aversions, snake phobias, and grammar acquisition). Evidence strongly supports the view that learning is caused by a multiplicity of programs (Gallistel, 2000). Without specifying which program is the cause, one has explained little, if anything, by invoking “learning” as an explanation for a behavior. Labeling something learning does not remove the requirement to spell out the evolved machinery involved; it only makes the weak claim that interaction with the environment participated in the process (which is always the case, anyway). In short, learning is a phenomenon that itself requires explanation. A coherent explanation for how people learn about a given domain must include (i) a description of what the evolved learning program looks like, (ii) why it came to have that structure, both developmentally and over evolutionary time, and (iii) what information is available to the organism that is executing that evolved program.

Of course, everyone is also an environmentalist, whether they know it or not. Even the most die-hard nativist understands that organisms learn—or, even more broadly, that an organism’s evolved mechanisms extract information from the environment and process it to regulate behavior. Hence the environment regulates behavior, and it is the presence of evolved mechanisms that makes this possible.

So evolved programs—instincts, if you will—are not the opposite of learning. They are the engines or programs through which learning takes place. We learn only through instincts—

learning and reasoning instincts. There are instincts in song birds for learning songs, instincts in geese for learning which individual is one's mother, instincts in desert ants for learning how to return home, and instincts in humans for learning a language. The more specialized learning programs we are equipped with, the more we can learn from experience.

**Specialized or general-purpose?** If the “innate versus learned” controversy is meaningless, there is a genuine and illuminating question to be answered: *What is the precise structure of these evolved learning and regulatory programs?* Are there many, or just a few? Which embody knowledge about enduring aspects of the world, and what knowledge do their procedures reflect? To what extent is a program—whether it governs learning or not—functionally specialized to produce the outcome that you have observed?

What effect a given environmental factor will have on an organism depends critically on the details of the designs of its evolved cognitive programs. So the discovery of their structure is a pivotal question. Indeed, one of the few genuine nature-nurture issues concerns the extent to which each evolved program is specialized for producing a given outcome (Symons, 1987). Most nature/nurture issues disappear when one understands more about evolution, cognitive science, and developmental biology, but this one does not.

So, the important question for any particular behavior is not “Is it learned” but “What kind of evolved programs produced it?” More specifically, “What is the nature of the universal, species-typical evolved cognitive programs through which one learns this particular type of behavior, acquires this kind of knowledge, or produces this form of behavior?”

For any given outcome, there are three alternative possibilities: (1) It is the product of domain-general programs; (2) it is the product of cognitive programs that are specialized for producing that outcome; or (3) it is a byproduct of specialized cognitive programs that evolved to solve a different problem.

The debate about language acquisition, which began in 1959 when Noam Chomsky reviewed (and panned) B. F. Skinner's book, *Verbal Behavior*, brings this issue into sharp focus, because Chomsky and Skinner disagreed about precisely these issues. Both sides in the ensuing controversy admit, as coherence demands, that the human mind contains innate learning programs. But the two camps differ in their answer to the question: Does a single set of general-purpose cognitive programs cause children to learn everything, with language as one incidental example? Or is language learning caused, in part or in whole, by programs that are specialized for performing this task: by what Chomsky called a *language acquisition device*?

Questions about functional specialization cannot be answered *a priori*, by theory or logic alone. Each proposal needs to be evaluated on its own merits. The theoretical tools and empirical studies necessary will differ, depending on whether the proposal is about language learning, inferring mental states, acquiring gender roles, developing friendships, eliciting jealousy, or something else. For language, thirty years of research supports the hypothesis that humans have evolved programs specialized for various aspects of language acquisition, although the debate remains heated (Pinker, 1994). With the emergence of evolutionary psychology, and under the weight of discoveries in many areas of biology, the debate over adaptive specializations has now widened to include all human competences. Is how people reason or feel about groups the product of general-purpose learning, or are there specializations for coalitional psychology? Are there specializations that govern how people learn and reason about exchange, threats, family relations, friendship, incest avoidance, and so on, or are these processes governed solely by general-purpose learning?

A key adaptationist insight offered by evolutionary psychology is that these learning and reasoning devices were themselves built by natural selection. They are systems of parts that fit together over our evolutionary history because they functioned to solve the actual set of adaptive problems that our ancestors faced. Like other adaptations, their detailed structures should reflect their evolved functions, and so knowing the adaptive problems they evolved to solve catapults us ahead in the enterprise of discovering their structures. The study of what hunter-gatherers had to learn about and reason about should help us reverse engineer the battery of human cognitive devices.

A central goal of evolutionary psychology is to inventory all of the learning programs—specialized or not—in the human cognitive architecture, and decode their structures to figure out how they work. If it turns out that at least some of these programs are specialized, with their own built-in content, then this will be a turning point in the history of the human sciences, because it will falsify assumptions, such as the belief in the blank slate, on which the modern social and behavioral sciences are built.

**Present at birth?** Sometimes people think that to show that a program is part of our evolved architecture, one needs to show that it is present from birth. Otherwise, the behavior is “learned” (by which they implicitly mean, learned through general-purpose processes). But this assumes that all of the evolved programs that cause development operate before birth, and none after birth.

This is clearly wrong. Teeth, breasts, and beards are all standard parts of our evolved architecture, but they develop after birth, 10 or 15 years after in the case of breasts and beards. Newborns lack teeth, but does this mean that infants and toddlers acquire their first set through learning? Does cultural pressure lead them to lose the first set in favor of the second?

Organs and design features can mature at any point of the life-cycle, and this applies to the cognitive programs in our brains just as much as it does to the features of our bodies. For this reason, the fact that a behavior emerges after birth tells one very little about how it was acquired or why it has a certain organization. Organs can be disassembled on schedule as well: consider the placenta, umbilical cord, and fetal haemoglobin. Evolutionists expect, and the evidence appears to bear them out, that many mechanisms will appear and disappear on a timetable based on when they would have been needed, under ancestral conditions, to solve the challenges of that life-stage. Infants need the sucking reflex; adolescents need sexual desires.

Presence at birth is only a function of what is needed at birth, not an indicator of whether something is or is not part of our evolved architecture. Accordingly, much of what is present in adult minds may have been put there by evolution, and activated through neural maturation, without depending on the accidents of personal experience. For example, infants who cannot crawl do not need a fear of heights, whereas infants who can crawl do. But experiments have demonstrated that a fear of heights is not learned by trial-and-error; rather, it is an evolved competence that is triggered when the baby starts to self-locomote, even if you contrive the situation such that the baby never experiences a fall (Campos, Bertenthal, & Kermoian, 1992).

Of course, the early presence of features is not completely irrelevant when evaluating alternative hypotheses about our evolved design. For example, the early emergence of a competence, before the social world could plausibly have acted, may falsify or undermine a particular social constructionist hypothesis. But the early *absence* of a competence does nothing by itself to undermine the claim that it is part of our evolved design.

**The twin fallacies of genetic determinism and environmental determinism.**

Traditional researchers hold a series of beliefs that are widely accepted and that sound eminently

reasonable, but that are based on a series of fallacies about how the world works. The first belief is that some behaviors are genetically determined whereas others are environmentally determined. The second is that evolutionary psychology only deals with behavior that is genetically determined, not the much larger set of behaviors that are environmentally determined. These beliefs are wrong for many reasons (Tooby & Cosmides, 1990a, 1992; Tooby, Cosmides, & Barrett, 2003), of which we will mention just two (see also Hagen, this volume).

First, genes are regulatory elements that use environments to construct organisms. Thus every single component of an organism is co-determined by the interaction of genes with environments. Moreover, some of those components are computational mechanisms, designed to produce behavior on the basis of information from the environment. Seen in this way, it is senseless to ask whether kin detection or language acquisition or snake phobias are caused by the genes or the environment: these phenomena are caused by evolved mechanisms that operate on information from the environment in particular ways, and these evolved mechanisms were themselves constructed by the interaction of genes with the environment.

Second, the view that evolutionary psychology deals only with “genetic” behaviors erroneously assumes that environmental causation is non-evolutionary. To see this, it is useful to distinguish between “the environment” in the sense of all properties of the universe and a species’ developmentally relevant environment—the set of properties of the world that affect the development of organisms of a given species.

Evolution acts *through* genes, but it acts on the *relationship* between the genes and the environment, choreographing their interaction to cause evolved design. Genes are the so-called units of selection, which are inherited, selected, or eliminated, and so they are indeed something that evolves. But every time one gene is selected over another, one design for a developmental program is selected as well. (If this is not clear, remember that we all start as a single cell—brainless, limbless, gutless. Every cell and organ system subsequently develops from that cell, and there must be processes that cause this to happen: developmental programs.) Developmental programs, by virtue of their design, make some parts of the world relevant to development, and other parts irrelevant. Over evolutionary time, genetic variation in developmental programs (with selective retention of advantageous variants) explores the properties of the environment, discovering those that are useful sources of information in the task of regulating development and behavior, and rendering those features of the environment that are unreliable or disruptive irrelevant to development. Step by step, as natural selection constructs the species’ gene set (chosen from the available mutations), it selects in tandem which enduring properties of the world will be relevant to development. Thus a species’ *developmentally relevant environment*—that set of features of the world that a zygote and the subsequently developing organism depend on or use as inputs—is just as much the creation of the evolutionary process as the genes are. The evolutionary process can be said to store information necessary for development in both the environment and the genes.

The developmentally relevant environment can be viewed as a second system of inheritance comparable in some ways to genetic systems of inheritance. A zygote in an environment can be seen as inheriting a set of genetic determinants (including cellular machinery), and simultaneously a set of environmental determinants. The environmental determinants are transmitted or inherited in a peculiar fashion: they simply endure as physical arrangements in the world across generations over the range where the lineal series of zygotes appear. Some environmental determinants are perfectly replicated across generations (e.g., the

three dimensional nature of space, the properties of light, the properties of chemical compounds, the presence of other humans (for a zygote that survives)); others are replicated reliably but imperfectly (e.g., mother smiling in response to an infant's smile; the presence of fathers during childhood; a correlation between duration of childhood co-residence with genetic relatedness; cycles of drought and rain). Organismic designs successfully reproduce based on the degree to which their genetic and environmental inheritances are coordinated with each other. Change in either inheritance (either through genetic mutation or environmental change) disrupts the coordination, and the greater or more rapid the change, the greater the disruption.

Obviously, this view of development is not gene-centered or a form "genetic determinism" if by that one means the idea that genes by themselves determine everything, immune from environmental influence, or even that genes determine "more" than the environment does. Although not gene-centered, however, this view is very much natural selection centered, because it is natural selection that chooses some genes rather than others, and in so doing orchestrates the interaction between the two inheritances so that high degrees of recurrent functional order can emerge and persist, such as eyes or maternal love.

Moreover, this view explains how reliable development both can and does ordinarily occur—that is, it explains why a robust, species-typical design emerges in almost all individuals (e.g., what can be seen in *Gray's Anatomy*). The species-typical features of the genome interact with the features of evolutionarily long-enduring, species-typical environments to produce the species-typical design observable in all of us. Failures of reliable development are attributable to genetic mutation, to environmental mutation (change), or both.

The closest that the world actually comes to the fallacious distinction between biologically or genetically determined traits versus environmentally or socially determined traits is in the following real distinction: Some neural programs were designed by natural selection to take in substantial amounts of environmental input (e.g., the language acquisition device) whereas others were designed to take in less information (e.g., the reflex that causes the eye to blink in response to a looming figure). But in all cases, there is an underlying neural program designed by natural selection, and a set of environmental regularities necessary for that program's reliable development. Indeed, as we will see later, there is not a zero-sum relationship between nature and nurture: more nature means more nurture.

**Universal architectural design versus genetic differences.** How are we to reconcile the claim that there is a universal species-typical design—including a universal human nature—with the existence of individual differences, especially those caused by genetic differences between people?

At a certain level of abstraction, every species has a universal, species-typical evolved architecture. For example, we humans all have a heart, two lungs, a stomach, and so on. This is not to say there is no biochemical individuality, especially in quantitative features: stomachs, for example, vary in size, shape, and amount of hydrochloric acid produced. Yet all stomachs have the same basic *functional* design: they are attached at one end to an esophagus and at the other to the small intestine, they secrete the same chemicals necessary for digestion, they are made of the same cell types, and so on. Indeed, when humans are described from the point of view of their complex adaptations, differences tend to disappear, and a universal architecture emerges. This is theoretically predicted, empirically true (*Gray's Anatomy* describes this architecture in minute detail), and expected to be reflected at the genetic level through a largely universal and species-typical genetic architecture ("the" human genome).

The logic is as follows (see Tooby & Cosmides, 1990a and Tooby, 1982 for a more complete explanation):

1. Complex adaptations are intricate machines. Adaptations that consist of complexly structured functional elements require, in turn, complex specification at the genetic level. That is, they require coordinated gene expression, often involving hundreds or even thousands of genes to regulate their development.
2. Like any other intricate machine, the parts of a complex adaptation must all be present and fit together precisely if the adaptation is to work properly. Parts of complex adaptations are functionally interdependent. This means that all the genes necessary to build each component part and assemble them correctly must be reliably brought together in the same individual. This is not a problem for organisms that reproduce by cloning, but it is for sexual reproducers.
3. Each new human originates sexually: a randomly selected half of the mother's genes is recombined with a randomly selected half of the father's genes. During gamete and zygote formation, sexual reproduction automatically breaks apart existing sets of genes and randomly generates in the offspring new combinations at those loci that vary from individual to individual. This would not be a problem if the mother and father were genetically identical at all loci. But it is a problem to the extent that their genes differ at those loci underlying complex adaptations.
4. Hence, the successful assembly of a complex adaptation in a new individual requires that all of the genes necessary for that adaptation be supplied by the two gametes, even though gametes are both randomly generated, and consist of only half of each parent's DNA. Successful assembly would not be possible if only some individuals in the population had the complex adaptation (and the suite of genes that specified all of its necessary component parts). If in a given generation, different individuals had different complex adaptations, each of which was coded for by a different suite of genes, then during the formation of the gametes for the next generation the random sampling of subsets of the parental genes would break apart each suite. During zygote formation, these incomplete specifications of incompatible adaptations would be shuffled together. Consequently, the offspring generation would be a handicapped jumble of pieces of functionally incompatible adaptations. The simultaneous demand for functional compatibility of complex adaptations and sexual reproduction places strong constraints on the nature and distribution of functional variation.
5. Specifically, the only way that each generation can be supplied with the genetic specification for complex adaptations is if the entire suite of genes necessary for coding for each complex adaptation is effectively universal, and hence reliably supplied by each parent regardless of which genes are sampled. By analogy, if you attempted to build a new car engine by randomly sampling parts from two parent cars, you would fail if one parent were a Toyota and the other a Jaguar. To build a new engine whose component parts fit together, you would have to salvage parts from two parents that were of the same make and model.
6. By the same token, sexually reproducing populations of organisms freely tolerate genetic variation to the extent that this variation does not impact the complex adaptive organization shared across individuals. To return to the car engine example, the color of the parts is functionally irrelevant to the operation of the car and so can vary arbitrarily and superficially among cars of the same make and model. But the shapes of the parts are critical to functional performance and so cannot vary if the offspring design is to function successfully.
7. The constraint of functional universality applies to only adaptations whose genetic basis is complex – that is, whose genetic basis involves multiple independently segregating loci. This selection pressure starts when there are two independent loci, and becomes combinatorially more

powerful with each additional locus. However, if an adaptation can be coded for by a single gene in a way that is not impacted by genes at other loci, then sexual recombination does not disassemble it, and individuals may vary locally or regionally. Similarly, quantitative genetic variation (e.g., height, arm length, how easily an individual is angered) is not constrained by sexual reproduction and functional compatibility, and so may also vary locally or regionally. Quantitative genetic variation we consider to be variation that shifts phenotypes quantitatively, but not outside the boundaries imposed by the demand for functional compatibility.

8. Some evolved outcomes are the result of frequency-dependent selection. That is, the population stabilizes at intermediate frequencies with two or more alternative designs, such as male and female, because the relative reproductive advantage of being one over the other decreases with increasing frequency (Fisher 1932). If the adaptation involves only a single locus, then two or more alternative designs can persist indefinitely in the species.

9. Finally, selection for genetic universality in complex adaptations does not rule out the possibility that some individuals will express complex adaptations that others will not (as the two sexes, and different life stages do). Such expression, however, must be based on a genetic architecture that is largely universal, and simply activated by an environmental trigger or a single locus genetic switch (such as the unrecombining regions of the Y chromosome). For example, women express a different set of complex reproductive organs than men, but not because men lack any of the genes necessary to code for ovaries and a uterus. If males and females were different because each lacked the complex genetic specification of the adaptations of the other sex, then when they produced offspring they would be nonreproductive individuals of intermediate sex. In other words, *functional* aspects of the architecture will tend to be universal at the genetic level, even though their expression may be limited to a particular sex or age, or be contingent on the presence of an eliciting cue in the environment or at a single locus.

10. The living world sharply clusters into sets of organisms that share properties – species – because of the demand for functional compatibility among sexual reproducers. Indeed, it is striking the degree to which species are characterized by a complex, shared, and instantly recognizable designs. Still, the degree to which functional variation can be tolerated in a species is a function of a number of variables, such as fecundity, migration rate, and population density. In species where successful parents have large numbers of offspring, reproductive rates are high, and migration rates are low between populations, populations may diverge in some complex adaptations, because local mates will be more likely to share functionally compatible genotypes even if there is variation elsewhere in the species. Compared the great majority of other species, however, ancestral humans were very low fecundity, had an open breeding structure, and migrated across substantial distances. For these reasons, humans are both expected to be, and are observed to be, characterized by a greater tendency toward species-typicality than many other species.

Thus humans are free to vary genetically in their superficial, nonfunctional traits, but are constrained by natural selection to share a largely universal genetic design for their complex, evolved functional architecture. Even relatively simple cognitive programs must contain a large number of interdependent processing steps, limiting the nature of the variation that can exist without violating the program's functional integrity. The psychic unity of humankind—that is, a universal and uniform human nature—is necessarily imposed to the extent and along those dimensions that our psychologies are collections of complex adaptations. In short, selection,



interacting with sexual recombination, tends to impose at the genetic level near uniformity in the functional design of our complex neurocomputational machinery.

**Evolutionary psychology and behavior genetics ask different questions.** This provides a framework for thinking about universal design and genetic differences. Behavior geneticists, through twin studies and comparisons of kin raised together and apart, explore the extent to which *differences* between individuals are accounted for by *differences* in their genes. This is expressed as a heritability statistic— $h = Vg / (Vg + Ve + Vge)$ —which tells you the proportion of variance in a population of individuals that is caused by differences in their genes (compared to all causes: variance due to differences in environment, genes, and their interaction). In contrast, evolutionary psychologists explore the design of the universal, evolved psychological and neural architecture that we all share by virtue of being human.

Evolutionary psychologists are usually less interested in human characteristics that vary due to genetic differences, because they recognize that these are unlikely to be evolved adaptations central to human nature. Of the three kinds of characteristics that are found in the design of organisms—adaptations, byproducts, and noise—traits caused by genetic variants are predominantly evolutionary noise, with little adaptive significance, while complex adaptations are likely to be universal in the species.

Why is uniformity associated with functionality, and variability associated with lack of function? The first reason involves the constraints on organic design imposed by sexual recombination, as explained above. The second reason is as follows. Alternative genes at the same locus (the same location in the human genome) are in a zero-sum competition for relative frequency in the species: The more common one allele is, the less common the others are. Natural selection tends to eliminate genetic differences whenever two alternative alleles (genes) differ in their ability to promote reproduction (except in the case of frequency-dependent selection). Usually, the better functioning gene increases in frequency, squeezing out the less functional gene variant, until it disappears from the species. When this happens, there is no longer genetic variability at that locus: natural selection has produced genetic uniformity, instead. The more important the function, the more natural selection tends to enforce genetic uniformity. Thus our important functional machinery tends to be universal at the genetic level, and the heritability statistic associated with this machinery will be close to zero (because there is little variation between individuals caused by genes). In contrast, whenever a mutation fails to make a functional difference, selection will not act on it, and such minor variants can build up at the locus until there is a lot of genetic variability for the trait, and its heritability statistic will be high (because most variation between individuals is caused by variation in genes). For this reason, genetic variability tends to be predominantly nonadaptive or maladaptive evolutionary noise: neutral variants, negative mutations on their way to being eliminated, and so on. Such variants may be, of course, of the greatest medical, personal, or practical significance, as, for example, in the search for possible genetic causes of schizophrenia, depression, and autism, or the discovery that a formerly neutral variant causes differential drug metabolism. The point is, however, genetic variants causing medical vulnerabilities or personality differences are generally unlikely to be adaptations designed to cause those effects. If something is highly functional, selection usually acts to spread its genetic basis to the entire species.

There is, nonetheless, a great deal of genetic variability within species, which is in tension with the functional advantages of genetic uniformity. Aside from mutations and neutral variants, there is a third reason for this genetic diversity. Genetic variability, such as the ABO blood group system, is retained in the species because genetically-based biochemical

individuality interferes with the transmission of infectious diseases from host to host (Tooby, 1982). Diseases that use or depend on a protein found in their present host are thwarted when the next individual they jump to has a different protein instead. Hence, natural selection sifts for genetic variants which supply approximately the same functional properties to the adaptations they participate in, but which “taste different” from the point of view of disease organisms. Because we catch diseases from those we have contact with—such as our family, neighbors, and other locals—selection favors maximizing genetically based protein diversity locally, which requires pulling into every local population as many of the genetic variants found anywhere in the species as possible. This is why individuals are genetically different from each other, but different populations tend to be so surprisingly genetically similar. These genetic differences introduce minor perturbations into our universal designs. The result is that each normal human expresses the universal human design but, simultaneously, each human is slightly different from every other in personality, temperament, and appearance. These differences tend to be quantitative in nature – a little more of this, a little less of that – while the overall architecture remains the same.

One final category is the possibility of alternative, genetically based psychological designs that are maintained through frequency-dependent selection. The existence of male and female—two alternative designs—shows that such frequency-dependent equilibria are not only possible but real for humans. Moreover, multiple behavioral strategies often emerge in theoretical models through frequency-dependent selection. Nevertheless, the constraints created by sexual reproduction place strong limitations on the emergence of such systems in real species (even the system of two sexes is based almost entirely on genetic uniformity). Indeed, as the case of the sexes shows, alternative phenotypic strategies can be based more easily on substantial genetic uniformity and alternative developmental pathways than on genetic differences encoding the alternative adaptations. At this point, it remains unclear the extent to which humans exhibit frequency-dependent behavioral strategies, and there are no well-established cases.

The interaction of universal design with genetic variation has many implications for understanding personality variation; for discussion see Tooby and Cosmides (1990a).

### **Evolutionary versus traditional approaches to psychology: How are they different?**

If all psychologists are engineers working in reverse, if the goal of all psychologists is to discover the design of the human mind, then how does evolutionary psychology differ from traditional approaches?

Traditional approaches to psychology are not guided by any specific theory of what the mind was designed to do. As animal species go, humans are startling in their capabilities—from making lemon chiffon pies to writing jingles to sending rockets to the moon, we are capable of solving many problems that no hunter-gatherer ever had to solve (and that no other animal does solve).<sup>ix</sup> It therefore seemed obvious to many that our minds are not designed to do anything in particular; rather, they are designed to “reason” and to “learn”, by virtue of mechanisms so general in function that they can be applied to any domain of human activity. Obviously, reasoning and learning require certain auxiliary processes: a memory to retain what is learned or inferred, perceptual systems to bring sense data to the learning and reasoning mechanisms, attention to “spotlight” some aspects of perception for further analysis. But these auxiliary processes were also thought to be domain-general. Noting the disconnect between assumptions

in psychology and biology, Randy Gallistel (2000, p. 1179) made the following observation about the study of learning:

“Biological mechanisms are hierarchically nested adaptive specializations, each mechanism constituting a particular solution to a particular problem. ...One cannot use a hemoglobin molecule as the first stage in light transduction and one cannot use a rhodopsin molecule as an oxygen carrier, any more than one can see with an ear or hear with an eye. Adaptive specialization of mechanism is so ubiquitous and so obvious in biology, at every level of analysis, and for every kind of function, that no one thinks it necessary to call attention to it as a general principle about biological mechanisms. In this light, it is odd but true that most past and contemporary theorizing about learning does not assume that learning mechanisms are adaptively specialized for the solution of particular kinds of problems. Most theorizing assumes that there is a general purpose learning process in the brain, a process adapted only to solving the problem of learning. There is no attempt to formalize what the problem of learning is and thereby determine whether it can in fact be conceived as a single or uniform problem. From a biological perspective, this assumption is equivalent to assuming that there is a general purpose sensory organ, which solves the problem of sensing.”

The same passage could have been written about reasoning, memory, or attention. The reigning assumption has been that the function of the mind is quite general—to acquire information that is (roughly) true—which requires programs general enough to handle content drawn from any and all domains. Thus the study of reasoning has concentrated on procedures that are content-free. Examples include logical procedures (which are designed to produce true conclusions from true premises, no matter what the subject matter of the premises is), mathematical procedures, such as Bayes’ theorem or multiple regression (which operate over quantities of anything), and heuristics of judgment that use very general principles such as similarity (the representativeness heuristic), frequency (the availability heuristic), or what came first (anchoring and adjustment) (e.g., Rips, 1994; Kahneman, Slovic, & Tversky, 1982; but see Gigerenzer, Todd, et al., 1999; Cosmides & Tooby, 1996). Memory has been conceived as a single system—after all, it had to be able to store and retrieve information from all domains of human life. When multiple memory systems are proposed, they are usually individuated by information modality or source (a storage system for perceptual representations? motor skills? general knowledge?) rather than by information content (Schacter & Tulving, 1994; but see Sherry & Schacter, 1987; Caramazza & Shelton, 1998; Klein, 2005; Klein, Cosmides, Tooby & Chance, 2002). Attention has primarily been seen as a content-free mechanism that selects some information in an array for further processing. If true—if attention contains no domain-specialized selection procedures—then it should be safe to study it using artificial stimuli that are easy to modify and manipulate in a controlled fashion (Posner, 1978; Triesmann, 2005; but see Braun, 2003; Li, Van Rullen, Koch, & Perona, 2002; New et al., under review).

This notion of content-free cognitive processes has been aided and abetted by our folk psychology: common sense tells us that behavior is caused by a person’s beliefs and desires: I go to the kitchen because I *want* a cookie and I *believe* cookies are there.<sup>x</sup> What more needs to be explained? People in different places and times seem to want and believe different things, so obviously humans can want or believe just about anything. They must learn what to want from their surrounding culture. Therefore, to determine the content of their beliefs and desires, we must consult an anthropologist who studies culture. No answers will be found by studying the architecture of the human mind.

This set of assumptions (plus some others) is what we have elsewhere called the Standard Social Science Model (SSSM; Tooby & Cosmides, 1992). This model dominated research in psychology and the social sciences for most of the 20<sup>th</sup> century and, although its hold is weaker now, it is still more common than any alternative view. The SSSM's fundamental premise is that the evolved architecture of the human mind is comprised mainly of cognitive processes that are content-free, few in number and general purpose—a blank slate. These general-purpose mechanisms fly under names such as “learning”, “induction”, “imitation”, “reasoning” and “the capacity for culture”. Their structure is rarely specified computationally, yet these mechanisms are thought to explain nearly every human phenomenon. According to the SSSM, the same learning process is 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 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, no matter what content, subject matter, or domain of life experience they are operating on. (For this reason, such procedures are described as *content-independent, domain-general or content-free*).

The premise that these learning and reasoning mechanisms have no content to impart is what leads to the doctrine central to the modern behavioral and social sciences: that all of our particular mental content originated in the social and physical world and flows into the mind through perception. As Aquinas put this empiricist tenet a millennium ago, “There is nothing in the intellect that was not first in the senses.”

This view of the mind is radically at variance with the view that emerges from evolutionary psychology. Evolutionary psychologists expect a mind packed with domain-specific, content-rich programs specialized for solving ancestral problems. For example, evolutionary psychologists would view “attention” not as a single mechanism, but as an umbrella term for a whole *suite* of mechanisms, each designed to select different information from a scene for different processing purposes. Some of these may be relatively domain-general and deployed via volitional systems to any task-relevant element in a scene—these are the attentional mechanisms that have been studied most, using artificial stimuli. The mistake is not to think these exist, but to think they are *all* that exist (Braun, 2003). For example, research with change detection and attentional blink paradigms is uncovering attentional systems that are highly domain-specific and deployed in the absence of any specific task demand. One system preferentially attends to human faces (Ro, Russell, & Lavie, 2001). Another reflexively directs attention to the location at which an index finger (but not a thumb!) is pointing (German & New, under review). A similar system snaps attention to the location at which a pair of eyes is gazing (XX). Yet another monitors animals for changes in their state and location: changes to animals are detected more quickly and reliably than changes to buildings, plants, tools—even vehicles (New, Cosmides & Tooby, forthcoming). Better change detection for animals than vehicles is significant because it shows a monitoring system tuned to ancestral rather than modern priorities. Our ability to quickly detect changes in the state and location of cars on the highway has life or death consequences, and is a highly trained ability in 21<sup>st</sup> century America, where the studies were done. Yet we are better at detecting changes in the states and locations of animals—an ability that had life or death consequences for our hunter-gatherer ancestors, but is merely a distraction in modern cities and suburbs.

The point is not just that attention will be comprised of many different domain-specific mechanisms, but that each domain-specialized attentional mechanism will be part of a vertically integrated system linking the attended objects to domain-specialized inferential, learning, and memory systems. True, animals needed to be closely monitored because they presented either dangers (e.g., predators) or opportunities for hunting (prey). But once detected, other specialized processing is needed. Is the animal a predator or not? If it is a predator, is it hunting now and has it seen you? Barrett (1999) has shown that, across a wide array of animals (insects, reptiles, mammals) and mental state terms (see, think, doubt, etc.), people activate mental state inferences more in predatory contexts than in others. For example, even though everyone knows lions can see, people judge the sentence *The lion saw the zebra* as more “reasonable” than *The lion saw the other lion*. Barrett has also shown that a predator-prey inference system develops early, regardless of relevant experiences: 3- and 4-year old children have a sophisticated understanding of predator-prey interactions, whether they grow up in urban Berlin or in a Shuar village in the jaguar- and crocodile-infested Amazon, eating animals that their fathers hunted and killed (Barrett, this volume; Barrett, Tooby, & Cosmides, forthcoming). Steen and Owens (2001) have shown that chase play in toddlers and preschoolers has features of special design as a system for practicing and perfecting escape from predators (see also Marks, 1987).

Learning about animals is specialized as well. Mandler and McDonough (1998) have shown that babies distinguish animals from vehicles by 7 months of age, and make different inferences about the two by 11-14 months. A detailed knowledge of animal behavior is necessary for successful hunting (Blurton Jones & Konner, 1976; Walker, Hill, Kaplan & McMillan, 2002), and even preschoolers are equipped with systems specialized for making inductive inferences about the properties of animals (Markman 1989, Keil 1994, Springer, 1995; and discussion thereof in Boyer, 2001, Boyer & Barrett, this volume). Atran and colleagues (1998; López, Atran, Coley, Medin, & Smith, 1997) provide cross-cultural evidence for a system specialized for sorting living kinds into hierarchically organized, mutually exclusive taxonomic categories, which organize inductive inferences: The closer two species are in this taxonomic structure, the more likely one is to assume that a trait of one is present in the other. Barrett has found a second parallel inductive system that uses predatory role to guide inferences: this system assumes that two species are more likely to share a trait if they are both predators than if one is a predator and the other an herbivore. This system categorizes animals as predators or not on the basis of minimal dietary information scattered amidst other facts about the species’ natural history. If the text mentions that a striped bass, which has a three-lobed liver, eats flies, then people are more likely to assume that a three-lobed liver will also be found in a trout that eats worms than in a spotted bass that eats algae. That is, the category *predator* is triggered by the information *eats animals*, and guides inductive learning; the effect on trait induction is strong—twice the size of the taxonomic effect (Barrett, this volume; Barrett, Cosmides, & Tooby, forthcoming). Animal-specialized memory systems appear to exist as well. For example, Caramazza provides neuropsychological evidence that information about animals is stored in a category-specific memory system, functionally and neurally separate from that which stores information about artifacts (Caramazza, 2000; Caramazza & Shelton, 1998).

We are emphasizing the content-specialized nature of processing about animals to illustrate an important point. It makes no sense to have an attentional system specialized for monitoring animals unless its output is fed into inferential systems that infer their mental states and use this information to predict their likely behavior. The inferences and predictions generated by the mental state system are themselves useless unless they are fed into decision

rules that determine whether escape is necessary. The monitoring system should also feed learning mechanisms that incidentally acquire information about the animal's properties and these, in turn, should feed memory systems designed to encode, store, and retrieve information about the animals monitored, according to ecologically relevant categories such as *predator*, *taxonomically related*, and so on. Animal-specialized attentional, inferential, behavioral, learning, and memory systems should be *functionally integrated with one another*, forming a distinct, category based *system*. The same should be true for other content domains: Distinct content-based information-processing systems will exist to the extent that the computational requirements for adaptive problem solving for one content area are functionally incompatible with those for another (Sherry & Shacter, 1987; Tooby & Cosmides, 1992; Tooby, Cosmides & Barrett, 2005).

Seen from this perspective, the ordinary categories of psychology dissolve. To have a textbook chapter on “attention”, and a separate one on “memory” and then “learning” and “reasoning” divides the mind in exactly the wrong way. Instead there will be a domain-specialized system for dealing with animals, with its own proprietary attentional, inferential, behavioral, learning and memory systems that are designed to work together as an integrated system.

The organization of these specialized systems will be nothing like Fodor's (1983, 2000) “pipelines” (for discussion, see Barrett, in press; Boyer & Barrett, this volume). Some components of the system for making inferences about animals will also be activated for plants and other living things as well (e.g., taxonomic organization (Atran, 1990) or inferences that parts have functions (Keil, 1994)). Other components of the animal system will be activated only in response to animals—or, more precisely, to things manifesting those psychophysical properties the system uses to detect animals, such as contingent reactivity or self-propelled motion, whether the manifesting entity is a meerkat, Tickle-me Elmo, or Bugs Bunny. Because many components of the animal system will be functionally specialized for solving animal-specific adaptive problems, they will be composed of representations and procedures that have little in common with those in a system for making inferences about plants, or artifacts, or cooperation between people (Boyer & Barrett, this volume). Nor will the boundaries between category-based systems be clean: people may be attended by the animal monitoring system, but also by the system for monitoring social gestures; for inferences about growth and bodily functions people may be processed as animals, but perhaps not for inferences about social behavior. The organization of specializations will be complex and heterarchical, but with a functional logic that arose because of its excellence at solving ancestral problems of survival and reproduction

The old categories of psychological research have not led to robust models of the human mind because they do not carve nature at the joints. Content-specialization is the rule, not the exception: the easiest way to make a domain-general model of learning, reasoning, attention, or memory collapse is to introduce stimuli drawn from different adaptive domains (e.g., Anderson & Phelps, 2001; Boyer & Barrett, this volume; Braun, 2003, Cosmides & Tooby, this volume; Gallistel, 2000). A more sober and sensible research strategy is to start developing some formal (or even informal) analyses of specific adaptive problems and let these guide research. If there are general systems or principles to be found, they will eventually emerge as we gain a clear understanding of how each content-specialized system functions (for an example, see Leslie, German & Polizzi, 2005).

Biology is not split into evolutionary biology and non-evolutionary biology: all of biology is organized by evolutionary principles. At some point, all psychology will be evolutionary psychology, simply because it will make no sense to wall off the study of humans from the rest of the natural world. When that happens, textbooks in psychology will no longer be organized according to folk psychological categories, such as “attention”, “memory”, “reasoning”, and “learning”. Their chapter headings will be more like those found in textbooks in evolutionary biology and behavioral ecology, which are organized according to adaptive problems animals must solve to survive and reproduce: foraging (hunting, gathering), kinship, predator defense, resource competition, cooperation, aggression, parental care, dominance and status, inbreeding avoidance, courtship, mateship maintenance, trade-offs between mating effort and parenting effort, mating system, sexual conflict, paternity uncertainty and sexual jealousy, signaling and communication, navigation, habitat selection, and so on (e.g., see Buss, 1999).

Textbooks in behavioral ecology are organized according to adaptive problems because these are the only problems that natural selection can build mechanisms for solving. Just as importantly, when scientists look for programs that are functionally specialized for solving these problems, they find them in species after species. As Gallistel (2000) points out, those who study learning in nonhuman animals have discovered many mechanisms that are adaptively specialized for learning in specific task domains—dead reckoning in desert ants, celestial navigation by birds, food aversion learning in rats—but none that are general purpose (not even classical conditioning; see above). Future psychology textbooks will surely contain some additional chapters, which capture zoologically unusual aspects of human behavior, such as language acquisition, coalition formation, deep engagement friendships, counterfactual reasoning, metarepresentation, and autobiographical memory. But theories of the computational mechanisms that make these unusual abilities possible will include how they interact with and are supported by a wide variety of adaptive specializations (e.g., Boyer, 2001; Leslie, German & Polizzi, 2005; Klein, German, Cosmides & Gabriel, 2004; Cosmides & Tooby, 2000a; Sperber, 1994; Sperber & Wilson, 1995).

But the field of psychology is not at that point yet. Few psychologists derive their hypotheses from theories of adaptive function. But without such theories, there is no principled source of hypotheses about what the mind was designed to do—nothing to guide a research program other than intuition, introspection, and folk psychology. Instinct blindness rules the day. As a result, the topics found in behavioral ecology texts are usually absent from works in psychology. Where is the research community studying the cognitive architecture underlying predator defense? Kin detection? Courtship? Coalitional aggression? Inbreeding avoidance? Habitat selection? Parenting? Social exchange? Research communities investigating these topics are absent from mainstream psychology, absent from funding agencies, absent from texts. If these topics are studied at all, it is by the world’s small community of evolutionary psychologists, such as those represented in this handbook.

This topic void is made more puzzling by the fact that modern cognitive scientists understand that any mechanism that processes information must have a computational description—even those that motivate behavior. This means that mechanisms causing the perception of beauty, sexual jealousy, sexual attraction, or disgust should all be describable in computational or cognitive terms, which specify the relevant representations and the procedures that act on them. Yet most cognitive scientists would not even recognize these topics as within their domain of study.

## Cognition, motivation, and the void

One reason for cognitive psychology's topic agnosia is an arbitrary distinction that is typical made between concepts and knowledge acquisition on the one hand, and motivation, emotion, and preferences on the other. Those who make this distinction view cognition as the study of knowledge acquisition and leave motivation, emotion, and action to other research communities—a practice which presumes that knowledge and motivation are not coevolved aspects of the same unified systems of representation and action (see Fodor, 2000, for an example).

The problem with this view is that natural selection does not build knowledge acquisition systems for the beauty of pure contemplation; it only builds such systems when the knowledge so acquired routinely affects behavioral choices in a way that promoted reproduction under ancestral conditions. This means that the design of any system designed to acquire, store, and retrieve knowledge will not be motivationally neutral: Evolved systems for motivational computation will need specific kinds of evolved concepts and knowledge to operate properly, so motivational computation and knowledge computation cannot be isolated from each other into separate systems, as we will show below.

### The weakness of content-free 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? And won't mathematical and logical inference engines produce knowledge that is true, thereby providing a sound basis for choosing the most adaptive course of action?

To be a plausible model of how the mind works, any hypothetical domain-general cognitive architecture would have had to reliably generate solutions to all of the problems that were necessary for survival and reproduction in the Pleistocene. For humans and most other species, this is a remarkably diverse, highly structured and very complex set of problems. 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 view of the mind as consisting solely or primarily of domain-general programs fails. There appear to be a very large number of such problems—at minimum, any kind of information-processing problem that involves motivation, and many others as well (the list topics typically studied in behavioral ecology provide some examples). This leads to the inference that the human cognitive architecture must contain many information-processing mechanisms that are domain-specific, content-dependent, and specialized for solving particular adaptive problems. We have developed this argument in detail elsewhere (Cosmides, 1985; Cosmides & Tooby, 1987, 1994a, b; Tooby & Cosmides, 1990b, 1992; Tooby, Cosmides & Barrett, 2005), so we will not belabor it here. Instead, we will simply summarize a few of the relevant points.

**1. Content-free is content-poor.** There are inferences that are usefully applied to some domains but not to others. For example, when predicting the behavior of people, it is useful to assume they have *beliefs* and *desires*: invisible mental states that can be inferred but never observed. When predicting the behavior of rocks rolling down a hill, computing their beliefs and desires is useless. Accordingly, the human cognitive architecture has evolved two separate



inference systems for these two domains: a “mindreading” system for inferring the mental states of people (which can be selectively impaired in autism; Leslie & Thaiss, 1992; Baron-Cohen, 1995) and an object mechanics system for understanding the interactions of inanimate objects (Spelke, 1990; Leslie, 1994). Each inference system is designed to be activated by cues particular to its domain of applicability (e.g., human behavior for the mindreading system; inanimate motion for the object mechanics system). Because their domain of applicability is restricted, specialized inferences appropriate for one domain can be made without producing absurd inferences for another. This property allows domain-specific systems to include rich, contentful inferential rules. For example, in content-free logics, “If P then Q” does not imply “If Q then P” because it would lead to absurd inferences (“If you saw a horse, then you saw an animal” does not imply “If you saw an animal, then you saw a horse”). But a “logic” restricted to situations of social exchange, operating over a more content-restricted set of representations (*benefits, entitlement, obligation*, and so on), can usefully specify that “If you take the benefit, then you are obligated to satisfy the requirement” implies “If you satisfy the requirement, then you are entitled to take the benefit”—an inference that is invalid for any content-free logic (see Cosmides & Tooby, this volume). Because they can have content-restricted, specialized inference rules, domain-specific systems can be inferentially powerful: small amounts of information can support many inductions or deductions.

Notice, however, that these powerful, content-rich inference systems are unavailable to a truly domain general system. To maintain its domain-generality, a system must be equipped with rules that generate valid inferences across all domains—people, rocks, plants, tools, nonhuman animals, and so on. This means it cannot take advantage of any inference rules that are useful for one domain but misleading if applied to another. It can have no mindreading system, no object mechanics system, no predator-prey inference system, no specializations for tool use (e.g., Defeyter & German, 2003; German & Barrett, 2005). The only kind of inference rules that are left are content-free ones, such as those found in logic and mathematics. Domain-general systems are crippled by this constraint.

**2. Combinatorial explosion.** Combinatorial explosion paralyzes even moderately domain-general systems when encountering real-world complexity. Imagine trying to induce what caused your nausea in the absence of any privileged hypotheses: your entire life preceded the nausea, and a truly “open-minded” system would have to consider every action, thought, sight, smell, taste, sound, and combination thereof as a potential cause. In deciding how to respond, every possible action would have to be considered. There would be nothing to privilege the hypothesis that the cause was a recently consumed food, and nothing to privilege vomiting or future avoidance of that food as behavioral responses.

As the generality of a system 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-free, specialization-free architecture contains no rules of relevance, procedural knowledge, or privileged hypotheses, and so could not solve any biological problem of routine complexity in the amount of time an organism has to solve it (for further discussion see, e.g., Gallistel et al., 1991; Keil, 1989; Markman, 1989; Tooby & Cosmides, 1992; Carruthers, 2005; Gigerenzer & Selten, 2002).

Acknowledging the necessity of a few “constraints” on learning will not solve this problem. As Gallistel (2000, p. 1180) notes:

“Early work focusing on the role of adaptive specialization in learning tended to formulate the problem in terms of the constraints...or boundaries...that biological considerations placed on *the*

learning process. . . . [The constrastring argument] is that there is no such thing as *the* learning process; rather there are many different learning processes. While it is true that the structure of these processes constrain the outcome of learning in interesting ways, the more important point is that it is the problem-specific structure of these processes that makes learning possible.”

Problem-specific learning specializations are necessary because the problem of combinatorial explosion cannot be overcome by placing a few “constraints” on a single, general learning process. Instead of asking “How much specialization does a general purpose system require?”, psychologists should be asking “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 guarantee that real systems can tolerate only a small number. Without domain-specialized learning mechanisms, we would learn nothing at all.

**3. Clueless environments.** Animals subsist on information. The single most limiting resource to reproduction is not food or safety or access to mates, but what makes them each possible: the information required for making adaptive behavioral choices. Many important features of the world cannot be perceived directly, however. Content-free architectures are limited to knowing what can be validly derived by general processes from perceptual information. 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. When perceptual evidence is lacking or difficult to obtain, they can fill in the blanks by using cues (perceivable states or events) to infer the status of important, nonperceivable sets of conditions, provided there was a predictable probabilistic relationship between the cues and the unobservables over evolutionary time. For example, it is difficult or impossible to tell from experience that sex with siblings has a higher chance of producing defective offspring—many conceptions are lost in utero, and whatever problems exist in children born of such matings could have been caused by any number of prior events. In contrast, a domain-specialized system can trigger disgust at the prospect of sex with a sibling, drastically reducing the probability of inbreeding. This will work, without one having any knowledge, conscious or otherwise, about the pitfalls of inbreeding. Incestuous sex will simply seem disgusting and wrong (Lieberman, Tooby, & Cosmides, 2003; Haidt, 2001). Similarly, ancestral hominids had no method by which they could directly “see” another person’s genes to tell whether they are blood siblings or not. But a mind equipped with a domain-specific kin detection system can estimate kinship on the basis of cues, such as co-residence during childhood, that were correlated with genetic relatedness ancestrally. The person need not be aware of the cues used by this system, the computational process employed, or even the concept “genetic relative”.

**4. The “Stoppit” problem.** There is a Gary Larson cartoon about an “All-Purpose” product called Stoppit. When sprayed from an aerosol can, Stoppit stops faucet drips, taxis, cigarette smoking, crying babies, and charging elephants. The joke should be obvious: such a product is impossible because stopping each of these things requires radically different actions. An “all-purpose” cognitive program is no more feasible for an analogous reason: *what counts as adaptive behavior differs markedly from domain to domain*. An architecture equipped only with content-free 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 (for argument, see Cosmides & Tooby, 1987). For example, what counts as a “good” mate has little in common with a “good” lunch or a “good” brother. Designing a computational program to choose foods based on their kindness, or to choose friends

based on their flavor and the aggregate calories to be gained from consuming their flesh, suggests the kind of functional incompatibility issues that naturally sort human activities into incommensurate motivational domains. 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.

A *motivational domain* is a set of represented inputs, contents, objects, outcomes, or actions that a functionally specialized set of evaluative procedures was designed by evolution to act over (e.g., representations of foods, contaminants, animate dangers, people to emulate, potential retaliations to provocations). For a given species, there is an irreducible number of these motivational domains; within each motivational domain, there is an irreducible set of domain-specific criteria or value-assigning procedures operating. For food domain in humans, for example, criteria and value-assigning operations include: salt, sweet, bitter, sour, savory, fat affordances, putrefying smell avoidance, previous history with the aversion acquisition system, temporal tracking of health consequences by the immune system, stage of pregnancy, boundaries on entities and properties considered by the system, perhaps maggot-ridden food avoidance, and scores of other factors. When the required assignments of value within a domain (such as food) cannot all be derived from a common neurocomputational procedure, then the number of motivational elements must necessarily be multiplied to account for the data.

Thus by evolved design, different content domains should activate different evolved criteria of value, including different trade-offs between alternative criteria. Cases of motivational incommensurability are numerous, and easily identified via careful analyses of adaptive problems. Distinct and incommensurable evolved motivational principles exist for food, sexual attraction, mate acquisition, mate retention, parenting, kinship, incest avoidance, coalitions, disease avoidance, friendship, predators, provocations, snakes, spiders, habitats, safety, competitors, being observed, behavior when sick, certain categories of moral transgression, and scores of other entities, conditions, acts, and relationships.

There has not been very much progress over the last century towards constructing an inventory of motivational domains. Without any proof or even an informal argument, psychologists have presumed that most values are derived from the environment, by computing contingencies between environmental conditions and a tiny set of reinforcers (food, water, sex, pain; Herrnstein, 1977). As a field, we have been shrugging off the issue of evolved motivations through the shell game of implying that any given motivation is secondarily acquired, without obliging ourselves to specify computationally how and from what. Yet there are strong reasons to doubt that a system of this kind would track fitness at all (Cosmides & Tooby, 1987).

Value and behavior cannot be induced from the environment alone. No environmental stimulus intrinsically mandates any response, or any value hierarchy of responses. In the tangled bank of coevolved organisms that Darwin memorably contemplated at the end of the *Origin of Species*, naturally selected differences in the brains of different species cause them to treat the same objects in a rich and conflicting diversity of ways: The infant that is the object of caring attention by one organism is the object of predatory ambition by another, an ectoparasitic home to a third, and a barrier requiring effortful trajectory-change to a fourth. It is the brains of these organisms that introduce behavior-regulatory valuation into the causal stream, and natural selection that introduced into brains the neural subsystems that accomplish valuation. The same stimulus set cannot, by itself, explain differences in the preferences and actions they provoke, nor indeed, the preferences themselves.

Value is not in the world even for members of the same species. Members of the same species view the same objects differently: The very same object is one person's husband and another's father—an object of sexual preference in one case and sexual aversion in the other. Moreover, because each evolved organism is by design the center of its own unique valuer-centered web of valuations, evolved value by its nature cannot have an objective character (Hamilton, 1964; Cosmides & Tooby, 1981). Because of the structure of natural selection, social organisms are regularly in social conflict, so that the objective states of the world that are preferred by some are aversive or neutral to others (e.g., that this individual and not that should get the contested food, mating opportunity, territory, parental effort, status, grooming, and so on). This gives value for organisms an intrinsically indexical quality. Indeed, fitness “interests”—the causal feedback conditions of gene frequency that value computation evolved to track—cannot be properly assigned to such a high level entity as a person, but are indexical to sets of genes inside the genome defined in terms of their tendency to replicate under the same conditions (Cosmides & Tooby, 1981). Whatever else might be attainable by sense data and content-free operations, value or its regulatory equivalents must be added by our evolved architecture.

**5. Values and knowledge.** We can now address why, *pace* Fodor, knowledge acquisition cannot be divorced from motivation, valuation, and preferences.

To behave adaptively, some actions, entities or states of affairs must be valued more than others, with a motivational system organized to pursue higher over lower valued options. The computations whereby value is assigned typically involves many of the same elements of conceptual structure that are the traditional objects cognitive science (representations of persons, foods, objects, animals, actions, events). This means that the evolution of motivational elements will mandate the evolution of an irreducible set of conceptual elements as well. Why? A valuation is not meaningful or causally efficacious for regulating behavior unless it includes some specification of *what is valued*. That is, the specification of what the value applies to generally involves conceptual structure.

For example, for natural selection to cause safe distances from snakes to be preferred to closeness to snakes, it must build the recognition of snake-like entities into our neurocomputational architecture. This system of recognition and tagging operations is, for certain purposes, equivalent to having a snake *concept*, albeit a skeletally specified one. Evidence supports the view that humans and related species do indeed have a valuation system specialized to respond to snakes (e.g., Marks, 1987; Mineka, Davidson, Cook, & Keir, 1984; Mineka & Cook, 1993; Yerkes & Yerkes, 1936). This one consideration alone forces us to add to a fourth “innate idea” to Kant's space, time, and causality. Yerkes and Yerkes's finding of evolved snake fear in chimps counts as empirically based philosophical progress, and as straightforward progress in the cognitive science of knowledge as well—derived (*pace* Fodor) from evolutionarily motivated theories of function.

This argument not only establishes the necessity of evolved motivational elements, but it resurrects the argument for the necessity of “innate ideas”: that is, evolved conceptual procedures within the cognitive architecture that embody knowledge about the world and are triggered by stimuli with certain features (however abstractly described). It is the specificity of the coupling to the particular valuation procedure that individuates the concept with respect to the set of motivational functions (e.g., *beloved*[your children]; *suspicious*[snakes]).

Consider, for example, the series of interacting conceptual components necessary to build a snake avoidance system. The system needs a psychophysical front-end: One of its

subcomponents assigns the evolved, internal tag *snake* through visual and biomechanical motion cues to a perceptual representation of some entity in the world. It has a second subcomponent that maps in a parameter, *distance*, between the *snake* and the valued entity (like *self* or *child*). Obviously, the distance-representing component is used by many systems. However, it also must have a component that assigns and updates different specific valuation intensities for different distances, so that further away is better than closer for snakes (but not for food or other motivational domains). It need not be the case that a particular bad event (like an imagined snake bite) is specifically represented as a negative goal state in the snake avoidance system, with distance acquiring its significance through backward induction and means-ends analysis. The distance-fear relationship could fill the representation of space with a motivational manifold that itself motivates avoidance (closeness is increasingly unpleasant). But such action-inviting affordances are not the same, computationally, as a represented goal state.

The metric of valuation against distance (and its update rules) are proprietary to snakes, but the output value parameter it produces must be accessible to other systems (so that distance from snakes can be ranked against other goods, like getting closer in order to extract your child from the python's coils). Snake, distance, person, and the *distance*[person, snake] valuation metric all necessarily operate together for this simple system to work. Snakes, the entity to be protected, and distance cannot be assigned to one computational process, with valuation assigned to another. Even in this simple example, conceptual and valuation functions indivisibly interpenetrate each other, with the representations necessarily co-existing within the same structure.

Learning, another clearly cognitive topic, is implicated in snake aversion as well, but the learning process is domain-specific. It appears that the snake avoidance system recalibrates based on individual experience, possibly slowly habituating in the absence of negative experiences or observations, and increasing sharply if snake contact leads to injury. It also narrowly accepts inputs from the social world—a conspecific expressing fear toward a snake (but not toward other stimuli, such as rabbits or flowers)—and uses this information to recalibrate the individual's snake valuation (Mineka, Davidson, Cook & Keir, 1984; Mineka & Cook, 1993). Presumably this evolved because the system operates more functionally by upregulating or downregulating fear as a function of the local distribution of fear intensities in others, which index to some degree the local rate at which venomous snakes are encountered.

The key point here is that even this apparently simple, one-function motivational system involves a series of evolved content-specific conceptual elements, including snakes, distance, conspecifics, that fear-faces have specific referents in the world, that snakes are one of the privileged referents of a fear-face, and the output of fear itself. Of course, not all of these elements are unique to the snake system (although several are) but their pattern of distribution among motivational systems is heterarchical and itself not something that could be derived by content-independent operations acting on experience.

As this form of analysis is applied to the other tasks humans perform, we think it will be impossible to escape the general conclusion that cognitive science intrinsically involves motivation, and that the science of motivation intrinsically involves cognition. The brain evolved as a control system, designed to generate action. From this perspective, there is not just a cognitive science of areas such as language, intuitive physics, and number, but a cognitive science of parenting, eating, kinship, friendship, alliance, groups, mating, status, fighting, tools, minds, foraging, natural history, and scores of other ancient realms of human action. Separating knowledge acquisition from motivation has placed the study of motivation in cognitive eclipse

and diverted cognitive scientists from studying conceptual structure, motivation, and action as a single integrated system (which they seem likely to be). It ignores the many causal pathways whereby our evolved architecture should have been designed to manufacture, store, communicate, and act on the basis of representations that would not qualify as a rational architecture's efficient attempt at constructing true beliefs (Gigerenzer & Murray, 1987; Haselton & Buss, 2000; Tooby & Cosmides, in press). Evolved systems for motivational computation use conceptual structure in targeted ways, so motivational computation and knowledge computation cannot be isolated from each other into separate systems. (For a more complete discussion, see Tooby, Cosmides & Barrett, 2005).

### **Emotions as a solution to the problem of mechanism coordination**

The discussion above leads one to view the mind as a crowded zoo of evolved, domain-specific programs. Each is functionally specialized for solving a different adaptive problem that arose during hominid evolutionary history, such as face recognition, foraging, mate choice, heart rate regulation, sleep management, or predator vigilance, and each is activated by a different set of cues from the environment. But the existence of all these microprograms itself creates an adaptive problem: Programs that are individually designed to solve specific adaptive problems could, if simultaneously activated, deliver outputs that conflict with one another, interfering with or nullifying each other's functional products. For example, sleep and flight from a predator require mutually inconsistent actions, computations, and physiological states. It is difficult to sleep when your heart and mind are racing with fear, and this is no accident: disastrous consequences would ensue if proprioceptive cues were activating sleep programs at the same time that the sight of a stalking lion was activating ones designed for predator evasion. To avoid such consequences, the mind must be equipped with superordinate programs that override some programs when others are activated (e.g., a program that deactivates sleep programs when predator evasion subroutines are activated). Furthermore, many adaptive problems are best solved by the simultaneous activation of many different *components* of the cognitive architecture, such that each component assumes one of several alternative states (e.g., predator avoidance may require simultaneous shifts in both heart rate and auditory acuity; see below). Again, a superordinate program is needed that coordinates these components, snapping each into the right configuration at the right time.

We have proposed that emotions are such programs (Cosmides & Tooby, 2000b; Tooby & Cosmides, 1990b; Tooby, 1985). To behave functionally according to evolutionary standards, the mind's many subprograms need to be orchestrated so that their joint product at any given time is functionally coordinated, rather than cacophonous and self-defeating. This coordination is accomplished by a set of superordinate programs: the emotions. On this view, emotions are adaptations that have arisen in response to the adaptive problem of mechanism orchestration. This implies that the exploration of the statistical structure of ancestral situations and their relationship to the mind's battery of functionally specialized programs is central to mapping the emotions. This is because the most useful (or least harmful) deployment of programs at any given time will depend critically on the exact nature of the confronting situation.

How did emotions arise and assume their distinctive structures? Fighting, falling in love, escaping predators, confronting sexual infidelity, experiencing a failure-driven loss in status, responding to the death of a family member (and so on) each involved conditions, contingencies, situations, or event-types that recurred innumerable times in hominid evolutionary history.

Repeated encounters with each kind of situation selected for adaptations that guided information-processing, behavior and the body adaptively through the clusters of conditions, demands, and contingencies that characterized that particular class of situation. This could be accomplished by engineering superordinate programs, each of which jointly mobilizes a subset of the psychological architecture's other programs in a particular configuration. Each configuration would be selected to deploy computational and physiological mechanisms in a way that, when averaged over individuals and generations, would have led to the most fitness-promoting subsequent lifetime outcome given that ancestral situation-type.

This coordinated adjustment and entrainment of mechanisms is a *mode of operation for the entire psychological architecture*, and serves as the basis for a precise computational and functional definition of each emotion state. Each emotion entrains various other adaptive programs—deactivating some, activating others, and adjusting the modifiable parameters of still others—so that the whole system operates in a particularly harmonious and efficacious way when the individual is confronting certain kinds of triggering conditions or situations. The conditions or situations relevant to the emotions are those that (1) recurred ancestrally; (2) could not be negotiated successfully unless there was a superordinate level of program coordination (i.e., circumstances in which the independent operation of programs caused no conflicts would not have selected for an emotion program, and would lead to emotionally neutral states of mind); (3) had a rich and reliable repeated structure; (4) had recognizable cues signaling their presence;<sup>xi</sup> and (5) in which an error would have resulted in large fitness costs. When a condition or situation of an evolutionarily recognizable kind is detected, a signal is sent out from the emotion program that activates the specific constellation of subprograms appropriate to solving the type of adaptive problems that were regularly embedded in that situation, and deactivates programs whose operation might interfere with solving those types of adaptive problem. Programs directed to remain active may be cued to enter subroutines that are specific to that emotion mode, and that were tailored by natural selection to solve the problems inherent in the triggering situation with special efficiency.

According to this theoretical framework, an emotion is a superordinate program whose function is to direct the activities and interactions of many subprograms, including those governing perception, attention, inference, learning, memory, goal choice, motivational priorities, categorization and conceptual frameworks, physiological reactions (such as heart rate, endocrine function, immune function, gamete release), reflexes, behavioral decision rules, motor systems, communication processes, energy level and effort allocation, affective coloration of events and stimuli, and the recalibration of probability estimates, situation assessments, values, and regulatory variables (e.g., self-esteem, estimations of relative formidability, relative value of alternative goal states, efficacy discount rate). An emotion is not reducible to any one category of effects, such as effects on physiology, behavioral inclinations, cognitive appraisals, or feeling states, because it involves evolved instructions for all of them together, as well as other mechanisms distributed throughout the human mental and physical architecture.

All cognitive programs – including superordinate programs of this kind – are sometimes mistaken for “homunculi”, that is, entities endowed with “free will”. A homunculus scans the environment and freely chooses successful actions in a way that is not systematic enough to be implemented by a program. It is the task of cognitive psychologists to replace theories that implicitly posit such an impossible entity with theories that can be implemented as fixed programs with open parameters. Emotion programs, for example, have a front end that is designed to detect evolutionarily reliable cues that a situation exists (whether or not these cues

reliably signal the presence of that situation in the modern world); when triggered, they entrain a specific set of subprograms: those that natural selection “chose” as most useful for solving the problems that situation posed in ancestral environments. Just as a computer can have a hierarchy of programs, some of which control the activation of others, the human mind can as well. Far from being internal free agents, these programs have an unchanging structure regardless of the needs of the individual or her circumstances, because they were designed to create states that worked well in ancestral situations, regardless of their consequences in the present.

### **Fear (an example)**

Consider the following example. The ancestrally recurrent situation is being alone at night and a situation-detector circuit perceives cues that indicate the possible presence of a human or animal predator. The emotion mode is a fear of being stalked. (In this conceptualization of emotion, there might be several distinct emotion modes that are lumped together under the folk category “fear”, but that are computationally and empirically distinguishable by the different constellation of programs each entrains.) When the situation detector signals that one has entered the situation “possible stalking and ambush”, the following kinds of mental programs are entrained or modified: (1) There are shifts in perception and attention: You may suddenly hear with far greater clarity sounds that bear on the hypothesis that you are being stalked, but that ordinarily you would not perceive or attend to, such as creaks or rustling. Are the creaks footsteps? Is the rustling caused by something moving stealthily through the bushes? Signal detection thresholds shift: Less evidence is required before you respond as if there were a threat, and more true positives will be perceived at the cost of a higher rate of false alarms. (2) Goals and motivational weightings change: Safety becomes a far higher priority. Other goals and the computational systems that subservise them are deactivated: You are no longer hungry; you cease to think about how to charm a potential mate; practicing a new skill no longer seems rewarding. Your planning focus narrows to the present: worries about yesterday and tomorrow temporarily vanish. Hunger, thirst, and pain are suppressed. (3) Information-gathering programs are redirected: Where is my baby? Where are others who can protect me? Is there somewhere I can go where I can see and hear what is going on better? (4) Conceptual frames shift, with the automatic imposition of categories such as “dangerous” or “safe”. Walking a familiar and usually comfortable route may now be mentally tagged as “dangerous”. Odd places that you normally would not occupy—a hallway closet, the branches of a tree—suddenly may become salient as instances of the category “safe” or “hiding place”. (5) Memory processes are directed to new retrieval tasks: Where was that tree I climbed before? Did my adversary and his friend look at me furtively the last time I saw them? (6) Communication processes change: Depending on the circumstances, decision rules might cause you to emit an alarm cry, or be paralyzed and unable to speak. Your face may automatically assume a species-typical fear expression. (7) Specialized inference systems are activated: Information about a lion’s trajectory or eye direction might be fed into systems for inferring whether the lion saw you. If the inference is yes, then a program automatically infers that the lion knows where you are; if no, then the lion does not know where you are (the “seeing-is-knowing” circuit identified by Baron-Cohen 1995, and inactive in people with autism). This variable may automatically govern whether you freeze in terror or bolt (Barrett, this volume). Are there cues in the lion’s behavior that indicate whether it has eaten recently, and so is unlikely to be predatory in the near future? (Savanna ungulates, such as zebras and wildebeests, commonly make this kind of judgment; Marks, 1987). (8) Specialized learning systems are activated, as the large literature on



fear conditioning indicates (e.g., LeDoux, 1995; Mineka & Cook, 1993; Pitman & Orr, 1995). If the threat is real, and the ambush occurs, the victim may experience an amygdala-mediated recalibration (as in post-traumatic stress disorder) that can last for the remainder of his or her life (Pitman & Orr, 1995). (9) Physiology changes: Gastric mucosa turn white as blood leaves the digestive tract (another concomitant of motivational priorities changing from feeding to safety); adrenalin spikes; heart rate may go up or down (depending on whether the situation calls for flight or immobility), blood rushes to the periphery, and so on (Cannon, 1929; Tomaka, Blascovich, Kibler, & Ernst, 1997); instructions to the musculature (face, and elsewhere) are sent (Ekman, 1982). Indeed, the nature of the physiological response can depend in detailed ways on the nature of the threat and the best response option (Marks, 1987). (10) Behavioral decision rules are activated: Depending on the nature of the potential threat, different courses of action will be potentiated: hiding, flight, self-defense, or even tonic immobility (the latter is a common response to actual attacks, both in other animals and in humans<sup>xiii</sup>). Some of these responses may be experienced as automatic or involuntary.

From the point of view of avoiding danger, these computational changes are crucial: They are what allowed the adaptive problem to be solved with high probability, on average over evolutionary time. Of course, in any single case they may fail, because they are only the evolutionarily-computed best bet, based on ancestrally summed outcomes; they are not a sure bet, based on an unattainable perfect knowledge of the present.

Whether individuals report consciously experiencing fear is a separate question from whether their mechanisms assumed the characteristic configuration that, according to this theoretical approach, defines the fear emotion state. Individuals often behave as if they are in the grip of an emotion, while denying they are feeling that emotion. We think it is perfectly possible that individuals sometimes remain unaware of their emotion states, which is one reason we do not think subjective experience should be considered the *sine qua non* of emotion. At present, both the function of conscious awareness, and the principles that regulate conscious access to emotion states and other mental programs are complex and unresolved questions. Mapping the design features of emotion programs can proceed independently of their resolution, at least for the present. This computational approach also allows one to test for the presence of emotion programs cross-culturally: the design features of an emotion mode should be present and ascertainable experimentally, whether the language has a word for an emotion state or not (Lutz, 1988).

### **The functional structure of an emotion program evolved to match the evolutionarily summed structure of its target situation.**

According to this framework, the set of human emotion programs assumed their evolved designs through interacting with the statistically defined structure of human environments of evolutionary adaptedness. Each emotion program was constructed by a selective regime imposed by a particular evolutionarily recurrent situation. By an evolutionarily recurrent situation, we mean a cluster of repeated probabilistic relationships among events, conditions, actions, and choice-consequences, that endured over a sufficient stretch of evolutionary time to have had selective consequences on the design of the mind, and that were probabilistically associated with cues detectable by humans.

For example, the condition of having a mate plus the condition of one's mate copulating with someone else constitutes a situation of sexual infidelity: a situation that has recurred over evolutionary time, even though it has not happened to every individual. Associated with this

situation were cues reliable enough to allow the evolution of a “situation detector” (e.g., observing a sexual act, flirtation, or even the repeated simultaneous absence of the suspected lovers are cues that could trigger the categorization of a situation as one of infidelity). Even more importantly, there were many necessarily or probabilistically associated elements that tended to be present in the situation of infidelity as encountered among our hunter-gatherer ancestors. Additional elements include: (1) a sexual rival with a capacity for social action and violence, as well as allies of the rival; (2) a discrete probability that one’s mate has conceived with the sexual rival; (3) changes in the net lifetime reproductive returns of investing further in the mating relationship; (4) a probable decrease in the degree to which the unfaithful mate’s mechanisms value the victim of infidelity (the presence of an alternative mate lowers replacement costs); (5) a cue that the victim of the infidelity will likely have been deceived about a range of past events, leading the victim to confront the likelihood that his or her memory is permeated with false information; (6) the victim’s status and reputation for being effective at defending his or her interests in general would be likely to plummet, inviting challenges in other arenas. These are just a few of the many factors that constitute a list of elements associated in a probabilistic cluster: they constitute the evolutionary recurrent structure of a *situation* of sexual infidelity. The emotion of sexual jealousy evolved in response to these properties of the world—this situation—and there should be evidence of this in its computational design (Buss, 2000; Daly, Wilson, & Weghorst, 1982).

Emotion programs have evolved to take such elements into account, whether they can be perceived or not. Thus, not only do cues of a situation trigger an emotion mode, but embedded in that emotion mode is a way of seeing the world and feeling about the world related to the ancestral cluster of associated elements. Depending on the intensity of the jealousy evoked, less and less evidence will be required for an individual to believe that these conditions apply to their personal situation. Individuals with morbid jealousy, for example, may hallucinate counterfactual but evolutionarily thematic contents.

To the extent that situations exhibit a structure repeated over evolutionary time, their statistical properties will be used as the basis for natural selection to build an emotion program whose detailed design features are tailored for that situation. This is accomplished by selection, acting over evolutionary time, differentially incorporating program components that dovetail with individual items on the list of properties probabilistically associated with the situation.

For example, if in ancestral situations of sexual infidelity there was a substantially higher probability of a violent encounter than in its absence, then the sexual jealousy program will have been shaped by the distillation of those encounters, and the jealousy subroutines will have been adjusted to prepare for violence in proportion to the raised probability in the ancestral world. (Natural selection acts too slowly to have updated the mind to post-hunter-gatherer conditions.) Each of these sub-elements and the adaptive circuits they require can be added together to form a general theory of sexual jealousy.

The emotion of sexual jealousy constitutes an organized mode of operation specifically designed to deploy the programs governing each psychological mechanism so that each is poised to deal with the exposed infidelity: physiological processes are prepared for such things as violence, sperm competition, and the withdrawal of investment; the goal of deterring, injuring, or murdering the rival emerges; the goal of punishing, deterring, or deserting the mate appears; the desire to make oneself more competitively attractive to alternative mates emerges; memory is activated to reanalyze the past; confident assessments of the past are transformed into doubts; the general estimate of the reliability and trustworthiness of the opposite sex (or indeed everyone)

may decline; associated shame programs may be triggered to search for situations in which the individual can publicly demonstrate acts of violence or punishment that work to counteract an (imagined or real) social perception of weakness; and so on.

It is the relationship between the summed details of the ancestral condition and the detailed structure of the resulting emotion program that makes this approach so useful for emotion researchers. Each functionally distinct emotion state—fear of predators, guilt, sexual jealousy, rage, grief, and so on—will correspond to an integrated mode of operation that functions as a solution designed to take advantage of the particular structure of the recurrent situation or triggering condition to which that emotion corresponds. This approach can be used to create theories of each individual emotion, through three steps: (1) Reconstructing the clusters of properties of ancestral situations; (2) Constructing engineering analyses about how each of the known or suspected psychological mechanisms in the human mental architecture should be designed to deal with each ancestral condition or cluster of conditions, and integrating these into a model of the emotion program; (3) Constructing or conducting experiments and other investigations to test and revise the models of emotion programs.

It is also important to understand that evolutionarily recurrent situations can be arrayed along a spectrum in terms of how rich or skeletal is the set of probabilistically associated elements that defines the situation. A richly structured situation, such as sexual infidelity or predator ambush, will support a richly substructured emotion program in response to the many ancestrally correlated features: Many detailed adjustments will be made to many psychological mechanisms as instructions for the mode of operation. In contrast, some recurrent situations have less structure (i.e., they share fewer properties in common), and so the emotion mode makes fewer highly specialized adjustments, imposes fewer specialized and compelling interpretations and behavioral inclinations, and so on. For example, surges of happiness or joy are an emotion program that evolved to respond to the recurrent situation of encountering unexpected positive events (as will be explained). The class of events captured by “unexpectedly positive” is extremely broad, general, and have only a few additional properties in common. Emotion programs at the most general and skeletal end of this spectrum correspond to what some call “mood” (happiness, sadness, excitement, anxiety, playfulness, homesickness, and so on).

### **Recalibrational emotions, evolved regulatory variables, and imagined experience.**

Information about outcomes is not equally spread throughout all points in time and all situations. Some situations are information-dense, full of ancestrally stable cues that reliably predicted the fitness consequences of certain decisions or revealed important variables (e.g., discovering who your father really is or how good a friend someone has been to you) and could therefore be used to alter weightings in decision rules.

Indeed, we expect that the architecture of the human mind is full of evolved variables whose function is to store summary magnitudes that are useful for regulating behavior and computation. These are not explicit concepts, representations, or goal states, but rather registers or indices that acquire their meaning by the evolved behavior-controlling and computation-controlling procedures that access them. Such regulatory variables may include measures of: how valuable to the individual a mate is, a child is, one’s own life is, etc.; how stable or variable the food productivity of the habitat is; the distribution of condition-independent mortality in the habitat; one’s expected future lifespan or period of efficacy; how good a friend someone has been to you; the extent of one’s social support; one’s aggressive formidability; one’s sexual

attractiveness; one's status or self-esteem; the status of the coalition one belongs to; present energy stores; present health; the degree to which subsistence requires collective action, and so on.

Most evolutionarily recurrent situations that select for emotion programs involve the discovery of information that allows the recomputation of one or more of these variables. Recalibration (which, when consciously accessible, appears to produce rich and distinct feeling states) is therefore a major functional component of most emotion programs. Jealousy, for example, involves several sets of recalibrations (e.g., decrease in estimate of own mate value, decrease in trust). *Recalibrational emotion programs* are emotion programs such as guilt, grief, depression, shame, and gratitude, whose primary function is to carry out such recomputations (Tooby & Cosmides, 1990b), rather than to orchestrate any short run behavioral response. These are emotion programs that have appeared puzzling from a functional perspective because the feelings they engender interfere with short-term utilitarian action that an active organism might be expected to engage in.

Consider guilt. Hamilton's (1964) rule defines the selection pressures that acted to build the circuits governing how organisms are motivated to allocate benefits between self and kin. This rule says nothing, however, about the procedures by which a mechanism could estimate the value of, say, a particular piece of food to oneself and one's kin. The fitness payoffs of such acts of assistance vary with circumstances. Consequently, each decision about where to allocate assistance depends on inferences about the relative weights of these variables. These nonconscious computations are subject to error. Imagine a mechanism that evolved to allocate food according to Hamilton's rule, situated (for example) in a hunter-gatherer woman. The mechanism in the woman has been using the best information available to her to weight the relative values of the meat to herself and her sister, perhaps reassuring her that it is safe to be away from her sister for awhile. The sudden discovery that her sister, since she was last contacted, has been starving and has become sick, functions as an information-dense situation allowing the recalibration of the algorithms that weighted the relative values of the meat to self and sister. The sister's sickness functions as a cue that the previous allocation weighting was in error and that the variables need to be reweighted—including all of the weightings embedded in habitual action sequences. We believe that guilt functions as an emotion mode specialized for recalibration of regulatory variables that control trade-offs in welfare between self and other (Tooby & Cosmides, 1990b).

One significant subcomponent of these recomputational bouts is imagined experience, including both factual and counterfactual elements, to potentiate branching decision points and the variables that govern them (Cosmides & Tooby, 2000a, b; Tooby & Cosmides, 2001). Previous courses of action are brought to mind (I could have helped then, why didn't I think to?), with the effect of resetting choice points in decision rules. The negative valence of depression may be explained similarly: former actions that seemed pleasurable in the past, but which ultimately turned out to lead to bad outcomes, are re-experienced in imagination with a new affective coloration, so that in the future entirely different weightings are called up during choices.

### **Recalibrational releasing engines.**

The environment of evolutionary adaptedness was full of event relationships (e.g., mother is dead) and psychophysical regularities (e.g., blood indicates injury) that cued reliable information about the functional meanings and properties of things, events, persons, and regulatory variables to the psychological architecture. For example, certain body proportions

and motions indicated immaturity and need, activating emotion programs for nurturing in response to “cuteness” releasers (see, Eibl-Eibesfeldt, 1970). Others indicated sexual attractiveness (Symons, 1979; Buss 1994). To be moved with gratitude, to be glad to be home, to see someone desperately pleading, to hold one’s newborn baby in one’s arms for the first time, to see a family member leave on a long trip, to encounter someone desperate with hunger, to hear one’s baby cry with distress, to be warm while it is storming outside: these all *mean* something to us. How does this happen?

In addition to the situation-detecting algorithms associated with major emotion programs such as fear, anger, or jealousy, we believe that humans have a far larger set of evolved specializations that we call *recalibrational releasing engines* that involve situation-detecting algorithms, and whose function is to trigger appropriate recalibrations, including affective recalibrations, when certain evolutionarily recognizable situations are encountered. By coordinating the mental contents of individuals in the same situation (since both intuitively know that, for example, the loss of one’s mother is, as a default, experienced as a sad and painful event), these programs also facilitate communication and culture-learning, both of which depend on a shared frame of reference. Although these pervasive micro-programs construct a great deal of our world, investigations are only beginning into adaptations of this nature.

**The role of imagery and emotion in planning.** Imagery is the representation of perceptual information in a format that resembles actual perceptual input. In the evolution of animal nervous systems, simpler designs preceded more complex designs. The evolutionary designs of all modern species, including humans, use distinctive constellations of perceptual inputs as signals of states of affairs (for the rabbit, the outline of a hawk silhouette means a hawk is swooping in). Consequently, the key to unlocking and activating many complex evolved decision and evaluation programs was chained to the present: to being in an environment displaying specific perceptually detectable cues and cue constellations (sweetness, predators, running sores, emotion expressions).

There is a large inventory of wisdom stored in such programs, but this information, initially, could be used only by organisms in the environment displaying the activating cues—a profound limitation. An important design advance was achieved when psychological architectures evolved in which these programs could be accessed by feeding a decoupled fictional or counterfactual set of perceptual images, or event-relations, so that the response of these programs could be unleashed, experienced and analyzed as part of planning and other motivational and recalibrational functions (Tooby & Cosmides, 1990b, 2001; Cosmides & Tooby, 2000a,b). For example, the earlier design would go into a fear emotion mode and flee the predator when encountered. The new design could imagine that a planned course of action would, as a side-effect, bring it into confrontation with a predator, experience (in appropriately attenuated and decoupled form the fear program, and recognize that prospective, potential course of action as one to be avoided. (On mechanisms allowing decoupled cognition, see Leslie, 1987.)

Recreating cues through imagery in a decoupled, offline mode triggers the same emotion programs (minus their behavioral manifestations), and allows the planning function to evaluate imagined situations by using the same circuits that evaluate real situations.<sup>xiii</sup> This would allow alternative courses of action to be evaluated in a way similar to the way in which experienced situations are evaluated. In other words, image-based representations may serve to unlock, for the purposes of planning, the same evolved mechanisms that are triggered by an actual encounter with a situation displaying the imagined perceptual and situational cues. For example, imagining

the death of your child can call up the emotion state you would experience had this actually happened, activating previously dormant algorithms and making new information available to many different mechanisms. As many have recognized, this simulation process can help in making decisions about future plans: Even though you have never actually experienced the death of a child, for example, an imagined death may activate an image-based representation of extremely negative proprioceptive cues that “tell” the planning function that this is a situation to be avoided. Paradoxically, grief provoked by death may be a byproduct of mechanisms designed to take imagined situations as input: it may be intense so that, if triggered by imagination in advance, it is properly deterrent. Alternatively (or additionally), grief may be intense in order to recalibrate weightings in the decision rules that governed choices prior to the death. If your child died because you made an incorrect choice (and given the absence of a controlled study with alternative realities, a bad outcome always raises the probability that you made an incorrect choice), then experiencing grief will recalibrate you for subsequent choices. Death may involve guilt, grief, and depression because of the problem of recalibration of weights on courses of action. One may be haunted by guilt, meaning that courses of action retrospectively judged to be erroneous may be replayed in imagination over and over again, until the reweighting is accomplished. (From this perspective, the fact that counterfactual reasoning in children is triggered only by negative outcomes (German 1999) may be a design feature of a recalibrational emotion). Similarly, joyful experiences may be savored, that is, replayed with attention to all of the details of the experience, so that every step of the course of action can be colored with positive weightings as it is rehearsed, again, until the simulated experience of these pseudo-“learning trials” has sufficiently reweighted the decision rules.

### **Coda**

Now that we have sketched an evolutionary perspective on cognition, motivation, and emotion, and the role that imagery and decoupled cognition play in human mental life, let us briefly return to an earlier question. We began our discussion of traditional versus evolutionary approaches to psychology by noting that humans are able to solve a wide array of problems that were no part of their evolutionary history, and that this observation lent appeal to the view that the mind is a general purpose machine. But this is to confuse the range of problems solved with the architecture that solves it. After all, an architecture packed with specialized programs can solve a wide range of problems in a flexible, sophisticated fashion. The more programs the mind is equipped with, the more problems it can solve. This includes evolutionarily novel problems.

What determines whether a program can solve a problem is its causal structure, which sometimes matches an evolutionarily novel problem well-enough to provide a solution. Moreover, the set of conditions that activate a domain-specific program—its actual domain of application—is necessarily larger than its proper domain of application (i.e., the set of conditions for which it evolved; Sperber, 1994). Domain-specific programs are activated by cues that were correlated ancestrally with the presence of the adaptive problem they were designed to solve. But correlation is never perfect: contingent reactivity and self-propelled motion may reliably indicate that an object is an animal, for example, but these cues can also be present when one sees a child interact with Tickle-me Elmo, a car moving on the freeway, cartoons, or even a wind-blown branch. After all, signal detection problems are ubiquitous, and will apply to situation-detectors and psychophysical activating cues as well as to other problems. Ancestrally and now, mechanisms will sometimes be triggered outside the context for which they evolved. Sometimes this will lead to useful inferences, sometimes not. For example, ancient astronomers

observed that stars move across the sky, an observation that may have activated their mental state inference system. But construing stars as intentional beings with souls did not lead to inferences that advanced astronomy. In contrast, construing stars and other celestial bodies them as physical objects, no different in principle than physical objects on earth, was highly productive and led to our modern understanding of astronomy.

Lastly, it would be wrong to exclude the machinery of “higher cognition” from an evolutionary analysis. The evolved architecture of the mind includes specialized mechanisms that permit off-line, decoupled cognition, in which metarepresentations, imagery, and a scope syntax, interact with the outputs of domain-specific mechanisms to allow the counterfactual and suppositional thinking (Leslie, 1987; Sperber, 1994; Cosmides & Tooby, 2000a). Decoupled cognition may have evolved to help calibrate or recalibrate mechanisms through synthesized experience, support planning, infer other people’s mental contents, or imagine solutions to social, tool-use or other problems. And it still does these things. But it also permits the kind of thinking that underlies scientific discovery, religious ideas, and other uniquely human pre-occupations (Sperber, 1994; Cosmides & Tooby, 2000a, 2001; Boyer, 2001; Tooby & Cosmides, 2001).

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<sup>i</sup> The argument that not every beneficial effect of a trait is its function was central to Williams' 1966 critique, which had played a crucial role in the development of sociobiology, which was based on rigorous selectionist theories rather than fuzzy notions of function. Thus many of us were surprised when, twelve years later, Stephen Jay Gould began to make the exact same critique, writing as if it were unknown to the sociobiological community he was criticizing.

<sup>ii</sup> The flawed approach within human sociobiology, pursued only by some, involved measuring the reproductive success of people engaging in different behaviors. These accounts tried to *explain* behavioral choices in terms of their reproductive consequences *in the present and future*. This is similar to axioms of economics, in which it is assumed that actors desire goods, and act so as to acquire them, given their beliefs about current and future situations. The only difference is that "offspring" is substituted for "goods" or utility as the quantity maximized. Both approaches assume that unbounded rationality is possible, and that the mind is a general purpose computer that can figure out, in any situation, what will maximize a given quantity over the long term (whether utility or children). Our view is that one cannot build a computational device that exhibits this form of unbounded rationality (Cosmides & Tooby, 1987). Moreover, Darwin's theory of natural selection does not predict that an animal chooses between alternative behaviors in the *present* by computing their differential consequences for reproduction in the *future*. Instead, it is an account of how *past* selection pressures designed a species' *present* phenotype; it predicts people will behave according to the parameters of their current phenotype. To give a concrete example, in the absence of birth control, males only need a desire to have sex to have offspring. They do not need to be equipped with an independent desire *to sire offspring* (do we really think that worms, oysters, and oak trees have a *desire* for offspring? No: they are designed *such that they produce* offspring.) In the modern world, sex can be decoupled from reproduction via effective birth control. Given that natural selection produced a desire for sex, we should not be surprised to find men who wish to have sex using birth control; nor should we be surprised to find that men are more likely to seek out sexual encounters than opportunities to contribute to sperm banks. Evolutionary psychology arose as distinct from human sociobiology in part because of debates over these issues. Evolutionary psychological objections are detailed in Symons (1989, 1992), Cosmides & Tooby (1987) and Tooby & Cosmides (1990b, 1992). For those interested, the same 1989 volume of *Ethology and Sociobiology* contains papers arguing both sides of this debate.

<sup>iii</sup> We sometimes read that the term "evolutionary psychology" was chosen to avoid the bad political press that sociobiology had received, and that evolutionary psychology is "really" just sociobiology. This is historically false,

and betrays a certain ignorance about the debates among people who were interested in sociobiology about what a Darwinian approach actually entails (see footnote 2). In the late 1980s, Martin Daly, Margo Wilson, Don Symons, John Tooby, Leda Cosmides, and David Buss had many discussions about what to call this new field, some at Daly and Wilson's kangaroo rat field site in Palm Desert, some in Santa Barbara, and some at the Center for Advanced Study in the Behavioral Sciences. Politics and the press did not enter these discussions (indeed, each of us had been willing to take the heat when we thought the sociobiology label applied to our interests). What we *did* discuss was that this new field focused on psychology—on the design of the human mind—whereas sociobiology had not. Sociobiology had focused mostly on selectionist theories and therefore “ultimate” explanations (coupled sometimes with the view that understanding proximate mechanisms (psychological or otherwise) was a trivial pursuit better left to duller minds). The subject matter of evolutionary psychology was simply different from that of sociobiology, in the same way that sociobiology was quite different from the ethology that preceded it, and that cognitive psychology was different from the behaviorist psychology—necessitating a new name in each case.

<sup>iv</sup> Unidimensional traits, caused by quantitative genetic variation (e.g., taller, shorter), can be adjusted in less time; see Tooby & Cosmides, 1990a.

<sup>v</sup> Humans do not manufacture vitamin B12 but need B12 to live; B12 is found almost exclusively in meat; mammals do not waste metabolic resources manufacturing essential vitamins that are plentiful in their diets; from these facts we can infer that our ancestors ate meat. How much of this came from hunting versus scavenging is not known, though studies of modern hunter-gatherers suggest most meat comes from hunting. Birds can be exclusive scavengers because they can aerially reconnoiter large expanses in search of kills, but exclusive scavenging is not known in large African land mammals—those that scavenge meat also hunt (scavenging is dangerous given the competition with lions, hyenas, etc; it requires some of the same skills as hunting). From these facts we can infer that the meat our ancestors' consumed was procured, at least in part, through hunting.

<sup>vi</sup> In the case of computer programming, these might include the numerical abilities that underwrite foraging (Wynn, 1998), recursion for producing metarepresentations (Leslie, 1987), grammatical mechanisms (Pinker, 1994), certain deductive capacities (Rips, 1994), and so on. To determine which adaptations underwrite the ability to program computers would require cognitive experimentation aimed at discovering which information-processing mechanisms are activated when someone is engaged in this evolutionarily novel activity. Moreover, different constellations of mechanisms might be activated when different individuals program, precisely because there has not been enough time for natural selection to produce an integrated design specifically for this purpose.

<sup>vii</sup> If this is not clear, imagine you are looking inside a television and considering ways to conceptually divide its innards into parts. A random parsing is unlikely to isolate the functional units that allow a TV to transduce electromagnetic radiation into a color bitmap (its function). Indeed, most ways of dividing its insides will fail to capture *any* functional components, and any such nonfunctional “parts” will be byproducts of the functional ones (Hagen, this volume)

<sup>viii</sup> It is not known, of course, how children learn facts in school—the notion that it is via some form of general purpose learning is an assumption, not a finding for which there is evidence. Indeed, there is starting to be evidence that school-learning piggy-backs off of domain-specific inference mechanisms, being fed linguistic representations (e.g., Hirschfeld & Gelman, 1994).

<sup>ix</sup> Usually little attention is paid to the socio-cultural conditions that must exist—technology, continent-wide markets, literacy, computers, mass communication—before there can be rockets to the moon (or even lemon chiffon pie).

<sup>x</sup> Ironically, the belief-desire folk psychology that blinds us to the need for further explanation is a fairly direct read-out of a neurocognitive specialization designed for inferring other people's mental states (the theory of mind mechanism; Leslie, 1987; Baron-Cohen, 1995).

<sup>xi</sup> If there is no repeated structure, or no cues to signal the presence of a repeated structure, then selection cannot build an adaptation to address the situation.

<sup>xii</sup> Marks (1987, p. 68-69) vividly conveys how many aspects of behavior and physiology may be entrained by certain kinds of fear: “During extreme fear humans may be ‘scared stiff’ or ‘frozen with fear’. A paralyzed conscious state with abrupt onset and termination is reported by survivors of attacks by wild animals, by shell-shocked soldiers, and by more than 50% of rape victims (Suarez & Gallup, 1979). Similarities between tonic immobility and rape-induced paralysis were listed by Suarez & Gallup (features noted by rape victims are in parentheses): (1) profound motor inhibition (inability to move); (2)

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Parkinsonian-like tremors (body-shaking); (3) silence (inability to call out or scream); (4) no loss of consciousness testified by retention of conditioned reactions acquired during the immobility (recall of details of the attack); (5) apparent analgesia (numbness and insensitivity to pain); (6) reduced core temperature (sensation of feeling cold); (7) abrupt onset and termination (sudden onset and remission of paralysis); (8) aggressive reactions at termination (attack of the rapist after recovery); (9) frequent inhibition of attack by a predator...”

<sup>xiii</sup> Recently there have been a spate of misguided experiments that place people under cognitive load and then show that certain evolved emotion programs, such as sexual jealousy, do not perform as predicted (XX). The idea is that evolved mechanisms are “automatic” and therefore should operate regardless of cognitive load. But this last inference is incorrect. If a situation, such as sexual infidelity, must be imagined in vivid detail to unleash the sexual jealousy emotion program, then placing someone under cognitive load will surely interfere.