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Cognition is a biological function, not a cultural invention. Our nervous systems detect, encode, and process information not because someone invented these capacities in antiquity, but because evolutionary forces shaped the organs that instantiate these biological functions. Cognition is the function that ensures a non-arbitrary relation between perception and action. Historically, psychologists have tended to overlook or downplay the role of biology and evolution when developing theories of cognitive functions, with the inevitable result that our theories have often provided inadequate predictions and explanations of cognitive phenomena, from basic inductive processes to higher cognition.

Evolution and Basic Inductive Processes Consider first investigations of spatial learning in the rat. In one standard paradigm, a rat is placed on a central platform with alleys radiating out from the platform like spokes in a wheel. A cache of food is placed at the end of one of the alleys. The maze is constructed such that the rat cannot see the ends of the alleys, and air flow is directed such that no olfactory cues are present to guide the rat to the food. The rat is allowed to explore the maze. After it has found and consumed the food, the rat is removed and placed again on the platform, and the same alley re-baited. What will the rat do now?

Reinforcement theory predicts that the rat will return to the alley where it previously found food because that choice was reinforced (see Hilgard & Bower, 1975, pp. 206-251). But in fact, the rat avoids that alley, exploring virtually every other one before returning to that one (Gaffan, Hansel, & Smith, 1983; Olton, 1978, 1979; Olton & Samuelson, 1976). Only by painstaking repeated trials will the rat eventually behave in accordance with reinforcement theory, returning to the alley that is always baited with food.

After observing this behavior, we may be tempted to conclude that rats are indeed very stupid creatures, failing to notice a very salient contingency between location and food, or that they have very poor spatial memory. But subsequent research suggested otherwise. Suppose on the second trial, another alley is baited, and the rat, during its wanderings discovers the food and consumes it. When given another chance to explore the maze, the rat will now avoid both alleys where it previously encountered food. This effect has been demonstrated in up to eight alleys, with rats studiously avoiding the eight locations where they previously encountered food. This pattern of behavior suggests that rats in fact have excellent spatial memory, but they capitalize on it in order to avoid previous food caches. This seemingly paradoxical result becomes entirely comprehensible if one considers the type of species one is examining—a forager. When foraging in a natural environment, food intake is maximized if locations that have already been stripped of food are avoided. So perhaps the rats' choices are indeed rational, having been shaped by a very long evolutionary history in which the effectiveness of an individual's foraging strategies played a large role in its survival and reproductive success. We can't explain this behavior in terms of learning because the rats used in these studies were naïve laboratory-raised creatures with no foraging experience. The biases they demonstrated were clearly not a result of learning. Their

inductive performance gave researchers a pristine view of how evolution had shaped the mind of this foraging species. This is not to say that rats can't learn to return always to a particular location. Indeed, they can. But it takes a large number of learning trials to overcome this innate foraging bias.

The second example that amply demonstrates the impact of evolutionary constraints on basic inductive processes is the Garcia effect, an effect that has been replicated numerous times in dozens of species (Garcia, Brett, & Rusiniak, 1989; Garcia & Koelling, 1966). In the standard paradigm, animals are allowed to drink bitter-tasting quinine-adulterated water in a room with flashing lights. Half receive a brief electric shock and the remaining half are irradiated to produce nausea. The question is what the animal learns from these experiences. Early learning theories rested on the assumption that an association could be made between any two stimuli through repeated pairings, as in the simple association Pavlov's dogs made between food and ringing bells (see Hilgard & Bower, 1975, pp. 62-89). In the Garcia paradigm, however, the painful shock is paired with flashing lights and bitter-tasting water, so according to simple learning induction principles, the animal should form a negative association equally to both. But that is not what happens. Instead, those shocked avoid drinking while the lights are flashing but are indifferent to bitter-tasting water. Conversely, those who experienced nausea will avoid bitter-tasting water but are indifferent as to whether lights are flashing while they drink.

This effect has been replicated in a number of species, including naïve laboratory-raised rats who could not possibly rely on previous experience with lightning or other worldly phenomena to guide their inductive processes. As this oft replicated effect shows, some associations are more readily induced than others. And this is equally true of humans: People who happen to become ill (e.g., with the flu) after eating an unusual food typically develop long-lasting aversions to the food, even if a day or two intervenes between ingestion and nausea (Bernstein & Borson, 1986; Logue, 1988). Phobias also show this preparedness to induce; people (and naïve laboratory-raised monkeys) are far more likely to develop fear responses to spiders, snakes, or other creatures that proved dangerous during their species' evolutionary histories than to benign creatures or artifacts, such as rabbits, flowers, or spatulas (Cook & Mineka, 1989, Seligman, 1971). In contrast, other types of associations (such as blinking in response to a light that is paired with a jarring puff of air to the eye) take numerous, carefully-paced trials to acquire. Clearly, not all associations are equal in the mind's eye, and our theories must accommodate these evolutionarily-based biases if they are to remain true to our data.

In each of these cases, researchers risked misconstruing the cognitive capacities of the species under consideration and the nature of their inductive learning because they failed to consider evolutionary constraints on otherwise domain-general inductive processes. When taken into account, a very different picture of the cognitive phenomena emerged.

Evolution and Higher Cognition

Cognitive psychologists who fail to take evolutionary history into account when investigating higher cognition risk making the same type of mistake. In his book on visual cognition, David Marr (1982) argued that psychological research and theory ought to be guided by consideration of the types of problems the system was designed (by evolution) to solve.

Although Marr's interest was visual cognition, this exhortation applies equally to all aspects of cognition. Generally speaking, psychologists consider evolutionary constraints only when faced with mounting disconfirming data or seemingly paradoxical, irrational behavior. In the case of higher cognition, the resistance toward considering evolutionary constraints has been strong enough that many have entirely capitulated to the view that human reasoning is error-prone, faulty, biased, and frequently irrational (e.g., Evans, 1989; Piatelli-Palmarini, 1994). Given the considerable scientific, technological, and artistic accomplishments that are the intellectual offspring of human reasoning, this constitutes a paradox indeed. How could a species whose reasoning is as deficient and error-prone as some accounts would have us believe possibly have produced rocket science, sophisticated market-based economies, and the great symphonic works of the nineteenth century? I offer here four examples of how seemingly faulty or irrational human reasoning performance takes on a very different appearance when viewed as psychological adaptations to frequently occurring problems in our species' evolution.

Psychological adaptations for reciprocity as an explanation for cooperation.

Individual self-interest is a fundamental assumption of economics, yet there is ample evidence of cooperative behavior that is inconsistent with this assumption (Camerer & Thaler, 1995; Dawes & Thaler, 1988; Thaler, 1988). Among the most striking demonstrations are results from experimental economics games that involve interactions between anonymous strangers. In the dictator game, for example, two subjects are assigned a provisional \$10. One subject, the dictator, then decides how the money is to be split between the two. While some dictators will give themselves the whole \$10, as standard self-interested economic analyses would suggest, a significant number of dictators--and in many cases the majority--will give the other person a nontrivial amount of the money (e.g., Forsythe, et al., 1994; Hoffman, et al., 1994; Hoffman, et al., 1996; Johannesson & Persson, 2000). In another version of this task, called the ultimatum game, the second player, the responder, has the opportunity to either accept the proposed split or turn it down causing both subjects to walk away with nothing. Significantly more proposers offer the responder a nontrivial amount of the money with the modal offer usually being a 50:50 split. Yet, according to standard game-theoretic analyses, the addition of this second phase of play should make little difference to the proposed divisions. By backwards induction, responders should favor any amount of money over nothing, and the proposers, knowing this, should offer the responders the smallest amount possible. Other studies show that when the subject's task is to decide whether to betray a collaborator and win a fixed amount of money, or trust them and possibly win more or less than the fixed amount (Prisoner's Dilemma game), subjects typically show a greater willingness to trust and a greater unwillingness to forgive betrayals of trust than is predicted by standard game theoretic analyses (Weg & Smith, 1993). Again, our data violate our theories—in this case, normative standards of rationality--and they again do so by showing us characteristic performance patterns that are stable and repeatable.

We can shore up our theories by pointing out that game-theoretic analyses of repeated games show that cooperation in the form of reciprocity—returning kindness for kindness and nastiness for nastiness—is indeed an equilibrium outcome of rationally self-interested play. These analyses, however, leave much unexplained. Reciprocity is just one of many equilibrium outcomes, yet it seems to be the most frequent one observed in experimental settings. Further,

the dictator and ultimatum games are not repeated games, so the participants have no prior experience with their partners upon which to base their decisions. Instead, participants seem to enter these games with a definite bias toward cooperation, and violations of cooperation are responded to quite vehemently. This bias is quite specific and robust. The question is whether it is the result of prior experience with similar situations in the course of everyday life, or whether (like the Garcia effect and foraging biases) it constitutes something more fundamental in the nature of human cognition.

In his seminal essay on reciprocal altruism (cooperative effort for mutual benefit), Trivers (1971) hypothesized that due to ancestral humans' long lifespans, low dispersal rates, and mutual dependence, there would have been many repeated opportunities for mutually cooperative interactions, and hence the evolution of reciprocity. Subsequent evolutionary analyses of reciprocity repeatedly showed that reciprocity cannot evolve as an evolutionarily stable strategy unless cheaters can be recognized and excluded from future transactions (e.g., Axelrod, 1984; Axelrod & Hamilton, 1981). Using this evolutionary foundation, Cosmides and Tooby (1989, 1992; Cosmides (1989) proposed an adaptationist account of social exchange (Social Contract Theory) in which they hypothesized that humans evolved psychological adaptations for engaging in mutually beneficial, reciprocal exchanges. Essentially, this is a commitment to the claim that humans are biologically predisposed to detect, engage in, and reason effectively about social exchange. A social exchange is defined in terms of mutual benefits, and can be expressed propositionally as: If Benefit [to Party X from Party Y] then Benefit [to Party Y from Party X]. When such a situation is encountered, algorithms for reasoning about social exchange are activated. One key algorithm (as predicted by evolutionary analyses of reciprocity) is cheater detection. Cooperators should be particularly keen on monitoring the behavior of their partners to ensure that cheating has not occurred, that is, that the partner has not reneged on reciprocation of benefits after having accepted the benefit offered.

When viewed from this evolutionary perspective, the bias for reciprocity that subjects show in experimental economics studies no longer seems surprising or paradoxical. If humans evolved predispositions for engaging in social exchange, these tendencies are likely to be invoked in modern experimental economics games where there is the potential for cooperative interaction. Even though experimental settings often are contrived to be one-shot games, the psychological mechanisms that are invoked evolved in repeated game situations. Consistent with this interpretation is the observation that the ability to detect and punish cheaters has a large influence in producing cooperative outcomes that deviate from standard game-theoretic predictions (Fehr & Gächter, 2000; Fehr, Gächter, & Kirchsteiger, 1997).

An alternative explanation for subjects' predispositions for reciprocity is simply that these experimental economics games, as contrived as they appear to be, are sufficiently similar to other situations that humans are likely to encounter frequently during everyday life (Camerer & Thaler, 1995). Other converging evidence from the developmental and comparative literatures, however, speaks against this interpretation. Within the first year of life, infants engage in reciprocal turn-taking behavior with caregivers (Vandell & Wilson, 1987), and by at least the third year of life, children are selective in their distribution of altruistic acts, preferring to aid those who have aided them in the past (Smith, 1988). Children as young as four years of age reason

effectively about reciprocal exchange, correctly identifying instances of compliance as well as instances of cheating (Harris, in press). Their performance on this type of social reasoning task contrasts sharply with typical performance on other types of reasoning tasks, such as transitive reasoning or syllogistic reasoning, which do not reliably emerge until considerably later in childhood (Bryant & Trabasso, 1971; Overton, Ward, Noveck, Black, & O'Brien, 1987).

Reciprocity also has been observed in the interactions of non-human animals, which is why evolutionary biologists took an interest in it in the first place. The most celebrated example is the reciprocity of vampire bats, which feed on the blood of other species (Wilkinson, 1984). Bats who have not been successful in their nightly foraging for blood will beg for some regurgitated blood from roost-mates. They are most likely to receive aid from bats with whom they have shared blood in the past. Similarly, vervet monkeys are more likely to respond to calls for help from non-kin in agonistic encounters if the caller has groomed them recently, and they also form the strongest alliances with individuals who groom them most often (Seyfarth, 1976; Seyfarth & Cheney, 1984). Chimpanzees retaliate against individuals who show a low rate of food distribution relative to others, either by directly aggressing against them when they themselves request food (de Waal, 1989), or by misinforming or failing to inform them about the location of food (Woodruff & Premack, 1979). Chimpanzees also show reciprocity of supportive and retaliative interventions in that the rate of intervention by individual A on behalf of B correlates with the rate by B on behalf of A, and the rate of intervention against A by B correlates with the rate of intervention against B by A (de Waal, 1992).

Reciprocity also appears to be the cement that binds alliances together, and the strength of one's alliances determines one's rank within the social group. Among male chimpanzees, rank is acquired and maintained through dyadic aggression, and alliances determine the fate of outranked individuals, including alpha males whose rank is usurped (Chapais, 1988, 1992; Datta, 1983a-b; Riss & Goodall, 1977; Uehara, Hiraiwa-Hasegawa, Hosaka, & Hamai, 1994). Alpha males who form or already possess strong alliances with other males maintain a relatively high, stable position within the group, while those who have no alliances or weak alliances are ostracized, maintaining a solitary existence outside the group. This is a particularly important finding because rank correlates with reproductive success (Altmann, et al., 1996), and reproductive success is the engine that drives the evolution of species. Essentially this means that reproductive success depends on alliance formation, and alliance formation in turn depends on forming and monitoring relationships based on reciprocity. With such evolutionary pressure surrounding this capacity, it should come as no surprise that reciprocity emerges very early in human development.

So perhaps, like rats in star mazes, human subjects in experimental economics studies are behaving quite rationally, and their performance patterns are providing a pristine view of how evolution shaped the nature of human cognition. The bias toward reciprocity is perhaps like the Garcia effect and the foraging behavior of rats--more biological bias than experientially induced. The early emergence of reciprocity in human development, its prominent role in evolutionary theory, its substantial contribution to reproductive success in other species, and the ubiquity with which it appears as a bias in experimental economics studies collectively substantiate this claim.

Reasoning about behavior vs reasoning about truth: Psychological adaptations for deontic reasoning. Imagine someone tells you something odd about a mutual friend of yours, namely:

If John stays overnight at his cabin, then he always comes home with a sack of garbage. (If p, then q)

As proof, your friend has kept tabs on John, writing down where he went and what he brought home with him everyday for the past three months. He stored the daily information on file cards. On one side of each card, he wrote down where John went and on the back he wrote down whether or not John returned with a sack of garbage. Here are four of these cards. Two are shown face side-up and two are back side-up.

<p><u>April 3</u> John stayed overnight at his cabin</p>	<p><u>April 15</u> John stayed overnight elsewhere</p>	<p><u>April 20</u> John returned home with a sack of garbage</p>	<p><u>April 25</u> John returned home without a sack of garbage</p>
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Suppose you wanted to prove your friend was wrong. Which card or cards would you turn over?

This is a truth-testing problem; your job is to find out whether the statement is true or false. This type of reasoning is sometimes called theoretical or discursive reasoning. When asked to test the truth of statements like this, people typically choose to inspect instances of P and Q (e.g., to inspect the cards labeled John stayed overnight at his cabin (P) and John returned home with a sack of garbage (Q)).

Now imagine that John's cabin is in a wildlife preserve, and it is required that all overnight visitors take their garbage out with them in order protect the environment and discourage scavenging. Suppose your job is to make sure John isn't breaking the rule. Which card or cards would you turn over?

In this case, we're not concerned with the truth of the rule. We assume the rule is true. Instead, we're interested in rule compliance because this rule is prescriptive. If John stays at his cabin, he is obligated to carry his garbage out. Reasoning about obligations, permissions, and prohibitions is called deontic (or practical) reasoning. We engage in deontic reasoning whenever we are concerned with determining what one may, must, or must not do. The typical answer on deontic problems like this is P and NOT-Q (e.g., to inspect the cards labeled John stayed overnight at his cabin and John returned without a sack of garbage).

These typical answers may seem so obvious that one may wonder why I'm discussing them at all. But consider this: In the truth-testing case, had we inspected the occasions in which John came home without a sack of garbage (NOT-Q card) and discovered that he'd been to his cabin, this would have provided incontrovertible proof that the statement was false. Instead, we tend to choose the Q card. Suppose we inspect the Q card and find that John had been somewhere else when he returned with a sack of garbage. Does that mean the statement is false? No. The statement doesn't say that he returns with garbage only when he's been to the cabin. Suppose we inspect the same card and discover that he'd been to the cabin. Can we safely

conclude that the statement is true? No. That card only shows that he returned with garbage on that occasion. It provides supporting but not conclusive evidence. In fact, suppose instead of one card, the display above represents entire stacks of cards, all of them oriented the way the top card is displayed. Now suppose we inspected every single Q card and found that everytime he returned with garbage, he'd been to his cabin. Can we conclude the statement is true? No. That stack doesn't contain all the occasions when he visited the cabin. The P stack contains all of those. Inspecting the Q card (or stack) is pretty uninformative either way you look at it, while inspecting the NOT-Q card (or stack) is potentially more informative. So we should choose to inspect P and NOT-Q in both versions of the task. Yet it does not occur to us to look for potential violations of the statement in the truth-testing case. The need only seems apparent in the deontic case.

If this apparent deficiency in our truth-testing reasoning seems more like a curiosity than something researchers should be getting exercised about, consider that this type of reasoning constitutes the foundation of scientific endeavors, jurisprudence, and investigative reporting. In each of these disciplines, decisions must be made about which evidence to seek, how evidence is to be evaluated, and what constitutes sufficient proof upon which to base a conclusion. In each, we are concerned with discovering the truth, often by testing assertions or hypotheses. Resoundingly poor performance on truth-testing tasks in psychological investigations therefore should give us considerable pause. We appear to perform better when evaluating compliance than when evaluating truth, and this deontic effect has been replicated in dozens of experiments using a variety of experimental tasks over the course of thirty years (see Cummins, 1996b for a review of this literature). The question is why.

A number of explanations for the deontic effect have been offered, none without controversy. Peter Wason first reported the confirmation-bias response pattern on the truth-testing version of this task in (1968 using an abstract problem involving cards and letters. The conditional used in the task was If a card has a vowel on one side, then it has an even number on the other side. Subsequent studies reported better performance on conditionals with more thematic content, and the poor performance observed on the original Wason task was attributed to the abstractness of the original materials (e.g., Johnson-Laird, Legrenzi, & Legrenzi, 1972). Subsequent research falsified this interpretation because not all familiar content produced a shift in response bias (e.g., Griggs & Cox, 1982; Reich & Ruth, 1982). It was not so much rule-familiarity that was found to produce the shift in performance but a difference in the type of reasoning that was evoked by the task. Truth-testing typically evokes a rule-confirming strategy while compliance-testing typically evokes a violation-detection strategy. Cheng and Holyoak (1985) argued that this shift in reasoning reflected the evocation of class-specific schemas, schemas that were induced through experience with frequently occurring, highly important classes of situations (such as permissions). This explanation, however, is insufficient because it either rests on an implicit assumption that people have more experience with cheating than with mistakes or lying (which pushes the envelope of credibility) or implies that we induce the correct strategy from our experiences with cheating but the wrong strategy from our experiences with testing truth.

A number of researchers have appealed to the notion of expected utility in explaining the deontic effect. For example, Oaksford and Chater (1994) have argued that the shift in selection patterns on the truth-testing and deontic versions of the Wason task indicates that people view these tasks in terms of optimal data selection, and shift their strategies from maximizing expected information gain on the truth-testing version to maximizing expected utility on the deontic version. Further, they argue that both strategies are rational and perfectly adapted to the structure of the tasks. The key to this rationality lies in the assumptions one makes about the distribution of P and Q cases in the population. When P and Q are rare, Q cases yield higher potential information gain than NOT-Q cases, so selecting Q cases on the truth-testing task optimizes expected information gain. Going back to our earlier example, suppose John rarely stays overnight at his cabin (P), but, given that he travels frequently, he often stays overnight other places (NOT-P). Suppose also that he rarely brings home garbage (Q) but frequently brings home other things (NOT-Q) due to his frequent travels. Given that information, one would assume that the P and Q stacks would be pretty small, but the NOT-P and NOT-Q stacks would be quite large. If you had better things to do with your time other than search through these stacks, it would make more sense to sample the Q stack than the NOT-Q stack. It's smaller in number and the incidence of P cases is small as well, so the likelihood of getting useful information on any given draw from the Q deck is greater than from the NOT-Q deck. You wouldn't get the definitive proof that you needed about the truth of the statement, but you are more likely to at least accumulate useful information (i.e., P & Q cases) in a shorter period of time. To get definitive proof, you would need to search the NOT-Q deck, but, again, if the number of cards in that deck is very large and the incidence of P cases is very small, the likelihood of finding the information you need (a P case in the NOT-Q deck) is very small. (If P were abundant, then selecting NOT-Q would be more informative.) There is one exception to the need to examine NOT-Q cases: If you knew that John had gone to the cabin exactly, say, five times, you could also get definitive proof if you just checked Q cases. If you found only four cases of John stayed overnight at his cabin (P) in the Q deck, you'd know the missing P case would have to be in the NOT-Q deck, so the statement is false. If you found all five in the Q deck, you'd know the statement is true. In actual cases of hypothesis-testing, however, we rarely have the means to examine every case in an entire population. Typically, we must sample the population and draw inferences on the basis of the distribution characteristics of that sample.

This entire explanation, however, depends on the rarity assumption and it isn't clear how often or under what circumstances people make such an assumption. Consider again our example of John and his garbage. No mention was made about the frequency with which John either visits his cabin or lugs home garbage. While one could possibly argue that people assume lugging home garbage is pretty rare, it seems a stretch to argue that they also assume John visits his cabin infrequently. In fact, the preferred P and Q selection response has been demonstrated repeatedly with conditionals that don't seem to invite this assumption, such as *When I go to work, I hurry* (Reich & Ruth, 1982) or *If a person is over 19, then the person must be drinking beer* (Cox & Griggs, 1982).

Oaksford and Chater (1994; 1996) explain the shift in response pattern on the deontic version of the task by arguing that people shift away from rule-testing to rule use. They argue

that under these conditions people seek to maximize expected subjective utility. In so doing, they attempt to avoid the criticism of invoking without explaining the deontic concepts of obligation and entitlement that appear to be pivotal in people's reasoning (Manktelow & Over, 1991), an approach taken by others as well (Kirby, 1994; Manktelow & Over, 1990, 1991, 1995). The rarity assumption is relaxed because the authors believe it is not reasonable to prejudge rarity on this task. Instead, it is assumed that people assign utilities to cards based on their goals, which are defined in terms of identifying rule violations or discovering instances of unfairness. The basic idea is that people look to satisfy their interests by obtaining benefits and minimizing costs. Subjective utility is assigned in advance to the cards, but the basis upon which those assignments are made is not addressed other than to say that those are the cards that would be of use given the nature of deontic structures such as obligations and permissions. For example, they argue that an enforcer's goal is to discover instances of rule violation, which consist of cases where the person being monitored performs an action without first satisfying its precondition, and these are the only instances that are assigned positive utility.

Manktelow and Over (1990, 1991, 1995) also explain performance on the deontic version of the selection task by modeling it as a process in which subjects seek to maximize subjective expected utility. Reasoners construct a model of the conditional statement along with possible outcomes, and evaluate these outcomes in terms of costs (negative utility) and benefits (positive utility). To explain the selection pattern on the truth-testing version of the task, Evans and Over (1996) invoke the concept of subjective epistemic utility rather than Oaksford and Chater's expected information gain. Subjective epistemic utility is defined as the usefulness of data in determining the truth status of an hypothesis relative to a rival hypothesis. Reasoners try to maximize expected epistemic utility by choosing evidence that will reduce their uncertainty about a particular claim relative to another. A card's informativeness depends on the magnitude of the difference between the certainty of one's belief in the statement before and after turning the card. If one revises the certainty of one's belief after turning the card, then the card has been informative. Consider again the tendency to choose the Q card on the truth-testing version of the task. If one's degree of uncertainty in the truth of the statement decreases as a result of turning this card, then the card has positive epistemic utility.

What should be apparent in this discussion is the stark asymmetry in the need for explanation between the two versions of the task. Virtually all researchers agree that people are concerned with subjective utility when testing compliance with prescriptive rules, but substantial disagreement exists concerning what counts as an efficacious and rational strategy when testing a statement's truth. Oaksford and Chater's (1994; 1996) analysis of truth-testing, for example, has drawn fire from a number of fronts (see Oaksford & Chater, 1996 for summaries and replies to these objections). One might ask, 'Why?' Why is the deontic version of the task so much clearer and easier for humans to reason about while the truth-testing version is not--even though they often require identical responses? Why, in fact, do people perform well on the deontic version of the task regardless of general intellectual ability or level of education while performance on the truth-testing version correlates positively with intelligence (Stanovich & West, 1998)? Is it something about the nature of the tasks or something about the nature of human cognition?

Perhaps what tilts the balance of evidence in favor of the latter is the early emergence of the deontic effect in human development. Unlike other reasoning skills which show pronounced performance improvements during development, children as young as three years of age show the same deontic effect that is apparent in adult reasoners: When presented with social rules, they spontaneously adopt a violation detection strategy (Cummins, 1996a), readily distinguish rule-violating behavior from compliant behavior (Harris & Nunez, 1996), and can give cogent explanations as to why noncompliance constitutes violations of social rules (Harris & Nuñez, 1996). Like adults, they also adopt a confirmation-seeking strategy when testing the truth of utterances (Cummins, 1996a). They also have difficulty distinguishing truth-violating from truth preserving instances (Harris & Nunez, 1996), and cannot give coherent explanations as to why a truth-violating instance is inconsistent with the rule (Harris & Nunez, 1996). From very early in childhood, we seem perfectly capable of inducing the rules that constrain behavior in our social groups, monitoring the behavior of others with respect to them, and detecting non-compliance. Evaluating truth, in contrast, proves decidedly more difficult.

As should be expected from our previous discussion of other cognitive phenomena, some researchers returned to the basic question of how evolution shaped cognition in order to explain this paradoxical cognitive phenomenon which emerges early in life and remains constant throughout the lifespan. The first to offer an evolution-based explanation was Leda Cosmides (1989), who explained the shift in performance on the two versions of the Wason task in terms of Social Contract Theory. She argued that the shift in response bias occurs only when subjects interpret the materials as social contracts with reciprocal benefit structures. An offer to engage in social exchange can be expressed by a rule of the form: If Benefit [to Party X, from Party Y] then Benefit [to Party Y, from Party X]. Subjects encountering such a rule should perceive that individuals who have accepted a benefit without returning a benefit are cheating. From Party X's perspective, the rule has the cost/benefit structure of a social contract: If Benefit Accepted then Cost Paid, where the four cards would now represent the contingencies: Benefit Accepted (P), Benefit not-Accepted (NOT-P), Cost Paid (Q), and Cost not-Paid (NOT-Q). Social Contract Theory predicts that subjects looking to see if Party X cheated will select the Benefit Accepted (P) and Cost not-Paid (not-Q) cards because those are the cases that constitute potential instances of cheating. Using the example above, it seems apparent to us that we need to check the P and NOT-Q cards because that's how John could cheat—by going to the cabin (P) without carrying out his garbage (NOT-Q).

According to Social Contract Theory, then, the deontic effect is simply cheater detection, a phenomenon that biologists have shown to be necessary for the evolution of reciprocity. To support this interpretation, Cosmides (1989) and, subsequently, Gigerenzer and Hug (1992) showed that selection patterns switch to other cards when the reasoner's perspective switches. For example, consider the rule If a customer spends \$100 or more on a purchase (P), the customer should be given a \$20 discount voucher (Q). The store could cheat the customer by not giving the discount voucher even though a purchase for \$100 or more was made. So from a customer's perspective, it's important to check instances where \$100 was spent on a purchase (P) to make sure the \$20 discount voucher was given, and instances where a \$20 discount was NOT given (NOT-Q) to make sure the purchase was for less than \$100. But the store can be

cheated if the \$20 discount was given even though the customer did NOT spend \$100 or more. So from a store manager's perspective, it's important to check instances where less than \$100 was spent (NOT-P) to make sure no discount voucher was given, and instances where the \$20 discount voucher was given (Q) to make sure the purchase was for \$100 or more. And that's in fact what happens: People switch their response bias depending on which perspective they adopt. When they adopt the customer's perspective, they tend to select P and NOT-Q, but when they adopt the store manager's perspective, they tend to select NOT-P and Q (Cosmides, 1989; Gigerenzer & Hug, 1992; Manktelow & Over, 1990; Politzer & Nguyen-Xuan, 1992). These shifts in response patterns are entirely rational because they indicate that people are protecting their interests by ensuring that they have not been cheated.

The Social Contract interpretation of the deontic effect has not been without its critics. Researchers have argued that evolution need not be invoked to explain perspective effects because they can be explained through reference to learned schemas (e.g., Holyoak, & Cheng, 1995; Politzer & Nguyen-Xuan, 1992) or expected subjective utility (Kirby, 1994; Manktelow & Over, 1995; Oaksford & Chater, 1994). One could argue, however, that Cosmides provided an explanation of how and why subjective utility matters by rooting these notions in terms of costs and benefits that impacted our ancestors' survival. Perhaps the most problematic aspect of the theory is that the rules employed in many of the studies evidencing the deontic effect do not appear to fit the definition of cooperative effort for mutual benefit. Instead, they appear to better fit the definition of social regulations or social norms. Social norms are constraints on behavior that are imposed either through convention or by authority. The distinction between a social contract (as defined in Social Contract Theory) and a social norm is analogous to the distinction between a contract and a law. Contracts are typically mutually-agreed upon obligations between two or more individuals. Laws are rules that govern all members of a social group and membership in the group either requires or implies adhering to the rules. Social Contract Theory is particularly restrictive because it applies only to contracts based on reciprocal obligations for mutual benefit; this is because it's theoretical machinery draws directly from evolutionary analyses of reciprocity and the key role played by cheater detection in those analyses. That leaves unexplained why the deontic effect has been observed for rules such as

Drinking Law: If a person is drinking beer, then the person must be over(19. (Griggs & Cox, 1982)

Postal Regulation: If an envelope is sealed, then it must have a 20 cent stamp. (Cheng & Holyoak, 1985)

Tribal Law: If a man eats cassava root, then he must have a tattoo on his face. (Cosmides, 1989)

It is a stretch to make these rules fit the definition of a contract between two or more individuals for mutual benefit. They better fit the definition of a social regulation or social norm. The last of these is of particular interest because it was one of the rules used by Cosmides as evidence in support of Social Contract Theory. The rule was instituted by tribal elders to restrict the use of

cassava root (which was an aphrodisiac) to married men (married men sported tattoos in this mythical tribe).

For this reason, I (Cummins, 1996a-c, 1997, 1998, 1999, 2000, in press) have argued that the deontic effect applies more broadly to any rules that constrain social behavior—not just contracts imposing reciprocal obligations for mutual benefit, and that it's robustness can be accounted for by our evolutionary heritage as a social species. According to standard evolutionary analyses, the fundamental problem that an organism must solve is maximizing reproductive success. That is how natural selection works: Individuals differ, some of these differences provide competitive advantage, allowing them to survive better or longer and therefore leave more offspring who live to reproduce themselves (which is called fitness). Maximizing reproductive success in turn reduces to solving problems of acquiring mates, accessing sufficient food, and avoiding or reducing the risk of death due to predation. One common solution to these problems found in nature is sociality—living in social groups. Despite the clear benefits that derive from sociality, living in social groups also imposes costs in terms constraints on the behavior of individuals. These constraints are termed social norms. Social norms appear not just in the societies of humans but in the societies of non-human animals as well, where they constrain virtually every activity, including who is allowed to sit next to, play with, share food with, groom, and mate with whom (Aruguete, 1994; Hall, 1964). In order to avoid agonistic encounters and ostracism, members of a social group must learn which behaviors are permitted, prohibited, and obligated under which conditions. Flouting these norms carries great risk; in fact, perceived violations of the social code has been designated as the single most common cause of aggression in primate groups (Hall, 1964). Cheater detection, therefore, applies to the breaking of social norms as much as it does to violations of reciprocity.

Explaining the deontic effect in this way accounts for more of the published data than does explaining it in terms of Social Contract Theory. Numerous studies have demonstrated the deontic effect using rules that better fit the definition of social norm than social contract (see Cummins, 1996b for a review of this literature). It also provides an evolutionary foundation upon which this type of cognition could plausibly emerge. Our deontic intuitions concerning obligations, permissions, and prohibitions are rooted in the evolution of social cognition, that is, the cognition that subserves extracting the regularities of the social environment (social norms), and monitoring the behavior of oneself and others with respect to them. Deontic concepts and reasoning strategies emerge early in cognitive development because they are crucial to survival.

The analysis of the social environment and its impact on cognition would not be complete, however, without addressing one final and crucially important aspect: social dominance. I call the complete analysis Dominance Theory. In addition to increasing opportunities for cooperation, sociality results in increased competition for resources. In most mammalian and avian species, this competition produces a complex social structure called a dominance hierarchy. In functional terms, a dominance hierarchy is simply the observation that particular individuals in social groups have regular priority of access to resources in competitive situations (Clutton-Brock & Harvey, 1976). A fundamental tenet of Dominance Theory is that, from a cognitive standpoint, a social dominance hierarchy constitutes a set of implicit social norms that reflect which behaviors are permitted, prohibited, or obligated given one's rank. In

most species, there is a direct relationship between dominance rank and survival, with higher ranking members being less likely to die of predation or starvation (Cheney & Seyfarth, 1990, pp. 33-34), and more likely to leave living offspring (e.g., Dewsbury, 1982; Clutton-Brock, 1988; Ellis, 1995; Fedigan, 1983; Hausfater, 1975; Tutin, 1979; Watts & Stokes, 1971). Among primate species in which dominance rank is unstable, the level of reproductive success achieved by any individual is directly related to the length of time during which the individual is high-ranking (Altmann et al., 1996). Maximizing reproductive success, therefore, is intimately connected to maximizing one's rank.

Low-ranking individuals attempt to improve their access to resources through cheating and deception. For example, they maintain possession of desirable objects or engage in forbidden behaviors by hiding them from view, acting quietly so as not to attract attention, avoiding looking at a desirable object themselves, or distracting attention away from the desired object or forbidden behaviors (Byrne, 1995; Mitchell, 1986; Whiten & Byrne, 1988). They also move forbidden trysts out of line of sight of dominant individuals and suppress copulation cries to avoid detection (Kummer, 1988; de Waal, 1988).

As is apparent, most of these acts of cheating and deception allow lower-ranking individuals to violate social norms without getting caught. This can have enormous beneficial consequences for the cheater or deceiver. The costs associated with cheating, however, can be quite high because dominant individuals maintain priority of access to resources by detecting and punishing cheaters, that is, individuals who attempt to access resources to which they are not entitled. (Interestingly, Cosmides and Tooby, 1997, p. 147, have recently re-defined cheating as taking a benefit that one is not entitled to.) For example, high-ranking individuals often punish acts of cheating as benign as grooming or sharing food with forbidden individuals (de Waal, 1992, pp. 246-249) as well as more serious transgressions such as attempting to mate with estrus females (de Waal, 1992).

Cheater detection is therefore crucial not just to reciprocity and preserving social norms, but to preserving the status quo. The benefits that accrue to individuals for compliance are continued acceptance within the social group (i.e., avoiding ostracism) and avoidance of agonistic encounters with dominants who preserve the status quo. The costs that accrue for compliance include lost opportunities to form alliances or garner a larger share of resources. High-status individuals preserve the status quo by punishing individuals who violate social norms, access resources to which they are not entitled, or engage in disputes with other subordinates.

Dominance Theory is based on an analysis of sociality in various species of non-human animals, particularly primates. Can this analysis be extended to humans? On the face of it, it would seem odd if it could not. This type of social organization and the cognition that subserves it were present and thriving prior to the emergence of protohumans, and natural selection operates on traits that are already present. Further, humans were (and still are) subject to the same pressures from the social environment that other social species are—inducing the norms that constraint behavior in one's social group. It has been argued, however, that despite humans sharing over 97% of our DNA with our closest biological cousin (the common chimpanzee), it is that last 3% that produces the enormous cognitive differences between them and us. So perhaps this is an adequate analysis of struggles in the wild, but it has little to do with modern Homo

sapiens. Testing Dominance Theory is therefore in order, and can be done in a number of ways. I will discuss just two avenues of evidence here: If Dominance Theory applies to humans, one would expect to find status hierarchies in human social groups, and to find that consideration of status impacts expectations regarding acceptable behavior. There is evidence to support both of these assertions.

With respect to the first assertion, status hierarchies emerge early in human development, having been observed in the playgroups of children as young as two years of age (Frankel & Arbel, 1980), and is the earliest and most enduring dimension of peer group social organization (Hold-Cavell & Borsutsky, 1986; La Freniere & Charlesworth, 1983; Lemerise, Harper, & Howes, 1998; Strayer & Trudel, 1984). By four years of age, children can reliably report the structure of these hierarchies indicating conscious awareness of status differences (Smith, 1988). In human socio-economic and socio-political systems, instances of dominance hierarchies include monopolies, monarchies, social stratification, caste and class systems, sexism, and racism. In each case, social, political, and economic power falls disproportionately into the hands of some members of a society at the expense of others. I think I need not point out that inequitable distribution of resources leads inevitably to social strife and disharmony, and that various attempts have been made throughout history to redistribute wealth and power (e.g., the Bolshevik Revolution, the Magna Carta, legal codes, graduated tax laws, and even affirmative action) with varying degrees of success. It probably safe to say that the bulk of human political history is a chronicle of struggles for and against dominance (privileged access to resources).

Dominance also influences socio-political decision-making (Pratto, Tatar, Conway-Lanz, 1999). People who score high on measures of social dominance tend to prefer hierarchical relationships in society, distribution of resources based on merit, conservative ideology, military programs, and punitive justice policies. These are all consistent with maintaining priority of access to resources. Those scoring low on social dominance measures tend to favor social equality, distribution of resources based on need, and social programs. In fact, social dominance measures have been found to account for much of the sex-linked variability in American political attitudes (Pratto, Stallworth, & Sidanius, 1997).

The latter assertion—that consideration of status impacts expectations concerning acceptable behavior—is a prediction that has been tested and supported experimentally. Cummins (1999) found higher levels of cheater detection when reasoners believed themselves to be of higher status than the individuals whose compliance they were monitoring with respect to a social norm. The Wason (1968) task was embedded in a scenario that encouraged the reasoner to adopt the perspective of either a student or a dormitory resident assistant. The rule employed was that if someone is assigned to tutor a study session, that person is required to tape-record the session. The people whose behavior was being monitored were either students or resident assistants, so reasoners who adopted the perspective of a resident assistant believed themselves to be checking on others who were either lower status (students) or equally high status (resident assistants) while reasoners who adopted the perspective of a student believed themselves to be checking on others who were either higher status (resident assistants) or equally low status (students). The proportion of cheater detection responses (P and NOT-Q) was significantly higher when reasoners adopted the perspective of a resident assistant checking on students than

in any other condition. In contrast, status perspective had no impact on the truth-testing version of the task. In this version, reasoners were told they overheard someone saying If I'm assigned to tutor a session, I always tape record the session. Their job was to select the cards that would allow them to discover whether or not the person told the truth. The modal response in this version of the task was P and Q, regardless of status perspective. These results were replicated in a second experiment that employed a within-subject design. In related work using a face recognition paradigm, Mealey and colleagues found that people were more likely to remember low-status cheaters than high-status cheaters or non-cheaters of either status (Mealey, Daood, & Krage, 1996). Social Contract Theory, as it is currently stated, cannot readily accommodate these findings, in part because it is based on an implicit assumption of contracts between individuals of equal exogenous status. Dominance Theory better accounts for these results because (a) it casts cheating as a violation of social norms, not just a violation of reciprocity and (b) the consequences of cheating depend on the individual's status.

The early emergence of the deontic effect in development, its endurance and robustness in adult reasoning, and the central role played by implicit permissions, obligations, and prohibitions in the social interactions of other social mammals are all consistent with an evolutionary interpretation. We are social beings from the moment of birth, and a crucial part of sociality is inducing the rules that constrain behavior and knowing when those rules are being violated. The paradox of selection patterns on the Wason task is no paradox: Of the two version of this task, only one has deep evolutionary roots. This seems to be the most parsimonious explanation of the deontic effect.

Reasoning about Frequencies and Covariation. Consider the following medical reasoning problem discussed by Gigerenzer (1998):

The probability that a person has colon cancer is 0.3%.

If a person has colon cancer, the probability that the test is positive is 50%.

If the person does *not* have colon cancer, the probability that the test is positive is 3%.

What is the probability that person who tests positive actually has colon cancer?

The inference from an observation (a positive test) to an hypothesis (diagnosis) is referred to as Bayesian inference because it can be modeled by Bayes Theorem. Applying Bayes rule to these data yields a probability of 4.7%. Twenty-four physicians were given this problem and asked to answer the final question. Only one physician came up with the Bayesian answer; the median estimate for the rest was 47%--an order of magnitude higher. Contrast this dismal result with physicians' performance on the following problem:

30 out of every 10,000 people have colon cancer.

Of these 30 people with colon cancer, 15 will test positive.

Of the remaining 9,970 people *without* colon cancer, 300 will still test positive.

Imagine a group of people who test positive. How many of these will actually have colon cancer? Using this natural frequency format, 67% of the physicians came up with the correct Bayesian answer. (Similar results were reported in a study involving 100 physicians.) In another study,

canc

college students worked 30 problems in which natural frequency and probability formats alternated from problem to problem. These students performed consistently well on the natural frequency format problems and consistently poorly on the probability format problems. The benefits of natural frequency formats on reasoning performance have been replicated numerous times with a variety of populations (see chapter \diamond of this volume for a complete discussion of this phenomenon).

Paradoxical results like these led many researchers to conclude that human reasoning is hopelessly biased, irrational, error-prone, and dependent on misleading heuristics. Considering that our medical, legal, technological and social institutions are all creations of human reasoning, this is a discomfiting conclusion. But, again, these paradoxical results appear far less paradoxical from an evolutionary viewpoint. Cognition is a biological adaptation for processing information from the physical and social environments. That information does not present itself in terms of single event probabilities and odds/ratios. It comes to us in the form of frequencies of entities and events. Probabilities and percentages are, evolutionarily speaking, quite recent forms of quantitative representations, emerging in the mid-seventeenth century (Hacking, 1975). Percentages did not become common notation until the nineteenth century, and even then were used for interest and taxes rather than as expressions of uncertainty (Gigerenzer, Swijtink, Porter, Daston, Beatty, & Krüger, 1989). It wasn't until the second half of the twentieth century that the terms probability and percentage became part of common parlance. It took millennia of literacy and numeracy to develop these notions culturally, and now takes years of schooling for individuals to develop them as everyday reasoning tools.

In contrast, the ability to *automatically* monitor absolute and relative frequencies appears to be a fundamental cognitive capacity. Numerous studies using a variety of stimuli have reported that people can track frequencies virtually effortlessly and flawlessly (see Hasher & Zacks, 1979), and are remarkably sensitive to covariations among events (Mandel & Lehman, 1998; Spellman, 1996; Waldmann, 2000). Infants as young as six months of age can enumerate objects and sequential actions (Starkey, Spelke, & Gelman, 1983, 1990; Wynn, 1996, 1998). Further, this capacity is not particular to humans. A large body of evidence indicates that a wide variety of vertebrate species are capable of monitoring absolute and relative frequencies as well as covariations. Rats can be trained to press a lever a specific number of times before pressing a second lever a single time to obtain a reward (Platt & Johnson, 1971). Rats, birds, and raccoons are capable of selecting objects based on their ordinal position in an array and learning to turn down the third, fourth, or fifth tunnel in a maze (Davis, 1984; Davis & Bradford, 1986; Pastore, 1961), and chimpanzees can be trained to select the Arabic numeral that correctly corresponds to the numerosity of display items (Matsuzawa, 1985). The results reported in these studies obtained even though potential non-numerical cues were controlled, such as size of the display, stimulus density, odor, location of targets, and elapsed time. And literally hundreds of experiments on conditioning have repeatedly shown that a variety of species (including humans) are sensitive to contingencies among stimuli. If event Y follows event X with sufficient regularity, animals (including humans) will show responses to event X that indicate they anticipate the occurrence of event Y (see Hilgard & Bower, 1975 Ch. 3), and humans will also verbally express the contingency (Waldmann, 2000).

Frequency monitoring and covariation detection are apparently unlearned biological functions that allow entities and events in the environment to be tracked. They contrast sharply with symbolic mathematical systems, which are cultural inventions that must be painstakingly taught. It took the genius of a Newton and a Leibniz to discover the connection between derivatives and integrals, thereby providing the foundation of the symbolic system known as the calculus. Unlike frequency monitoring and covariation detection, symbolic mathematical systems like the calculus must be taught through explicit education. The former capacities are biological capacities shaped by evolutionary forces, the latter are cultural inventions.

Evolution and physical reasoning. Early theories of cognitive development rested on the assumption that infants were little more than sensory-motor systems, and that complex concepts were constructed from these simple building blocks through experience with the environment (Piaget, 1952). But this tabula rasa view of the human mind has given way under the weight of two decades of research on infant cognition. Some types of domain-specific knowledge appear to emerge quite early in infancy, before infants have had sufficient time to induce that knowledge through experience. Rather than Piagetian sensory-motor systems, infants appear to be cognitively predisposed to interpret the world in terms of agents and objects whose behaviors are constrained by different sets of principles (Leslie, 1994; Shultz, 1982; Spelke, 1991, 1994).

Infants as young as 2 1/2 months of age evidence particular expectations concerning objects and their behavior, a sort of naive physics. They appreciate that objects are solid, rigid, and permanent entities that travel in continuous paths, cannot pass through each other, and can causally influence one another only by making direct contact (Spelke, 1994; Spelke, Phillips, & Woodward, 1996; Leslie, 1994; Leslie & Keeble, 1987). Our inferences about their cognition is based on repeated observations of their looking preferences. Infants spend less time looking at displays of objects whose behavior is consistent with these principles than at displays of objects whose behavior appears to violate them. But their impressive performance on these physical reasoning tasks breaks down when the tasks require an appreciation of gravity and inertia. For example, if a ball is dropped behind a screen, and the screen is lifted to reveal the ball hovering in midair above a table, very young infants don't find this any more surprising than if the ball is revealed to have landed on the table. It is not until the end of the first year of life that they begin to look longer at the hovering ball, suggesting a budding appreciation of the effects of gravity. Like gravity, appreciation of inertia seems slow to emerge during infancy. Until about nine months of age, infants don't find it surprising when a ball rolled with great force seems to stop suddenly or change direction of its own accord.

The intriguing thing about this pattern of results is that the physical knowledge that emerges first in infancy appears to constitute a core group of concepts that influence our reasoning even as adults (Spelke, 1991, 1994). In contrast, the knowledge that emerges later remains foreign to our world view, and is difficult to learn and understand. For example, in studies of naive physics, adults who had not studied physics were asked about the behavior of physical objects (McCloskey & Kohl, 1983). Rarely did they make mistakes regarding continuity, solidity, rigidity, or direct causation. These things seem perceptually obvious to them. Errors frequently occurred, however, on judgments concerning inertia and gravity. For example, approximately 50% of volunteers in these studies believed bombs would drop straight

down out of airplanes, instead of obeying the law of inertia and continuing to travel forward until gravity acted on them. They also believed that a ball emerging from a spiral casing would continue on a spiral path, again, instead of obeying the law of inertia and continuing to travel in the same direction it was traveling when it left the casing. College sophomores are not alone in these erroneous beliefs. So believed nearly every ancient and medieval scholar (see Cummins, 1995, pp. 170-174). For centuries, it was believed that setting an object in motion impressed in the object a force, or impetus, that served to keep it in motion. When released, it continued to trace the same trajectory until the force dissipated, even if that trajectory was a spiral. It was not until the 16th century A.D. that we as a species began to appreciate and understand the true physical laws of inertia and gravity, and it took the genius of Galileo and Newton to discover and explicate them. In fact, we owe nearly all of modern technology to the genius of just a handful of gifted people who were able to go beyond the cognitive biases shaped by evolution in order to discover and elucidate the true laws of the physical world.

Biological Determinism and Massive-Modularity vs. Biological Preparedness and Canalization

Developmental studies over the past few decades have given us an unbiased view of how evolution has shaped the nature of human cognition. It is clearly not the case that we come into the world with nothing but an ability to induce concepts from experiences. Instead, we appear to come into the world with certain biases and expectations that fast-tracks the acquisition of certain types of knowledge and reasoning strategies. These privileged domains are those with deep evolutionary histories. The final question in this evolutionary analysis is how these biases are instantiated neurologically.

Evolutionary explanations of cognitive phenomena are often erroneously thought to imply that the cognitive capacities targeted for evolutionary explanation are innate and modular. The term innate is often used to mean anything that is not learned and present at birth. A little reflection, however, shows the inadequacy of this concept. Secondary sexual characteristics are not present at birth but they are surely not learned either. Does this mean they are not innate? Much of the early emerging knowledge discussed earlier in this chapter does not appear to be present at birth, but does seem to come on line prior to the infant accruing sufficient experience to induce it. For this reason, the term innate does not serve us well when developing evolutionary explanations of behavior.

The modularity part of the innate modules view derives from Fodor (1983). But, whereas Fodor held that modules were largely peripheral mechanisms, the modules proposed to account for higher cognition know no such boundaries. Nor are all of Fodor's characteristics always, or even typically, assumed. Rather, the key features are domain specificity (both informationally and computationally), universality (i.e., present in every normal mind in the species), and relative encapsulation (insensitivity to collateral information). The massive modularity view holds that the mind/brain is a collection of relatively independent computational units, a view that is consistent with much of what we know about the adult brain, which exhibits a great deal of functional specialization. Although it is possible, for example,

to force auditory cortex to acquire the capacity for visual processing, the result is not normal vision (Roe, Pallas, Kwon, & Sur, 1992). Similarly, it is highly unlikely that the hippocampus is suited to do either visual or auditory processing. Furthermore, specific neural circuits subserve specific cognitive functions, and damage to those circuits typically produce selective impairments in cognition, not across-the-board reduction in intellectual function (e.g., Broca, 1861; Damasio, 1994; Farah, 1989; Squire, 1992; Warrington & Wieskrantz, 1968; Wernicke, 1874).

Neither the concept of innateness nor the concept of a Fodorian module, however, is necessitated by evolutionary explanations of particular cognitive effects. Instead, the impact of evolution can be conceived in terms of canalization (i.e., the degree to which the development of a trait is robust across normal environmental variations) (Ariew, 1996; Baillargeon, Koyovsky, & Needham, 1996; Cummins & Cummins, 1999; Lewontin, 1974; McKenzie & O'Farrell, 1993; Waddington, 1975). Evolutionary pressures can affect the degree to which the development of a trait is canalized. Canalization is a biological term used to refer to the combination of genetic and environmental factors that cause development to follow a particular pathway. Once begun, development is more or less likely to achieve a particular end-state depending on the type and amount of environmental stimulation the organism receives. Thinking of development in terms of biases and canalization is more consistent with what we know about the developing (as opposed to the adult) brain. The developing brain is better described as exhibiting biases than modules. The environment has profound effects on the developing brain during sensitive periods (Banich, 1997, p. 508). The nervous system is tremendously plastic during development, changing the type and location of cells and how they are interconnected with one another (Gazzaniga, Ivry, & Mangun, 1998, p. 484). Thus, there are neurological biases present at birth, but it is not clear that they fit the notion of a Fodorian module.

For example, limb development is highly canalized in humans (humans everywhere grow limbs in the same way) but not perfectly so, as the example of Thalidomide shows. Other examples are the neurological changes that subserve the development of binocular vision. Binocular columns (used in depth perception) are not present at birth, but appear in the visual cortex during a critical period after the infant has received visual input (Banich, 1997, p. 472). If the brain does not receive the critical input (as in the case of strabismus or exotropia), these columns may not develop at all. Other visual cortical cells show diffuse line orientation preferences at birth, firing maximally to lines of a particular orientation (e.g., vertical), but responding to lines of other orientations as well, albeit to a lesser degree (Hubel, 1988). After receiving visual input, however, these cell preferences are sharpened so that they respond maximally only to lines of a particular orientation (Blakemore, 1974). Further, if visual input is restricted to only a single orientation (e.g., the animal is exposed only to lines of vertical orientation), the majority of cells will shift their preferences to match their visual experiences, responding maximally to lines of vertical orientation even if their initial preferences were for lines of other orientations (Blakemore & Cooper, 1970; Hirsh & Spinelli, 1970). The animal, in short, is blind to all line orientations except that to which it was exposed during this critical period.

These effects are not seen in adult animals. They can be demonstrated only in the developing brain. Development of visual cognitive functions therefore depends on tightly coupled transactions between neurological predispositions and environmental inputs. Under normal circumstances, binocular columns will form in a particular area of visual cortex, and initial diffuse biases in visual cortical cells will sharpen into definite response preferences as a result of environmental stimulation during a critical period of development. The neurological predispositions are there at birth, but require an environmental co-author to fully develop into functions that subserve visual cognition.

With respect to higher cognition, high canalization can be the consequence of biasing learning/acquisition processes in ways that favor the development of concepts and cognitive functions that proved adaptive to an organism's ancestors. The end result of these biases is an adult organism that exhibits a number of highly specialized cognitive abilities that have many of the characteristics associated with modules: functional specialization, reliable emergence in spite of considerable environmental variability, and some degree of informational encapsulation. Perhaps the best example of this is language acquisition. Like vision, language development also shows a complex pattern of interplay between innate biases and environmental input. Deaf babies will begin to babble vocally just as hearing babies do, but their babbling declines and eventually ceases, presumably because they don't receive the auditory feedback hearing babies do (Oller & Eiler, 1988). In other words, babbling deaf babies are practicing sounds that they have never heard. Infants are also born with the capacity to hear all phonetic contrasts that occur in human communicative systems, yet within the first year of life they lose the capacity to distinguish among phonemes that are not marked in their language community (Kuhl, 1987; Eimas, 1975). Thus, they initially exhibit an auditory bias in processing speech sounds that treats the phonemes of human language as signal and everything else as noise, and subsequent language inputs modify this bias to include as signal only the phonemes of the child's native tongue. There also appears to be a critical period for language acquisition that ends approximately at puberty; children who do not acquire their first language during this critical period fail to acquire the rules governing the use of grammatical morphemes and the syntactic constraints necessary for forming grammatical sentences (Curtiss, 1977; Pinker, 1994). Further, the ability to extract the grammatical rules of a natural language is selectively impaired in certain genetic disorders (Gopnik, 1990a and b). Language development therefore is highly canalized, though not so highly as limb development. Though highly canalized, it is still learned. Biology puts strong constraints on what properties a language must have to be learnable (as a first language), and it virtually guarantees that language will be learned in a huge variety of environments. This is what is meant by the claim that language acquisition is highly canalized.

This framework can be readily extended to other cognitive capacities. Consider, for example, the deontic effect. As was discussed earlier, this effect emerges early in human development, having been observed in children as young as three years of age. But expectations concerning agents generally emerge much earlier. Newborns (no more than a few minutes old) show a distinct bias for looking at faces as compared to other equally complex stimuli (Goren, Sarty, & Wu, 1975). They will become distressed if an agent stands silently before their cribs, but are indifferent if a similarly sized stationary object is placed in the same location (Tronick,

Als, Adamson, Wise, & Brazelton, 1978). They also show distinct preferences for interacting with agents, and a keen knowledge concerning their emotional states. Ten-week-old infants distinguish among emotional facial expressions (Haviland & Lelwica, 1987) that other studies have shown to be universally recognized, such as anger, disgust, and happiness (Ekman, 1973). Within the first year of life, infants also engage in social referencing, looking at their caregivers' reactions to novel stimuli (Stenberg & Hagekull, 1997). By 18 months of age, they can succeed at tasks that require them to grasp another's goals, desires, or preferences (Bartsch & Wellman, 1989; Meltzoff, 1995). And by at least 24 months of age, reference to deontic concepts appear in their justifications of behavior (Dunn, 1988).

Infants' preference for attending to social stimuli, their precocity at interpreting emotional facial expressions and their proclivities for engaging in social referencing, constitute developmental biases that can fast track the induction of social norms and the development of compliance-monitoring strategies. Their proclivity for engaging in reciprocal play can also fast track the development of strategies for engaging in and monitoring reciprocity. In short, highly specialized functions need not be present at birth. Instead, the balance of comparative, developmental, and neuroscientific evidence weighs in on the side of fast-track learning through biological biases or predispositions that entrain the focus of our attention on the environmental stimuli and contingencies that really mattered to the survival and reproductive success of our ancestors. Our biological predispositions impose the framework that is necessary to learn the things most vital for survival in a complex social environment, while neurological plasticity allows our actual environmental experiences the final say in whether and how those predispositions are expressed.

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