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ADAPTIVE RATIONALITY: AN EVOLUTIONARY PERSPECTIVE ON COGNITIVE BIAS

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A casual look at the literature in social cognition reveals a vast collection of biases, errors, violations of rational choice, and failures to maximize utility. One is tempted to draw the conclusion that the human mind is woefully muddled. We present a three-category evolutionary taxonomy of evidence of biases: biases are (a) heuristics, (b) error management effects, or (c) experimental artifacts. We conclude that much of the research on cognitive biases can be profitably reframed and understood in evolutionary terms. An adaptationist perspective suggests that the mind is remarkably well designed for important problems of survival and reproduction, and not fundamentally irrational. Our analysis is not an apologia intended to place the rational mind on a pedestal for admiration. Rather, it promises practical outcomes including a clearer view of the architecture of systems for judgment and decision making, and exposure of clashes between adaptations designed for the ancestral past and the demands of the present.

By casually browsing journals in the social sciences one can discover a collection of human biases, errors, violations of rational choice, and failures to maximize utility. Papers published in *Social Cognition* are illustrative. In just 2007, the journal published a special issue dedicated to the hindsight bias, which is the tendency to believe that events that have occurred are more probable when assessing them after the fact than when estimating them prospectively (Blank, Musch, & Pohl, 2007). Other examples include misapprehensions of probability like the hot hand fallacy that leads people to erroneously believe that basketball players who have shot several successful baskets are more likely to succeed on the next try (Gilovich, Vallone, & Tversky, 1985). There are also many effects of emotion purported to cloud good judgment (e.g., Leith & Baumeister, 1996), overuses of stereotypes (Ross & Nisbett, 1991), misapprehensions of the motives of members of the opposite sex (Abbey, 1982), common violations of monetary utility in behavioral eco-

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conomic games (Camerer, 2003; Kahneman, Slovic, & Tversky, 1982), and distortions of memory (Loftus, 2004).

Consider the hindsight bias as an illustration. In studies demonstrating the hindsight bias, participants first estimate the likelihood that certain events will occur. A hindsight bias is found when individuals later report that their likelihood estimate was higher for events that did occur and lower for events that did not (Fischhoff, 2007). For example, if an initial skeptic recalled that her judgment of Barack Obama's likelihood of winning the 2008 presidential election was higher than her actual initial estimate, she would have committed the hindsight bias. There are several possible explanations for such an effect: the bias could be (1) a byproduct of an otherwise useful way of thinking, (2) an artifact of research designs that produce apparent flaws in thinking that are actually unlikely to happen in the natural world, or (3) a genuine error or flaw in the mind (Haselton & Funder, 2006).

The general tendency in psychology is to interpret the supposedly incorrect judgment or reasoning in terms of the last of these categories—as a genuine error or flaw in the mind, perhaps resulting from some sort of cognitive limitation (Lopes, 1991; also see Krueger & Funder, 2004, for a recent review). From an evolutionary perspective, however, it would be surprising if the mind were really so woefully muddled. The mind is an intricate, evolved machine that has allowed humans to inhabit and exploit an incredible range of environments. Humans effectively solve a variety of social-ecological problems including large-scale cooperation, social exchange, habitat formation, agriculture, and cumulative culture. We are a remarkably intelligent species, capable of surviving and reproducing in a complicated and ever-changing world. Could it really be that the human mind is as deeply flawed as the literature suggests?

Knowledge of biases and illusions is of course valuable. For example, demonstrating that a bias may occur in some situations but not others (context effects), or with certain classes of information and not others (content effects), can reveal structural features of the mind. Additionally, knowledge of biases and illusions may have important practical utility by preventing undesirable outcomes. For example, a pilot approaching a runway under conditions of reduced visibility might be subject to fatal visual illusions (Waldock, 1993). Nonetheless, we believe that the pendulum has swung too far away from documenting good judgment and decisions (also see Funder, 1987; Haselton & Funder, 2006; Krueger & Funder, 2004).

In this paper we outline an evolutionary perspective that reexamines biases and may cause the pendulum to swing back toward the center, shifting the focus away from flaws and toward an understanding of how natural selection—the process that generates functional design in nature—has shaped the human mind. This perspective leads to serious questions about whether evidence of bias and error reveals irrationality, and can teach surprising lessons about adaptive ways humans have evolved to think. We first consider what we should expect the mind to do well and then introduce a three-category evolutionary taxonomy of bias effects. Biases might be *heuristics*, *error management effects*, or *experimental artifacts*. We conclude with a discussion of the benefits of reconsidering evidence of irrationality in an evolutionary light.

WHAT SHOULD HUMANS DO WELL?

SOCIALITY, ECOLOGY, AND THE ADAPTIVE PROBLEMS OF OUR ANCESTORS

It is useful to begin by considering reasonable hypotheses about what the mind has evolved to do well. Humans are an intensely social species, and thus should possess cognitive machinery designed to handle the computational problems associated with social life. For example, because people engage in reciprocal social interactions with nonrelatives, we should expect a suite of cognitive adaptations designed to reason effectively about social exchanges (e.g., cheater detection; for a comprehensive review, see Cosmides & Tooby, 2005). In all domains of social reasoning we should see a variety of adaptive designs including evaluating commitment and sexual interest in prospective mates, diagnosing personality, navigating social hierarchies, learning from knowledgeable conspecifics, and so on (Haselton & Funder, 2006).

We should also expect the human mind to reason most effectively when presented with *ecologically valid* problems of the sort our human ancestors would have been likely to encounter (Tooby & DeVore, 1987). These include problems in particular content domains, such as those listed above, and in the informational formats present over human evolutionary history. For example, asking research participants to perform logical operations over abstract inputs (e.g., probabilities) or in artificial settings should be particularly likely to reveal apparent lapses in rational thinking (Gigerenzer, 1998). Concrete, naturalistic problems in domains such as parenting, mate choice, social exchange, social learning, and the like are the places where we should focus for evidence of adaptive specialization.

Lastly, an evolutionary perspective raises questions about the assumptions many psychologists hold about what counts as rational. Our human ancestors needed to find mates and reproduce, avoid getting killed, protect their families, avoid diseases, and obtain resources. Psychological mechanisms that have evolved to achieve these ends might not perform well against modern standards of monetary maximization and subjective well being, such as finding happiness, being "logical," or even representing the truth.

DOES ADAPTIVE = TRUTHFUL?

Traditionally, it was thought that humans differed from animals in that they were gifted with a propensity to uncover and strive for truth, or some version of it, such as correct judgment and logical inference. In fact, many theorists today still think along these lines, often implicitly, but in some cases explicitly. Fodor (2000), for example, recently declared, "there is nothing in the 'evolutionary,' or the 'biological,' or the 'scientific' worldview that shows, or even suggests, that the proper function of cognition is other than the fixation of true beliefs" (p. 68). In a recent exchange with Fodor, Pinker (2005a; also see Fodor, 2005; Pinker, 2005b) pointed out that the process of natural selection is not concerned with truth per se, and in some instances even disfavors a truth-seeking mind. For example, there are many adaptive problems in which the best solution sacrifices costly truth-seeking in fa-

vor of fast approximations. Moreover, beliefs play an important role in our social life, so pure inference is not the only function they serve. As Pinker (2005a) noted, "People are embraced or condemned according to their beliefs, so one function of the mind may be to hold beliefs that bring the belief-holder the greatest number of allies, protectors, or disciples, rather than beliefs that are most likely to be true" (p. 18). The conviction that one's own social group is somehow special, or even better than other comparable groups (e.g., Chow, Lowery, & Knowles, 2008), or the belief that one's current partner is the most amazing and irreplaceable person in the world (e.g., Murray, Holmes, Dolderman, & Griffin, 2000) could lead the believer to behave in ways that might contribute to his or her social success (e.g., conferring privileges to in-group members could lead to repeated exchange interactions benefiting all parties, or investing in a romantic partner might result in the production of viable offspring, etc.).

In order to generate adaptive behavior, the brain will sometimes use heuristic reasoning procedures, make fallible assumptions about the world, and hold false beliefs. As philosopher Patricia Churchland (1987) remarked, "The principal function of nervous systems is ... to get the body parts where they should be in order that the organism may survive. ... Truth, whatever that is, definitely takes the hindmost" (pp. 548-549). The idea that the primary function of the brain is to generate true beliefs and valid inferences is, of course, not entirely wrong. An organism that always made invalid judgments and false inferences could not be very successful. But this is quite different from claiming that the brain essentially strives for truth, as if it were evolutionarily optimized for arriving at truthful judgments and logical inference. From an evolutionary perspective, truth should matter only to the degree that it contributes to survival and reproductive success.

AN EVOLUTIONARY TAXONOMY OF COGNITIVE BIASES

Earlier we outlined three explanations of apparent cognitive biases: (1) byproducts of an otherwise useful way of thinking, (2) artifacts of research designs that produce apparent flaws in thinking that are actually unlikely to happen in the natural world, or (3) genuine errors or flaws in the mind. From an evolutionary perspective, effects in the third category can occur in individuals as a result of novel mutations or developmental defects. They can also arise as human universals due to suboptimal "kluge" solutions produced by a selection process that must innovate on the basis of random mutations and build upon existing structure (see Marcus, 2008). One well-known universal suboptimal design is in the visual system—the retina is installed backwards, producing a blind spot in each eye (Marcus, 2008; Williams, 1992). However, clear examples of such kluges are relatively rare in comparison to the many systems that appear exceptionally well-designed; and, while suboptimal, kluge solutions like the retina perform surprisingly well. In sum, we acknowledge the existence of genuine flaws in the design of the mind, but we contend that these flaws will be relatively rare or comparatively minor aspects of systems that are otherwise well adapted.

Leaving aside the notion that the mind is riddled with major flaws, we are left with the idea that apparent biases either reflect the operation of generally useful systems or are artifacts of research designs. The evolutionary taxonomy we present subdivides the former group into two categories. The first, *heuristics*, are

generally effective, often simple rules of thumb whose operations entail some limitations. This is the explanation of biases favored by most researchers in social cognition, including those who tend to view the mind as flawed. We will argue, however, that only a limited number of biases are likely to fit into this category and that many heuristics are amazingly *more* effective than complex decision-making strategies. The second, effects of *error-management*, are cases in which errors that were less costly over evolutionary history are favored over more expensive ones, producing biases in the direction of the less costly error (Haselton & Buss, 2000). A large number of new phenomena have been documented as a result of theorizing about error management, demonstrating the utility of this way of reconceptualizing the judgment strategies we should expect to find in the mind (Haselton & Nettle, 2006). The remaining category, *artifacts*, are biases or errors that result from research strategies in which people are given problems in unnatural formats or are evaluated on the basis of questionable normative standards. Surprisingly, many of the most famous biases might fall into this category. Table 1 summarizes the taxonomy (also see Haselton & Funder, 2006; Haselton, Nettle, & Andrews, 2005). These taxonomic designations are not intended to organize bias phenomena into mutually exclusive categories. For example, as we discuss below, some heuristics may contain an error management component. Rather, we present the taxonomy as a way of organizing evidence of bias and error in order to evaluate the extent to which it indicates irrationality.

We ultimately conclude that the mind is best described as *adaptively rational*. By adaptively rational we mean that the mind shows evidence of psychological design for coping with recurrent adaptive problems our ancestors encountered over evolutionary history—the mind is equipped with mechanisms that are constrained and sometimes imprecise, but nevertheless clear products of natural selection showing evidence of good design. This definition runs in contrast to the often implicit definitions of rationality used by many social science researchers, including that the mind should maximize “accuracy,” happiness, well-being, financial return, or adherence to abstract rules of logic. We do not deny that it is useful to compare human performance to these standards, as they may be those we wish to maximize in the modern world. Instead, we challenge the idea that deviations of performance from the standards means that the human mind is deeply flawed or poorly designed.

It is also important here to clarify the difference between proximal and distal causation. In social cognition, researchers often refer to “motivated reasoning” that benefits the self (e.g., Taylor & Brown, 1988) or is good for relationships (e.g., Murray et al., 2000). Although much of this evidence is well accepted, it also can be viewed as contradicting some definitions of rationality—particularly those espousing maximal accuracy. A reasonable question is the extent to which these more standard social cognitive explanations for biases are alternatives to evolutionary explanations for biases. We view them as complementary and typically operating at different levels of causation. Whereas many of the evolutionary explanations we offer in this paper make reference to causation in deep time that has shaped the mechanisms of the mind, social-cognitive explanations usually refer to causation occurring in “near-time” involving contemporaneous motives and goals.

For example, people will often differentially recall events from their past that confirm a positive opinion they have about themselves, such as remembering more academic successes than failures, which confirms one’s status as a good student

TABLE 1. Evolutionary Taxonomy of Evidence of Bias and Error

Cause of Apparent Bias	Examples
<i>Heuristic:</i> Heuristics are efficient solutions to problems of judgment and choice when time, knowledge, and information processing capacities are constrained (e.g., Gigerenzer, Todd, & the ABC Research Group, 1999). Heuristics work well in most circumstances but can fail in systematic ways. Apparently poor performance results when heuristics are studied in absence of environmental context.	<ul style="list-style-type: none"> • One-reason decision strategies, such as the recognition heuristic (Gigerenzer & Goldstein, 1996) • Hindsight bias as memory updating (Hoffrage et al., 2000) • Default assumption of nonindependence (an adaptation to clumped resources, Wilke & Barrett, 2009)
<i>Error Management:</i> Selection favors bias toward the less costly error (Haselton & Buss, 2000). Error management causes overall rates of error to increase, though net costs are minimized.	<ul style="list-style-type: none"> • Auditory looming (e.g., Neuhoff, 1998) • Defense overresponsiveness (e.g., Nesse, 2001) • Sexual overperception by men (Haselton & Buss, 2000)
<i>Artifact:</i> Apparent biases and errors are artifacts of research strategies. Biases result from the application of inappropriate norms (e.g., Cosmides & Tooby, 1996) or the placement of humans in unnatural settings.	<ul style="list-style-type: none"> • Some instances of base-rate neglect (Hertwig & Gigerenzer, 1999) • Some instances of confirmation bias (Cosmides, 1989)

(e.g., Kunda, 1987). Researchers have attributed this to motivated reasoning—that is, a tendency to evaluate evidence in a manner that leads to a desirable assessment. Proximately, people might indeed be motivated in such a way, but this does not fully explain the phenomenon. Evolutionary-based ultimate explanations often incorporate proximate motivations as means to adaptive ends. In this example, the motivation to maintain a positive self-assessment via a biased recall process might contribute to better performance, across a variety of domains, than either a negative assessment, or an unbiased one (Nettle, 2004; also see Taylor & Brown, 1988). Enhanced performance, in turn, can lead to a variety of fitness benefits, including attracting mates or social allies and gaining access to resources. It's not that people just "want" to believe it—believing it actually helps them.

HEURISTICS

FROM HEURISTICS-AND-BIASES TO A STUDY OF MINDS-IN-ENVIRONMENTS

Most researchers in social cognition favor the view that heuristics are simple, efficient shortcuts applied in judgment and decision-making when people face overly complex tasks, have limited time or cognitive ability, or deal with incomplete information in the world. In this light, heuristics work well in many instances, but are prone to break down in systematic ways—and whenever they do, more "evidence" has been found that the mind is flawed in its reasoning abilities. The traditional treatment of heuristics has been largely dominated by researchers working within the heuristics and biases program (Kahneman, Slovic, & Tversky, 1982; Tversky & Kahneman, 1974), who have argued that human judgment often substantially deviates from optimality predictions or normative standards of logic. Classic ex-

amples in this school of thought demonstrate the poor performance of research participants judging sequences of coin flips or making probability estimates about the likelihood of situations described in word vignettes. This program, however, generated much controversy when researchers questioned whether the proposed heuristics were sufficiently precise to be useful models of psychological functioning and whether the tools used to assess the functioning of the mind were ecologically valid and therefore capable of yielding insights into the adequacy of everyday decision-making (e.g., Gigerenzer, 1991, 1996; Kahneman & Tversky, 1996).

A fundamental criticism of the heuristics and biases program is that researchers might be neglecting the structure of the world in which the decision-making takes place. Ecologically-minded scientists have argued that in order to understand the mind's true cognitive abilities one needs to consider the environment in which it operates—or was designed to operate by natural selection. For example, Egon Brunswik (1955) emphasized that psychologists should study how the mind makes inferences based on the informational cues present in the natural environment, and Roger Shepard (2001) saw the mind as a mirror reflecting regularities of the physical world (see Todd & Gigerenzer, 2007). Consequently, what we call a *good* or a *bad* decision (or *rational* or *irrational* behavior) has to be judged with regard to specific decision environments rather than in a vacuum (Gigerenzer, Todd, & the ABC Research Group, 1999).

A related criticism addresses how much information is usually available in these decision environments and if the clear standard for comparing decision outcomes—the supposedly optimal way of thinking—should necessarily be informed by abstract standards of probability, logic, and mathematical optimization. Many traditional models of rational choice assume that humans (and animals) make inferences about the world virtually as if they were supernatural beings that have unlimited reasoning power, boundless knowledge, and unlimited time to make their decisions. However, real-world decision environments, both current and past, do not look like this and it is unrealistic to compare the human capacity for judgment and choice against such optimality predictions and assumptions (see Gigerenzer et al., 1999). For example, humans almost never have access to all of the pertinent information needed for making a decision about which mate to choose, what foods are best to eat, or which house to buy. Rather than following models of unbounded rationality, researchers pointed out that many decisions are made in a boundedly rational way (i.e., under conditions of limited time, information, and cognitive processing) and that heuristics are psychologically plausible solutions in situations where the one best solution does not exist or cannot be reached anyhow.

COGNITIVE LIMITATIONS CAN BE BENEFICIAL

Researchers have produced many new empirical findings by examining reasoning in concrete environments and incorporating the realistic everyday constraints decision-makers face in a world that favors bounded rationality (Todd, Gigerenzer, & the ABC Research Group, in press). Numerous experiments and a range of formal simulations have shown that a whole family of simple decision-making rules that use only one or a few pieces of information can work as well or *better* than more complex decision algorithms that use all of the available information (e.g., Brigh-

ton, 2006; Czerlinski, Gigerenzer, & Goldstein, 1999). The recognition heuristic, for instance, allows for making judgments about which of two alternatives will be higher on some criterion value by picking the alternative that is more familiar (e.g., which stock will be more successful or which city is larger; see Gigerenzer & Goldstein, 1996). Consider the following example. When asked which of two cities has a larger population, San Diego or San Antonio, most German students tend to guess right: San Diego, the city with which they are more familiar. American students who are asked to make the same choice, however, are more likely to answer incorrectly. This finding is an example of the *less-is-more-effect*: Only German students can use the recognition heuristic because American students are equally familiar with both cities and hence rely on cues other than familiarity, which are often less valid as predictors of size.

The less-is-more example illustrates that cognitive limitations, such as limited knowledge or limited processing capacity, can actually be beneficial. In some instances, they can even enable important cognitive functions. The rather small natural limit in our working memory capacity, for instance, facilitates the detection of correlation coefficients in small samples as the working memory imposes valuable constraints on the size of the information sample we take into account (Hertwig & Todd, 2003; Kareev, 2000). Another example is provided by the earlier noted hindsight bias, which can be understood as a byproduct of an adaptive memory process and learning after feedback (Hoffrage, Hertwig, & Gigerenzer, 2000). Once an additional event occurs, our knowledge is updated to reflect this new information and our knowledge after feedback becomes systematically shifted towards the new, updated reality. Thus, when the decision maker has to recall an earlier judgment in the future, the recalled judgment will be closer to the outcome of the new event than to the original judgment.

PRESENT AND PAST ENVIRONMENTS

The concept of ecological rationality describes the match between structure and representation of information in the environment on one side, and the simple decision-making algorithms such as heuristics on the other. Whenever this match exists, heuristics can perform well (Todd & Gigerenzer, 2007). Examples of ecologically-rational heuristics can be found in various problem domains such as parenting (Hertwig, Davis, & Sulloway, 2002), mating (Miller & Todd, 1998; Todd, Billari, & Simao, 2005) and food choice (Scheibehenne, Miesler, & Todd, 2007). Sometimes, however, it is important to consider the match between mind and the *past* environments in which the mind evolved. It is this latter focus that can provide insight into adaptive rationality, insight that is necessary when current and past environments differ.

As an example, consider the work of Wilke (2006) on human foraging behavior in patchy environments, which illustrates that an awareness of ancestral conditions can be the key to understanding human decision-making strategies. When resources are distributed in patches (i.e., areas with a high density of the resource surrounded by areas with low density), animals are required not only to make decisions on where to forage, but also on how long they should forage in a particular patch as resources diminish (Charnov, 1976). Behavioral ecologists have studied simple decision mechanisms that solve this problem of patch time allocation

(Bell, 1991) and identified resource environments where these mechanisms work well (Iwasa, Higashi, & Yamamura, 1981). Different patch-leaving strategies are necessary because resource environments differ in how resources are distributed across patches. The number of resource items within a patch can either be similar (evenly dispersed distributions), completely random (Poisson distribution), or some patches may only contain a few items while others will be very resource rich (aggregated distributions). Wilke and colleagues tested how well humans can adapt their patch-leaving behavior when faced with such resource distributions in a computerized foraging game (Hutchinson, Wilke, & Todd, 2008; Wilke, 2006; Wilke, Hutchinson, & Todd, 2004). The results showed that participants applied patch-leaving rules that were particularly appropriate for aggregated environments also in other types of environments (e.g., those with evenly dispersed and Poisson distributions). Why was this the case? Were research participants ecologically *irrational*?

This finding is less puzzling once one considers that aggregation in space and time, rather than dispersion, is likely to have been the norm for most of the natural resources humans encountered over evolutionary time. Species of plants and animals rarely, if ever, distribute themselves in a purely random manner in their natural environment, because individual organisms are not independent of one another: Whereas mutual attraction leads to aggregation for some species, mutual repulsion leads to regularity (dispersed environments) in others (Taylor, Woivod, & Perry, 1978). Most often, these deviations from randomness are in the direction of aggregation, because aggregation offers considerable benefits such as a common habitat, mating and parenting, or the benefits of group foraging (Krause & Ruxton, 2002). Since humans have been hunters and gatherers for about 99% of their history (Tooby & DeVore, 1987), it could well be that our evolved psychology is adapted to assume such aggregated resource distributions as the default. Thus, participants in the foraging experiment might not have behaved ecologically rationally, but rather *evolutionarily rationally* – in the sense that they are behaving in ways that are rational given the structure of the human evolutionary environment (c.f. Wilke, Hutchinson, Todd, & Czienskowski, 2009). As we discuss later in the artifacts section, the idea that humans expect aggregation in space and time also helps to explain why apparent misconceptions of probability, such as the hot-hand fallacy (Gilovich et al., 1985), may not reflect fundamental shortcomings of the human mind.

HEURISTICS: SUMMARY

The examples in this section illustrate that in an uncertain world, good decisions might often require ignoring part of the available information (Gigerenzer, 2000). Compared to more complex algorithms, heuristics are fast (because the underlying algorithm is simple) and frugal (because they utilize only little information) in their decision-making process. In contrast to the classic heuristics and biases viewpoint, these decision strategies can be seen as exquisitely adapted to problems present and past because simple decision strategies are often truly *effective* and by no means weak compromises that reveal limitations of the human mind. When human cognition is studied with respect to real environments, past and present, heuristics display their full potential by exploiting the structure of information in

the real world. Ecological and evolutionary rationality specify the environments in which heuristics perform well, and adaptive rationality includes both of these.

ERROR MANAGEMENT

Laboratory research on "error" ... attracts a great deal of attention because of what many take to be its dismal implications for the accuracy of human social reasoning. These implications are illusory, however, because an error is not the same thing as a "mistake."—Funder (1987, p. 75).

Using heuristics, people can make rapid adaptive decisions using simple and reliable cues, but they are still at risk of making errors. Eliminating errors altogether is rarely, if ever possible, but it is possible to systematically commit one type of error over another. Imagine the problem of reliably identifying a recurrent danger in the environment such as venomous snakes. For any given relevant percept (e.g., a long sinewy object on the ground), one must make a decision: snake present or no snake present. Because of the dire consequences of being bitten by a poisonous snake, it is better to have a low evidentiary threshold for inferring that long slender objects are snakes, and to identify every snake you encounter, than to require too much evidence and occasionally get a costly surprise. Put in more technical terms, because both types of error cannot be minimized at the same time, asymmetries in the costs of two types of error (false positives and false negatives, also often labeled false alarms and misses) should lead systems to be biased in the direction of the least costly error. This is the underlying logic of a recent approach to signal detection called error management theory (Haselton & Buss, 2000; also see Nesse, 2001, on the smoke detector principle, and Wiley, 1994, for a treatment in animal behavior).

Error management theory applies evolutionary logic to signal detection theory—an approach to psychophysics derived from statistical decision theory over 50 years ago (Tanner & Swets, 1954). In signal detection theory, performance in sensory tasks is understood as a two-stage process of discrimination and decision. People must determine whether some target object (i.e., the signal) is present in a stimulus, but in addition to the signal, there is not only irrelevant information in the environment (external noise) but also variability in the organism perceiving it (internal noise). Traditional signal detection analysis explains how decision criteria will be affected by the differential costs of false positives and false negatives. Decision makers must decide whether to adopt a liberal criterion (more false alarms, fewer misses) or a conservative criterion (fewer false alarms, more misses). This approach to sensory processes has proved quite fruitful in understanding a variety of phenomena such as detecting tumors in mammograms and cracks in airplane wings (see Swets, Dawes, & Monahan, 2002; Swets, 1998).

Until recently, a consideration of the historical fitness costs of errors was not included in the analysis of biases by signal detection theory. Error management theory added this crucial element to an existing powerful tool (also see Wiley, 1994). One critical component in the determination of where people will set decision criteria across many domains is the fitness cost associated with different errors. Error management theory proposes that a cognitive system will be biased in a particular direction depending on the recurrent cost asymmetry associated with inferences

in that problem domain. Although error management biases often increase overall error rates and thus appear irrational, they minimize overall fitness costs. In the remainder of this section we will describe how error management theory has been applied to understand perceptual biases, biases involved in dealing with threats from pathogens and out-group members, and mating decisions. We then describe potential applications of error management theory in other cognitive domains, such as language use. Table 2 summarizes the main studies that have applied error management theory in these domains.

PERCEPTUAL BIASES

Perception researchers have recently begun to appreciate the important relationship between historical asymmetries in error costs and the design of information processing systems. For example, Neuhoff (1998) found that listeners perceive tones with rising intensity to be changing faster than equivalent tones falling in intensity. *Auditory looming*, as the effect has been named, is well explained in an error management theory framework. The enhanced saliency of rising intensities associated with approaching objects causes listeners to reliably underestimate object arrival time. The bias occurs with tones but not broadband noise (Ghazanfar, Neuhoff, & Logothetis, 2002; Neuhoff, 1998) showing design for sound that not only provides reliable single-source information, but sound made almost exclusively by biological organisms. Any time a bias affects perception of the actual physical environment, there are risks of misapplying it to irrelevant objects that could lead to any variety of costly errors. The degree to which this is true will largely determine how advantageous the bias will be, and thus its impact over evolutionary time. In the case of auditory looming, the costs of false alarms (e.g., wasting time by being ready too early) are relatively low compared to the costs of misses (i.e., not being prepared for an approaching object). The difference in these costs allows for the selection of a bias that causes people to systematically overestimate a reliable auditory cue of movement towards a listener.

Other researchers have found various perceptual biases that error management theory explains well. People tend to differentially judge the steepness and distance of hills relative to flat ground as a function of the perceived difficulty of traversing them, a potentially adaptive bias tuned to costs of navigation effort (see Proffitt, 2006). Viewers also judge heights as greater when looking at a vertical surface from the top rather than the bottom, reflecting a predicted evolved bias to reduce costs associated with falling (Jackson & Cormack, 2007). These examples illustrate the powerful role evolution plays in shaping perceptual systems in response to adaptive problems. What appear objectively to be errors in judgment might actually be beneficial biases that help organisms make decisions that minimize fitness costs.

RESPONSES TO DISEASE AND OUTGROUP THREAT

Protective Biases in Disease Defense. The threat of contaminants and disease is also likely to have shaped error management biases. Nesse (2001) argued that bodily systems including allergies and coughing are adaptively over-responsive. These

TABLE 2. Key Applications of Error Management Theory Supported in the Research Literature

Domain	Bias	False Positive	False Negative	Cost of False Positive	Cost of False Negative	Type
Perception	Auditory looming; Tones are perceived to change faster when they are rising rather than falling (e.g., Ghazanfar et al., 2002; Neuhoff, 1998)	Rising intensities perceived to rise faster	Rising intensities perceived to rise more slowly	Low: Approaching objects arrive later than expected (e.g., a falling rock)	High: Approaching objects arrive earlier than expected (e.g., a falling rock); failure to avoid object	Paranoid
Perception	Overestimate steepness of hills (e.g., Proffitt, 2006)	Perceive hills as steeper and farther away than they actually are	Perceive hills as gentler, rolling, and closer than they actually are	Low: Miss out on resources in difficult terrain	High: Expend considerable energy traversing very difficult terrain	Paranoid
Perception	Overestimate heights when looking at vertical surface from top compared to bottom (e.g., Jackson & Cormack, 2007)	Overestimate height when looking down from top	Underestimate height when looking down from top	Low: More cautious around dangerous heights	High: Less cautious around dangerous heights	Paranoid
Disease	Rejecting food that is actually edible (e.g., Garcia, Hankins, & Rusiniak, 1976; Rozin & Kalat, 1971)	Avoiding a food that is usually harmless	Eating food that is harmful	Low: Miss out on potential food source	High: Sickness or death as a result of eating dangerous food	Paranoid
Disease	Avoid individuals with noncontagious physical afflictions (e.g., Kurzban & Leary, 2001; Park et al., 2003)	Avoid a person who is not infectious	Commune with a person who is infectious	Variable, potentially low: missed social partner	High: Become infected, get sick, and potentially die	Paranoid
Disease	Physical overresponse to disease threats (e.g., Nesse, 2001)	Unnecessarily strong reaction to disease or nondisease agent	No reaction or weak reaction to disease agent	Variable, potentially low: Waste energy by mounting physical response	High: Become infected, get sick, and potentially die	Paranoid
Conflict & Cooperation	Individuals are prosocial even in situations where they don't need to be (Yamagishi et al., 2003, 2007)	Infer that one's selfishness might be detected by others even when it's not	Infer that one's selfishness might not be detected by others even though it is	Variable, potentially low: Lose some resources unnecessarily	Variable, potentially high: Earn negative reputation and risk social ostracism	Paranoid
Conflict & Cooperation	Fear harmless outgroup members (e.g., Maner et al., 2005; Schaller et al., 2003)	Assume outgroup members are hostile when they are not	Assume outgroup members are friendly when they are hostile	Variable, potentially low: Miss potential cooperation partner	Very high: Unprepared for attack or exploitation by outgroup members	Paranoid

Conflict & Cooperation	Be overconfident of one's abilities in wars and competitions (e.g., Johnson, 2004; Johnson et al., 2006)	Assume strength relative to opponent when one is actually not stronger	Assume weakness relative to opponent when one is actually stronger	Highly variable: Engaging in conflict with stronger force	Highly variable, potentially very high: Failure to exploit opponent for resources; lower resolve against enemy; preemptive surrender	Optimistic
Mating	Men's overperception of women's sexual interest (e.g., Haselton, 2003; Maner et al., 2005)	Inferring interest when there is none	Inferring no interest when there is interest	Often low: wasted courtship effort	High: missed reproductive opportunity	Optimistic
Mating	Women's underperception of men's commitment intent (Haselton & Buss, 2000)	Inferring commitment intent when there is none	Inferring lack of commitment intent when there is commitment intent	High: Desertion	Low: Delayed start to reproduction	Paranoid
Mating	Women's overperception of men's sexual coerciveness at high fertility (e.g., Garver-Apgar et al., 2007)	Assuming sexual coerciveness when there is none	Failing to detect sexual coerciveness	Low: Missed opportunity for social interaction partner	Very high: Unwanted pregnancy; elimination of female choice	Paranoid
Mating	Underperception of romantic partner's forgiveness after a transgression (e.g., Friesen et al., 2005)	Assuming partner has fully forgiven when s/he has not	Assuming partner has not fully forgiven when s/he has	Potentially high: Partner's resentment might diminish relationship stability	Low: Extra time and energy spent trying to appease partner	Paranoid
Mating	Men's overestimation of likelihood that current partner has been sexually unfaithful (Andrews et al., in press)	Assuming partner unfaithfulness when partner was faithful	Failure to detect partner infidelity	Variable, potentially high: Loss of trust in partner; possible alienation of partner	Very high: Lost reproductive opportunity; investment of resources in offspring not one's own; loss of partner	Paranoid

Note. The table presents selected examples of findings that can be interpreted in the Error Management framework. The biases are categorized as paranoid (assuming that the state of the world is less desirable than it is in reality) or optimistic (assuming that the state of the world is more desirable than it is in reality). Adapted from Haselton and Nettle (2006).

systems are triggered in the absence of a real threat, and dampening their responses with drugs or by other means typically results in few negative outcomes. This is so, he argued, because the costs of being over-responsive are small compared to the cost of being under-responsive to the pathogenic threats these defenses help to combat.

The same logic applies to food aversions, particularly in environments in which food is abundant. Aversions to specific foods are reliably acquired in human and nonhuman animals following just a single incidence of sickness after eating a specific food (Garcia, Hankins, & Rusiniak, 1976; Rozin & Kalat, 1971). Even if these sicknesses were caused by something other than the food, systematically erring on the side of caution and avoiding food associated with sickness would often enhance survival in food-abundant environments more than erring on the side of excessive permissiveness in food choices.

If other people posed reliable threats of disease throughout evolutionary history (see Schaller & Duncan, 2007), humans could also possess adaptive biases that lead them to feel disgusted by and selectively avoid certain classes of others. One cue of disease that may precipitate such avoidance is the presence of physical abnormalities, including lesions, discoloration, impaired motor function, and atypical appearance of body parts. These cues might also indicate a history of accidents (e.g., falling) or bodily harm inflicted by others, each of which is not a communicable threat. The multiple factors that can cause physical disfigurement produce a signal detection problem with a serious consequence: because it is difficult to know with certainty the source of a physical anomaly, error management logic predicts that humans will err on the side of avoidance and treat phenotypically atypical others as if they are vectors of disease even when they are not. Kurzban and Leary (2001) proposed precisely this logic as an explanation for the pervasiveness of stigma associated with physical disabilities.

Recent research has directly tested this error management hypothesis about disease and disability. The work showed that people who perceive that they are vulnerable to disease are less likely to have disabled friends (Park, Faulkner, & Schaller, 2003). In addition, in reaction time studies, participants exposed to a disease prime unwittingly associated disease with well-known noncontagious individuals with disabilities, more so than with nondisabled individuals (Park et al., 2003). These results support the view that rather than being irrational, stigma surrounding disabled individuals is part of an evolved disease avoidance system that errs on the side of caution.

Protective Biases in Response to Outgroup Threat. Similar error management logic applies to outgroup threat. For ancestral humans, the cost of falsely assuming that outgroups were peaceful, and consequently being unprepared for an aggressive assault, would often have outweighed the comparatively lower cost of maintaining increased wariness toward friendly outgroup members. This reasoning is consistent with research showing that members of competing coalitions or out-groups are believed to be less benevolent (Brewer, 1979) and more hostile (Quillian & Pager, 2001) than are members of their own group. These biases can be strengthened by ecologically-valid contextual cues. For example, when there is ambient darkness rather than ambient light, individuals face greater risks of being attacked. In laboratory research manipulating light levels, participants tested in dark conditions had greater beliefs that out-group males are violent than those tested in the

light (Schaller, Park, & Faulkner, 2003; Schaller, Park, & Mueller, 2003). Similarly, when induced to feel fear, participants saw more anger in the neutral faces of outgroup males as compared to those induced to feel romantic arousal or in a neutral emotion condition (Maner et al., 2005). In sum, a variety of findings reveal a bias toward assuming that outgroup members are dangerous, especially when under conditions of increased threat.

Beyond these examples, error management logic applies in a wide array of domains relating to conflict and cooperation with others, including social exchange (Yamagishi, Tanida, Mashima, Shimoma, & Kanazawa, 2003; Yamagishi, Terai, Kiyonari, Mifune, & Kanazawa, 2007), overconfidence in war and competitions (Johnson, 2004; Johnson et al., 2006), and beliefs about the intentions of others (Barrett, Todd, Miller, & Blythe, 2005). With respect to the latter, for example, Barrett et al. (2005) showed adults animations of a variety of social interactions involving only naturalistic motion cues (modeled after Heider & Simmel, 1944). In the study, both German adults and Shuar hunter-horticulturalists from Ecuador were accurate in judging a variety of intention patterns, including chasing, following, courting, and so forth. The viewers in each group also had a systematic false alarm bias such that they inferred chasing when chasing was not present more so than the same false alarm for other intention categories. The authors of the study speculated that this pattern could reflect a universal error management bias designed to avoid the high costs of missing malevolent intentions in others.

BIASES IN MATING AND ROMANTIC RELATIONSHIPS

The previous sections show that many biases have probably evolved to cope with physical threats posed by the environment or other organisms. Error management theory has also been useful for identifying and classifying biases in the domain of mating. In this section, we describe a number of biases that people show when assessing the intentions of potential or current mates. We begin by reviewing the evidence pertaining to the most well-known error management hypothesis—the male sexual overperception hypothesis.

Sexual Overperception by Men. In the ancestral past, men more so than women gained fitness advantages by engaging in opportunistic sexual encounters with multiple partners (Trivers, 1972). The logic behind this proposal is that the sex with fewer obligatory investments in offspring (pregnancy, lactation) and higher reproductive potential (i.e., number of offspring which possibly could be produced), most often the male, substantially increased offspring number by mating more often. In contrast, for females, the costs of such a quantity-oriented strategy often outweighed the benefits. Women, for example, incurred tremendous costs as a result of having sex, including a minimum of nine months of pregnancy and a substantial lactation period. Only when the benefits of reproduction with a particular mate outweighed these costs did women benefit from having sex. As a result, men are generally more sexually eager than women and thus often more willing to engage in short-term uncommitted sexual relationships (Clark & Hatfield, 1989; Li & Kenrick, 2006) and with more partners (Schmitt et al., 2003; Simpson & Gangestad, 1991). Relative to men, women are more selective in their choice of sex partners and often require indications that partners will invest time and resources

before sex, during pregnancy, and throughout child rearing (Buss & Schmitt, 1993; Pillsworth & Haselton, 2006b).

Because men benefited more than women from short-term sexual encounters and more sexual partners, men have probably been selected for a keen ability to recognize cues of female sexual interest. This judgment, however, is made under considerable uncertainty and is prone to error. An error management perspective predicts that inaccurate judgments should be systematically biased toward overperception—perceiving sexual interest when there is none. It is plausible that an overestimation bias for men was selected because missing a sexual opportunity due to underestimating sexual interest would have been more reproductively costly than wasted time pursuing a disinterested woman due to overestimating sexual interest.

Many studies using diverse methods support the sexual overperception prediction. These methods have included judging sexual interest or intent in face-to-face interactions of opposite-sex stranger dyads (Abbey, 1982; Harnish, Abbey, & DeBono, 1990; Saal, Johnson, & Weber, 1989; Shea, 1993), videotaped interactions and/or photos (Abbey, Cozzarelli, McLaughlin, & Harnish, 1987; Abbey & Melby, 1986; Edmondson & Conger, 1995; Saal et al., 1989; Shotland & Craig, 1988), vignettes (Abbey & Harnish, 1995; DeSouza, Pierce, Zanelli, & Hutz, 1992; Haselton & Buss, 2000; Kowalski, 1993), naturalistic personal experiences (Haselton, 2003; Koenig, Kirkpatrick, & Ketelaar, 2007), and experiments (Maner et al., 2005).

For example, in a typical unscripted live or videotaped lab interaction study (e.g., Abbey, 1982), male observers judged female participants' sexual interest toward the male participant to be higher than did female observers, and higher than what the female participants themselves reported. This finding shows that men overestimate women's sexual interest relative to two potential baseline comparison points (judgments of other women and the reports of women themselves). In a representative vignette study (Haselton & Buss, 2000), male respondents inferred more sexual interest than did female respondents from a range of hypothetical behaviors enacted by a third-party woman in a fictitious dating scenario.

These results are not simply due to men overstating the sexual interest of all people. There is no consistent evidence of a directional bias when men judge other men's sexual interest (e.g., Abbey, 1982; Haselton & Buss, 2000). The bias is also not shared by women, who appear to either underperceive men's sexual interest (e.g., Abbey, 1982) or show no clear directional bias (e.g., Haselton & Buss, 2000), depending on the study. Overall, these findings point to a consistent sex difference in judging the sexual interest of opposite-sex individuals: men overperceive women's (and only women's) sexual interest, but not vice versa. Men's misperception bias appears to be further limited to women who are appropriate sex partners, so for instance, it is absent when men rate their sisters' sexual interest (Haselton & Buss, 2000).

The results amassed from these interaction studies are corroborated by naturalistic survey data. For example, Haselton (2003) asked responders to report past instances in which their sexual intentions (or lack thereof) were misperceived by opposite-sex others, and found that women, unlike men, reported episodes of overperception more often than underperception. Another study found that in opposite-sex college friendship dyads, men tended to rate the sexual interest of close female friends more highly than those female friends rated their own interest, whereas the reverse was true for women's ratings of their male friend's

interest (Koenig et al., 2007). The same predicted pattern of sex differences is revealed in research examining perception of affect. A recent study asked men and women to infer emotions ("microexpressions") in photographed faces that were actually emotionally neutral, and found that men who were induced to be in a romantic mood inferred more sexual arousal in female faces relative to men in a neutral mood, whereas women in a romantic mood did not exhibit the same shift when assessing male facial expressions (Maner et al., 2005). Another recent study failed to find evidence of the predicted sexual overperception effect. The authors concluded that men may simply be generally bad at decoding sexual vs. friendly cues rather than biased toward false positive errors (Farris, Treat, Viken, & McFall, 2008). However, given the abundance of the evidence showing that men's bias is directional (biased toward over- rather than under-perception), this result appears to be an anomaly.

Perceptions of Men's Commitment Intent: A Healthy Dose of Skepticism. Women's reproduction requires substantial obligatory investment in offspring during pregnancy and childrearing (Pillsworth & Haselton, 2006b; Trivers, 1972). These requirements have likely shaped women's preferences for mates who display convincing cues of long-term commitment and thus appear to be willing to provide resources during pregnancy and beyond (Buss & Schmitt, 1993). As with sexual intent, perceptions of commitment intent are prone to error due to incomplete information and an incentive for men to exaggerate their commitment (Haselton, Buss, Oubaid, & Angleitner, 2005). Error management theory predicts a directional bias for these errors: women should underestimate men's commitment intent rather than overestimate it. This is so because becoming pregnant and being deserted by a male partner as a result of overestimated commitment would have been more reproductively costly than temporarily delaying reproduction due to underestimated commitment (e.g., awaiting more evidence of commitment before having sex).

This prediction has not been tested as extensively as sexual overperception, but research has supported it. Using the same vignette scenarios as described above, Haselton and Buss (2000) asked participants to rate the likelihood that a variety of dating behaviors indicated an interest in a long-term romantic relationship. The results showed that female respondents inferred less long-term interest when men engaged in these behaviors (i.e., less commitment intent) than did male respondents. No such sex differences emerged in rating women's long-term interest from identical behaviors (Haselton & Buss, 2000; also see Haselton et al., 2005, for a discussion of additional evidence).

Perceptions of Men's Sexual Coerciveness Across the Ovulatory Cycle. An error management approach also predicts adaptive changes in the psychology of individuals across time based on cues indicating changes in the relative costs of false positive and false negative errors (Haselton & Nettle, 2006). One notable type of shift occurs in women across the ovulatory cycle: the costs of having sex with an undesirable partner rise as ovulation approaches and fertility increases (Gangestad & Thornhill, 2008; Pillsworth & Haselton, 2006a). Error management logic thus predicts that women will be particularly wary of sexual coercion when fertility is high—facilitated by erring on the side of overestimating sexual coerciveness in men. This is precisely what a recent study found: women in the high-fertility

phase of the cycle rated men appearing in videotaped interactions with women as more sexually coercive than did women in other cycle phases (Garver-Apgar, Gangestad, & Simpson, 2007).

Other Mating-Related Biases. Error management theory has also been applied to judgment biases in other mating-related domains, including underestimating the extent to which one has been forgiven by a romantic partner after a transgression (thus prompting a more complete mending of the relationship; Friesen, Fletcher, & Overall, 2005), overestimating the desirability of same-sex competitors (possibly to facilitate keener competition, Hill, 2007), and men overestimating the chances that their romantic partners have been sexually unfaithful (to protect against the high costs of cuckoldry; Andrews et al., 2008; also see Haselton & Nettle, 2006, for a variety of additional predictions not yet tested). In sum, across the many judgments and decisions people make in the courtship context, there are many biases that were predicted by and are sensible in light of error management theory.

ERROR MANAGEMENT: SUMMARY

These examples, like those in the heuristics section, demonstrate that biases often are not flaws that reveal fundamental irrationality of the mind. Rather, error management biases are solutions that minimize particularly costly errors and produce a net benefit to the decision maker. In contrast to common assumptions, the logic of error management shows that superior designs are not always those that maximize accuracy but are systematically biased to commit the least costly error. The direction of an error management bias—whether it is *optimistic* as in the case of sexual overperception or *paranoid* as in the case of disease avoidance—differs depending on the domain of decision, traits of the perceiver (e.g., male vs. female), and contextual cues indicating shifting costs and benefits (Haselton & Nettle, 2006). Successful hypotheses about the direction of bias often require models of the ancestral past and thus demonstrate the power of evolutionary thinking for understanding what otherwise might be deemed quirky features of the mind.

ARTIFACTS

A criticism of the classic heuristics and biases approach is that the strategies often used for identifying bias and evaluating cognitive performance might not be appropriate. If researchers place humans in unnatural settings, present problems for which the human mind is not designed, or evaluate performance in reference to standards other than those which would have aided our ancestors in survival and reproduction, it should not come as a surprise that humans appear systematically irrational. The third and final category in our evolutionary taxonomy of bias, *artifacts*, contains phenomena that are subject to these criticisms. We give two general examples within this category: (1) those resulting from the use of evolutionarily invalid problem formats or problem contents and, (2) evaluation in reference to normative standards that are not reasonable models of the evolved mind.

EVOLUTIONARILY-INVALID PROBLEM FORMATS AND CONTENTS

Frequencies Versus Probabilities. Many of the shortcomings of human reasoning claimed in the heuristics and biases literature concern failures in estimating event probabilities or likelihoods (Tversky & Kahneman, 1974, 1983). Spurring a long and active debate, Gigerenzer (1997), Cosmides and Tooby (1996), and others have suggested that people should demonstrate proficiency at likelihood estimation when presented with input in the form of discrete events—*natural frequencies*—as compared with numerical probabilities. Thus, investigations of likelihood estimation will be compromised when researchers do not use natural frequencies. The argument is that frequencies of events are observable in nature, whereas probabilities are mathematical abstractions that lack any direct connection to sensory input (e.g., Gigerenzer, 1997). In addition, when computing probabilities one loses information about base rates (Cosmides & Tooby, 1996), so frequencies actually convey superior information.

To illustrate, consider the famous *Linda problem*. Respondents read a personality description: "Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations." They were then asked to determine which of two options was more probable: (a) Linda is a bank teller, or (b) Linda is a bank teller and active in the feminist movement. Between 80% and 90% of respondents selected the second of the two—Linda is a bank teller and active in the feminist movement—as the more probable option, even though the conjunction of the two options cannot be more likely than either of its components. Hence, people committed the conjunction fallacy (Tversky & Kahneman, 1983).

As a test of the natural frequency hypothesis, several researchers presented classic problems in frequency rather than probability format (e.g., how many out of 200 women are bank tellers and how many out of 200 are bank tellers and feminists), and found that frequencies dramatically improved performance (Cosmides & Tooby, 1996; Fiedler, 1988; Hertwig & Gigerenzer, 1999; Tversky & Kahneman, 1983; but see Barbey & Sloman, 2007; Gaissmaier, Straubinger, & Funder, 2007; and Gigerenzer & Hoffrage, 2007, for a recent round of debate surrounding these studies). Improving performance by providing natural frequencies as input has implications that go beyond our general point about evolutionarily valid problem formats. In contrast to the ancestral world, in modern contexts such as medical diagnosis exact numerical probability judgments are often crucial, and it is important to give decision-makers information in a form they can easily use (Hoffrage, Lindsey, Hertwig, & Gigerenzer, 2000). Training doctors to translate diagnosis problems into natural frequencies has shown to be three times as effective in helping them correctly reason about outcomes as compared with traditional rule-based training (Kurzenhauser & Hoffrage, 2002).

Problem Content: Cheater Detection. Often researchers compare human performance to idealized rules of logic or mathematics. From an evolutionary perspective, however, the important problems of judgment are not so abstract. They involve dilemmas such as determining whether foods are safe to eat, who to choose as a mate, whether a patch of land will contain food resources, and who is a cheater in a social exchange. People find falsification logic neither intuitive nor easy to use, as anyone who has taught statistics knows. It does not come as a surprise

then, that people are not especially good at testing the abstract conditional rule, *if p then q*. In classic studies, Wason (1983) showed that people easily recognized that confirmatory evidence (the presence of *p*) is needed to test the conditional, but they often failed to test for falsifications (the absence of *q*). In the same line of research, however, problems involving particular contents dramatically changed performance on the task (e.g., Johnson-Laird, Legrenzi, & Legrenzi, 1972; Wason & Shapiro, 1971). Cosmides (1989) argued that the operation of a cheater-detection algorithm could explain many of these content effects. She argued that when the conditional rule involves social exchange (if you take the benefit, *p*, then you pay the cost, *q*), people look not only for confirmatory evidence (benefits taken, *p*) but also disconfirmatory evidence (costs not paid, not *q*). These contents changed performance from 25% correct (Wason, 1983) to 75% correct (Cosmides, 1989). Cosmides (1989) proposed that the performance differed because the content elicited mechanisms for cheater detection, which used falsification logic, given the nature of the adaptive problem to be solved (Cosmides, 1989; Fiddick, Cosmides, & Tooby, 2000; see Cosmides & Tooby, 1992, for an extensive discussion, including a description of the many variants of the task devised to rule out confounds and alternative explanations; also see Pereya, 2000, for similar content effects involving hazard detection).

An important point in this work is that humans do not reason according to the rules of abstract logic, but instead reason according to the task demands of specific adaptive information-processing problems. This is nicely demonstrated by manipulations in which adaptive responses systematically violate normative rules (e.g., switched social contracts, Cosmides, 1989). Proper adaptive functioning of the mind can only be observed when people encounter content that their minds are designed to handle.

QUESTIONING NORMATIVE STANDARDS AS GOOD MODELS OF THE EVOLVED MIND

In order to judge behavior as rational or not, there must be a standard for comparison—achieving accuracy, adherence to a logical rule, or maximizing some outcome. We have already questioned the standard of accuracy or *truth*—although adaptive systems should achieve reasonable accuracy, trade-offs in error costs often render systems biased toward particular errors superior to those maximizing accuracy. The cheater-detection example demonstrates that abstract logical rules often do not fit with the practical problems human beings must solve. The following are several other cases with questionable standards for comparison when the goal is to evaluate whether the mind is well designed.

The Hot-Hand Fallacy. The hot-hand fallacy occurs when research participants expect lucky streaks in hits and misses in everything from basketball to coin tosses (Gilovich et al., 1985) when in fact the probabilities of events are independent. When Kobe Bryant hits many shots in a row, for instance, the natural expectation is that he's got a hot hand and will shoot another successfully. People are often surprised to discover that this strong intuition does not square with the reality that the success of the next shot is determined independently from the shot before it. Heuristics and biases researchers attribute demonstrations of the hot-hand

phenomenon to humans' poor conceptions of chance, owing to the use of the fallible representativeness heuristic (Gilovich et al., 1985), in which participants mistakenly inferred that the small, observed sequence is representative of the larger sample as a whole.

The foraging example presented in the heuristics section hints at an alternative explanation for the hot hand phenomenon. Wilke and Barrett (2009) proposed that prior researchers might have started from the wrong place by asking why people are bad at random events and judging evolutionarily novel events like coin tosses, gambling, and sports. Instead, one can ask about the structure of objects and events surrounding important adaptive problems faced by our ancestors, and what kinds of adaptations might have been shaped by selection. Wilke and Barrett argued that many of these—plants, animals, human settlements, and even weather—would have been organized in an aggregated, clumpy fashion (Taylor, 1961; Taylor et al., 1978)—not perfectly at random (independent) like events in Las Vegas. Thus, the default human expectation is aggregation, clumpiness, and nonindependence.

To explore this hypothesis, Wilke and Barrett (2009) devised computer tasks in which participants could forage for fruits, coin tosses, and several other kinds of resources, and presented them to American undergraduates and a South American indigenous population of hunter-horticulturalists (the Shuar). In each population, research participants exhibited the hot-hand phenomenon for all resource types, despite the fact that the resources were distributed randomly by the computer. The exception was for coin tosses for the American students only, in which the hot-hand expectation was reduced though not altogether eliminated. Wilke and Barrett (2009) concluded that the expectation of aggregation in space and time may be the psychological default that is overcome only through extensive experience with truly independent random phenomena like coin tosses. This conclusion is quite different from the original explanation offered for the phenomenon—that it is attributable to the fallible representativeness heuristic and thus is a shortcoming of the mind.

Future Discounting. When evaluated against many standards of economic utility, humans have a tendency to overvalue immediate benefits relative to long-term gains (Frederick, Loewenstein, & O'Donoghue, 2002). For example, a person who prefers a reward of \$10 today over a reward of \$12 tomorrow is discounting the future. Much of the past research on the topic has investigated negative outcomes such as poorer academic performance and increased abuse of psychoactive substances that are experienced by high future discounters (e.g., Gottdiener, Murawski, & Kucharski, 2008), leading researchers to label people who prefer immediate rewards with terms like impulsive, short-sighted, lacking self-control, and ego-control failure (e.g., Ainslie, 1974; Gottdiener et al., 2008; Green, 1982; Logue, 1988; Mischel, Shoda, & Rodriguez, 1989; Rachlin & Green, 1972). The clear message from this literature is that preferring immediate rewards over later rewards is irrational—a puzzle to be solved.

Again, might the research question be set up backwards? Rather than simply noting mismatches between human preferences and monetary maximization, and seeking to explain the lapse in rationality, one could begin by asking how the psychology of intertemporal choice might reasonably have been shaped by evolution. Natural selection favors discounting the future and taking immediate rewards when the costs of waiting outweigh the benefits of waiting. These include the real

possibility that an organism could die before living to the future date to reap the reward, thus forfeiting the chance to translate the resource into the currency of reproduction (e.g., Daly & Wilson, 2005). Female parasitic wasps, for example, shift their egg-laying depending on changes in barometric pressure linked with the approach of deadly thunderstorms. The wasps lay more eggs on low-quality patches in a chamber mimicking the conditions of an incoming thunderstorm (rapidly dropping barometric pressure) than on a fair summer day (steady barometric pressure). Rather than delaying to search for a better option, wasps deposit their eggs immediately in a poor patch in order to avoid reproductive failure (Roitberg, Sircom, Roitberg, van Alphen, & Mangel, 1993). These results square with theorizing by some economists that future discounting is steep because there is uncertainty about the future (e.g., the individual might die before collecting the later reward), but these ideas have often lacked explicit considerations of the evolved mechanisms giving rise to steep discount rates.

Humans also show adaptive shifts in future discounting in response to changing conditions in the physical and social environment. For example, Wilson and Daly (2004) reasoned that cues indicating good returns on immediate efforts should lead to discounting the future more steeply. They predicted that exposure to attractive women would inspire men to become more present-oriented, possibly as a motivation to pursue immediate mating opportunities. Consistent with the hypothesis, men displayed greater financial future discounting after exposure to attractive women compared to when they were exposed to average women. This shift might be part of a broader system that reorients individuals to become more present-oriented when faced with opportunities that require immediate action.

The above logic indicates that discounting the future can be adaptive. One form of discounting that has resisted explanation, however, is the preference reversal under conditions of variable delays. An example is when a person accepts \$10 immediately rather than \$11 tomorrow, but prefers to accept \$11 in 366 days rather than \$10 in 365 days. In the first case, the person is impulsive; in the second case, he or she is patient. Putting aside the issue of transaction costs—it requires more effort to come back at a future date than to receive money immediately—why might these preference reversals occur?

One possibility is that different evolved systems are recruited when making these decisions. The first system manages choices between an immediate and a delayed reward (e.g., \$10 now or \$11 tomorrow), whereas the second system manages choices between a delayed and further delayed reward (e.g., \$10 in 365 days or \$11 in 366 days; McClure, Ericson, Laibson, Loewenstein, & Cohen, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004). Using fMRI methods, McClure and colleagues found support for the idea that the prospect of an immediate reward activates limbic system reward-related areas that are rich in dopaminergic innervation and are linked to impulsive behavior. The activation of the limbic system may prompt organisms to act immediately to secure the available rewards. In contrast, being presented with the choice of two delayed rewards activates prefrontal and parietal areas of the brain associated with deliberative processes and numerical computation. Although the precise adaptive functions of these brain areas remain to be specified, research along these lines demonstrates how thinking about whether systems with different functions are recruited to solve superficially similar problems can provide insights into why there are these apparent lapses in rationality.

ARTIFACTS: SUMMARY

We have presented just a few examples to illustrate how a reconsideration of the standards used to judge performance can radically change conclusions about human rationality. By asking what information would have been available over human evolutionary history as inputs for problem solving, what counts as a good solution within content domains crucial for survival and reproduction, and what ends humans should have evolved to maximize, we flip many of the conclusions drawn by heuristics and biases researchers on their heads. Instead of noting the mismatches between human performance and modern, idealized standards—and concluding that the mind is compromised in some way—evolutionary minded researchers reveal good solutions with a tight fit to enduring natural problems that may sometimes perform at their worst in the peculiar modern world.

DISCUSSION

ADAPTIVE RATIONALITY AND SPECIALIZED, EVOLVED DESIGN

A major theme emerging from our evolutionary analysis is the importance of specialized, evolved design: humans are adaptively rational to the extent that their minds are well designed for recurrent problems affecting survival and reproduction. We argue that the pendulum should continue to swing away from a focus on bias and error and toward developing models of the crucial adaptive problems our ancestors needed to solve, including realistic assessments of what information humans had available to them. In short, researchers benefit from developing models of design solutions to problems of judgment and decision making faced over millennia, and conducting research to test them. As demonstrated by the many examples presented in this article, once these models are developed and tested, the mind shows a remarkably tight fit to naturalistic human challenges. From this perspective, the mind appears reasonable, even *rational*. The emerging picture produced by these newer breeds of explanation is quite different from the heavy emphasis on irrationality in earlier treatments of heuristics and biases (see Lopes, 1991; Krueger & Funder, 2004).

The strategy of focusing on and elucidating good design is not an apologia intended to place the rational mind on a pedestal just for admiration: it is practical. Doing so should achieve at least four desirable outcomes. First, we take the success of key examples in this paper—ecologically rational simple heuristics, auditory looming and other error management phenomena, improving probability judgment with frequency formats, and so on—as an indication that researchers can achieve a clearer view of the architecture of the mind by using an evolutionary theoretical approach. Scientific progress will not grind to a halt without the approach, but surely researchers benefit from considering whether their theoretical assumptions and psychological models are evolutionarily sensible. Second, if we are correct that many bias and error phenomena are artifacts of unnatural research settings or questionable normative standards, the approach could help researchers “clean house” and focus instead on the phenomena likely to have more impact on humans’ daily thoughts and behaviors (Haselton & Funder, 2006). Third, this

strategy helps expose cases in which the evolved design of the mind is at odds with the demands of the modern environment, a point we elaborate below. And, fourth, it helps researchers sort through bias and error phenomena to determine which are actually reasonable features of the mind, and which are true oddities. Where there are these real mysteries, there are exciting discoveries to be made.

TAXONOMY OF BIASES

Our threefold taxonomy of biases and heuristics, error management effects and design artifacts does not perfectly organize biases into mutually exclusive categories. Rather, we offer this taxonomy as a tool for evaluating the causes of apparent lapses in rationality. For instance, our discussion on the hot-hand phenomenon and our suggestion that it serves as an adaptation to detect aggregation in the world (rather than being a fallacious perception about random sequences), can also be tackled from an error management perspective. If missing a resource pattern would have been so costly in past environments, then we might expect our perceptual system to more often falsely perceive the presence than the absence of a pattern than fail to do so (c.f. Nesse, 2001). Similarly, some biases of the social psychology literature can be considered as heuristics that contain elements of error management. For example, self-enhancement may result from an error asymmetry in which false modesty is more costly than mistaken pride (Krueger & Mueller, 2002).

OPEN VERSUS CLOSED DEVELOPMENTAL SYSTEMS

Many readers are surely wondering where experience—*learning*—is in our analysis. An important question for all research on psychological adaptations is to what extent any adaptation is developmentally closed, such that in nearly all typical developmental environments the same general design will emerge, or developmentally open to influence by environmental contingencies (Tooby & Cosmides, 1992; Mayr, 1974). Whether systems for making judgments and decisions are open or closed should depend on the demands of the adaptive problem, and thus the nature and extent of environmental influence should be evaluated on a case-by-case basis. Taking error management biases, for instance, Haselton and Nettle (2006) reasoned that systems of food aversion and snake fear are relatively developmentally closed since they appear only to require triggering by the environment and other, more deadly modern hazards do not show the same conservative patterning (e.g., fast-moving automobiles and obesity, which are much more likely to kill us). On the other hand, error management biases relating to optimism about achieving future benefits (positive illusions) appear much more open to environmental influence and they show greater variation in their manifestations across societies (see Haselton & Nettle, 2006, for a review).

Clearly, there are some learning systems that are sufficiently wide open that they can produce completely novel reasoning skills, such as how to do calculus or that coin flips in a series are truly independent. These skills are subjectively difficult. The fact that they require much practice and effort serves as a reminder that not all reasoning skills are equally learnable. The key point for this discussion is that

some evolved systems of judgment, reasoning, and decision-making are deeply entrenched and less responsive to alteration to any differing demands presented by the modern world, whereas others adapt more smoothly.

FROM THE PAST TO THE PRESENT

In closing, we wish to note that the approach we advocate does not necessarily diminish the lessons learned in earlier research. The modern world is governed by novel economic rules and new social challenges. Knowledge of how our evolved psychology leads us to behave in ways that contrast with our self-interest in light of these rules should prove important to human happiness: what benefited our ancestors' reproductive success is often at odds with our own wishes for how to live. Where there are these clash points, only by understanding each of the two pieces—the psychological adaptations in question and the modern context in which they operate—can we have the knowledge required to choose the best course of action.

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