Center for Adaptive Behavior and Cognition

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Introductory Overview

Truth is ever to be found in simplicity, and not in the multiplicity and confusion of things.
Isaac Newton

In this world nothing is certain but death and taxes.
Benjamin Franklin

The Center for Adaptive Behavior and Cognition (ABC) investigates reasoning and decision making under uncertainty at the levels of both individuals and social groups. The research group consists of psychologists, mathematicians, computer scientists, evolutionary biologists, economists, and researchers from other fields. With different methodological abilities—such as experimental methods, computer simulation, and mathematical analysis—they cooperate in solving the same problems.

The ABC program combines a strong theoretical focus with practical applications, that is, the research group both develops specific models and explores their applications. Those applications range from designing aids for web-based decisions to teaching statistical thinking and improving statistical reasoning—for instance, of expert witnesses in law courts—by particular representations of numerical information about risks.

The theoretical focus is on rationality and can be, albeit artificially, divided into three aspects: bounded, ecological, and social rationality.

Bounded Rationality

Models of bounded rationality attempt to answer the question of how people with limited time, knowledge, money, and other scarce resources make decisions. This program is an alternative to the dominant optimization paradigm in cognitive science, economics, and behavioral biology that poses the question of how Laplacean superintelligences or near omniscient beings would behave. We study the proximal mechanisms of bounded rationality, that is, the adaptive heuristics that enable quick and frugal decisions under uncertainty. This collection of heuristics and their building blocks is what we call the adaptive toolbox.

Ecological Rationality

Models of ecological rationality describe the structure and representation of information in actual environments and their match with mental strategies, such as boundedly rational heuristics. To the degree that such a match exists, heuristics need not trade accuracy for speed and frugality. The simultaneous focus on the mind and its environment, past and present, puts research on decision making under uncertainty into an evolutionary and ecological framework, a framework that is missing in most theories of reasoning, both descriptive and normative. In short, we study the adaptation of mental and social strategies to real-world environments rather than compare strategies to the laws of logic and probability theory.

Social Rationality

Social rationality is a variant of ecological rationality, one for which the environment is social rather than physical or technical. Models of social rationality describe the structure of social environments and their match with boundedly rational strategies people use. There is a variety of goals and heuristics unique to social environments. That is, in addition to the goals that define ecological rationality—to make fast, frugal, and fairly accurate decisions—social rationality is concerned with goals, such as choosing an option that one can defend with argument or moral justification, or that can create a consensus. To a much higher degree than for the purely cognitive focus of most research on bounded rationality, socially adaptive heuristics include emotions and social norms that can act as heuristic principles for decision making.

These three notions of rationality (according to which the present text is largely structured) converge on the same central issue: to understand human behavior and cognition as adaptations to specific environments, ecological and social, and to discover the heuristics that guide adaptive behavior. In a fourth section, we report on work that directly relates to evolutionary psychology, which, as a metatheoretical framework, lies behind the "adaptive" in our center's name. The research reported in the last section relates to methodological, historical, and theoretical questions, in particular the influence of methodological preferences—such as linear models—on theories of cognition. Our reflections on methodologies constitute a source of ideas that is of central importance to modeling visions of rationality.

The ABC program is an invitation to take a journey into an exciting territory. The journey ventures into a land of rationality that is different to the familiar one we know from the many stories in cognitive science and economics—tales in which humans with unlimited time and knowledge live in a world where the sun of enlightenment shines down in beams of logic and probability. The new land of rationality we set out to explore is, in contrast, shrouded in a mist of uncertainty. People in this world have only limited time, knowledge, and computational capacities with which to make inferences about what happens in their world. The notions of bounded, ecological, and social rationality are our guides to understanding how humble humans survive without following the heavenly rules of rational choice theory.

Bounded Rationality

Humans and animals must make inferences about unknown features of their world under constraints of limited time, knowledge, and computational capacities. We do not conceive bounded rationality as optimization under constraints, nor do we think of bounded rationality as the study of how people fail to meet normative ideals. Rather, bounded rationality is the key to understanding how people make decisions without utilities and probabilities. Bounded rationality consists of simple step-by-step rules that function well under the constraints of limited search, knowledge, and time—whether an optimal procedure is available or not. Just as a mechanic will pull out specific wrenches, pliers, and spark-plug gap gauges to maintain an engine rather than just hit everything with a hammer, different domains of thought require different specialized tools. The notion of a toolbox full of unique single-function devices lacks the beauty of Leibniz's dream of a single all-purpose inferential power tool. Instead, it evokes the abilities of a craftsman, who can provide serviceable solutions to almost any problem with just what is at hand.

The Adaptive Toolbox

This repertoire of specialized cognitive mechanisms, which include fast and frugal heuristics, were shaped by evolution, learning, and culture for specific domains of inference and reasoning. We call this collection of mechanisms the "adaptive toolbox." We clarify the concept of an adaptive toolbox as follows:

– It refers to a specific group of rules or heuristics rather than to a general-purpose decision-making algorithm.
– These heuristics are fast, frugal, and computationally cheap rather than consistent, coherent, and general.
– These heuristics are adapted to particular environments, past or present, physical or social.
– The heuristics in the adaptive toolbox are orchestrated by some mechanism reflecting the importance of conflicting motivations and goals.

Fast and Frugal Heuristics

Fast and frugal heuristics generally consist of three building blocks: simple rules for guiding search for information (in memory or in the environment), for stopping search, and for decision making. They are effective when they can exploit the structures of information in the environment. That is, their rationality is a form of "ecological rationality" rather than one of consistency and coherence. We have continued to explore how fast and frugal heuristics mesh with diverse disciplines, such as biology, economics, and cognitive psychology, and have applied them in the areas of consumer behavior, medicine, and the law. For example, a review by Hutchinson and Gigerenzer (in press-b) compares ABC's approach to biologists' research into simple rules of thumb used by animals. A primary goal of the paper is to highlight what each school might learn from the other. For instance only a few papers

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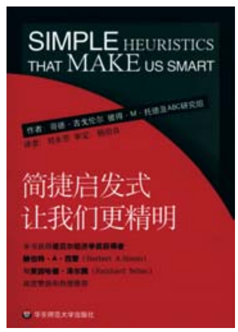

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Martignon, L., Foster, M., Vitouch, O., & **Takezawa, M.** (2003). Simple heuristics versus complex predictive instruments: Which is better and why? In D. Hardman & L. Macchi (Eds.), *Thinking: Psychological perspectives on reasoning, judgment and decision making* (pp. 189–211). Chichester: Wiley.

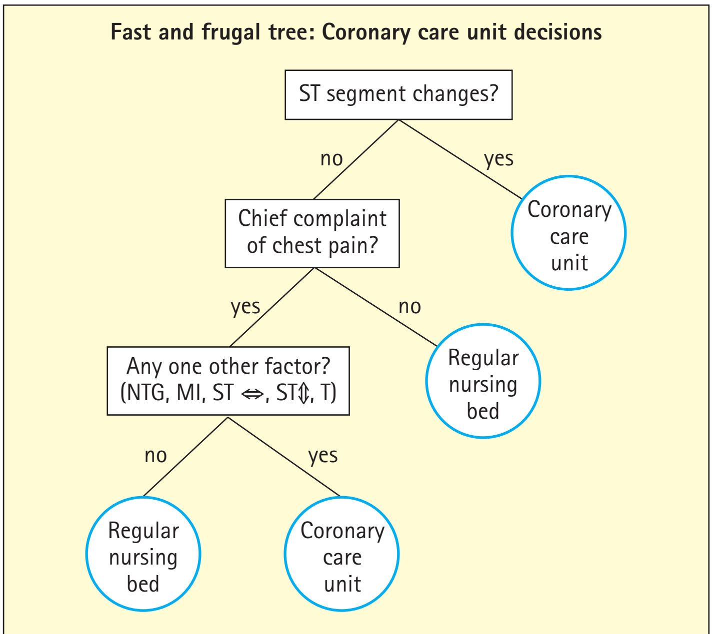
in biology recognize that simple rules might outperform more complex ones, and biology lacks ABC's theoretical perspective on how the best method of combining information from several cues depends on the statistical structure of the environment. ABC might learn from biological examples of the order in which cues are inspected, which seems to depend not so much on validity, but on the cost of inspecting different cues and when each becomes apparent as the animal approaches.

In the following, we will selectively report on some of the new findings and new areas of applications

Fast and Frugal Trees

A man is rushed to the hospital with serious chest pains. The doctors suspect a myocardial infarction (heart attack) and need to make a quick decision: Should the patient be assigned to the coronary care unit or a regular nursing bed? In a Michigan hospital, doctors sent 90% of their patients to the coronary care unit. This defensive decision making lead to a reduction in the quality of care because of overcrowding in the coronary care unit. An expert system and logistic regression did a better job of triage than the physicians, but the doctors did not take to these systems because they did not understand how they worked. To find a solution, researchers and the University of Michigan Hospital (Green & Mehr, 1997) used the building blocks of Take The Best to design the simple classification tree depicted in Figure 1.

Figure 1. A fast and frugal tree for coronary care unit allocation.



Source. Based on Green & Mehr, 1997.

The Green and Mehr (1997) tree is an example of a *fast and frugal tree*, a concept introduced by Martignon, Forster, Vitouch, and Takezawa (2003). These trees are simple sequential heuristics for assigning objects to one of two categories based on the values of a small number of binary cues. Even though they require little information, they still produce accurate classifications. In the heart disease example, the heuristic first asks whether the ST segment in the electrocardiogram is elevated or not. If it is, the patient is immediately classified as being at a high risk. If the ST segment is not elevated, the value of a second cue is inspected, and so on. The important point is that after each cue is looked up a classification can be made without consulting additional cues. Understanding why these simple trees perform so well and how they relate to other heuristics is currently an active area of research in the group. The simplicity of these trees produces pedagogical benefits as well. Fast and frugal trees can be drawn simply, making them easy for practitioners to see how they work. In another application, Dhami (2003) used fast and frugal trees to describe the process by which jurors in England make bail-or-jail decisions.

Coping With Too Much Choice

For many fast and frugal heuristics, including the trees described above, the number of alternatives in the choice set is fixed, and the focus is on how information about these alternatives is processed. We now turn to a set of studies where the focus is on situations in which there are many options to choose from.

Take the First

Research into decision making often uses tasks in which participants are presented with alternatives from which they must choose. Although tasks of this type may be useful in determining measures (e.g., preference) related to explicitly stated alternatives, they neglect an important aspect of many real-world decision-making environments, namely, the option-generation process. In handball, for instance, a player generates options under time pressure: pass the ball to the player on the left, the right, or take a shot. Do players make better decisions if they have more time to generate more options? Johnson and Raab (2003) placed experienced handball players in realistic situations that they might encounter during play and asked the athletes what they would do. Figure 2 shows that the quality of the options, as rated by experts, deteriorates with each successive option generated.

Decision-Facilitating Websites

The number of options is not only an issue in sports, but even more so for consumers: Most decisions nowadays present us with the "tyranny" of too much information and too much choice. One dramatic example is shopping online, where one is easily confronted with hundreds, if not thousands, of products characterized by dozens of attributes. To assist these difficult choices, a number of "decision-facilitating websites," such as www.activebuyersguide.com have

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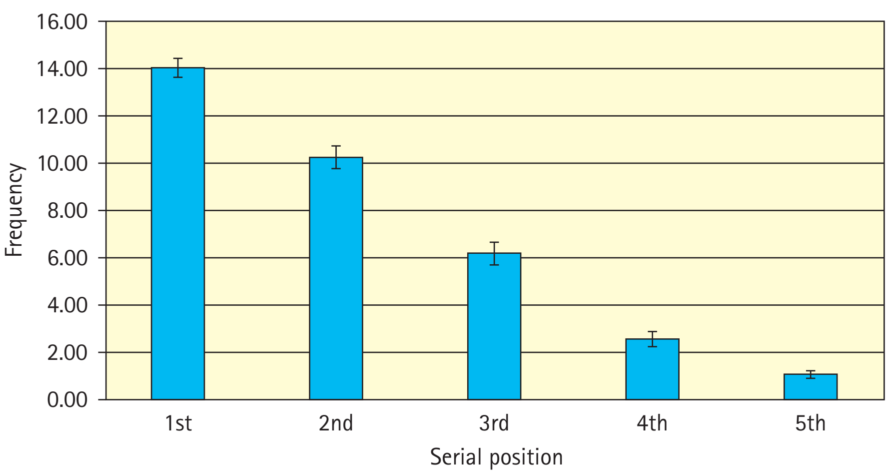

Source. Johnson & Raab, 2003.

Figure 2. Frequency of "appropriate" decisions, as rated by experts, summed over participants and trials, for the generated options in each serial position, with standard-error bars. The result illustrates that a decision based on the first alternative that comes to mind is often better than one based on generating many alternatives.

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appeared on the Internet. Curiously, there appear to be two prevailing designs of decision-facilitating websites: those that facilitate fast and frugal decisions that do not require compensation between a bad and a good attribute (noncompensatory sites); and those that draw on the normative decision process of Multi-Attribute Utility Theory, and let good and bad attributes compensate for each other (compensatory sites).

First appearing in the US, decision-facilitating websites gradually migrated to Europe. Fasolo, Motta, and Misuraca (in press) review and compare decision-facilitating websites popular in the US and in Europe, focusing on Italy. The review highlights the greater popularity of noncompensatory sites because of their greater transparency and user-friendliness, compared to compensatory websites.

Fasolo, McClelland, and Lange (in press) ran experiments to compare consumers' perceptions and choices on compensatory and noncompensatory sites. They found that liking and quality of choices on the two sites depended on the structure of the choice environment. When choices presented trade-offs among conflicting attributes (i.e., where attributes were negatively correlated), the compensatory site was better liked, but choice was perceived as difficult. Vice-versa, when trade-offs were not present (attributes were positively correlated), the noncompensatory site was better liked and choice was perceived as easy.

This work highlighted the need to investigate compensatory multiattribute algorithms that could combine the advantages of the two website designs: frugality and transparency, on the one hand, and ability to integrate conflicting attributes, on the other. Fasolo, McClelland, and Todd (in press) examine one such algorithm that could be implemented in future decision-facilitating websites. By means of simulations, they show that, in the presence of two constraints, consumers can make good choices despite neglecting most of the available product attributes. In particular, only one attribute is enough to select a good option—one within 90% of the highest value possible—as long as either the attributes are all positively correlated, or they are of unequal importance to the decision maker.

Biological Examples of Excessive Choice

Hutchinson (2005) reviewed evidence in animals of whether too much choice is ever aversive. The three key questions were whether animals prefer to visit sites where there is more choice, whether they are more likely to choose an item at such sites, and whether the items chosen at more diverse sites are better. For instance, a reanalysis of data on mating skew in leks (aggregations of males) of different sizes suggested that the probability of choosing one of the top *n*% of males might be highest at intermediate lek sizes.

Modeling the Hindsight Bias With Fast and Frugal Heuristics

Some years ago, the work on fast and frugal heuristics was extended to model a well-known phenomenon of memory research, the hindsight bias. Hindsight bias can occur when people make a judgment or choice and are later asked to recall what their judgment had been. If, in the interim, they are told what the correct judgment should have been, their memory for their own judgment tends to become biased toward the new information. To explain this phenomenon, Hoffrage, Hertwig, and Gigerenzer (2000) developed the RAFT model (Reconstruction After Feedback with Take The Best). The core assumption of the model is that new information updates the knowledge base, which, in turn, will be used to reconstruct the initial response.

Recently, Hertwig, Fanselow, and Hoffrage (2003) put this model to a further test. Although typically considered to be a robust phenomenon, the hindsight bias is subject to moderating circumstances. A well-known meta-analysis of the phenomenon revealed that the more experience people have with the task under consideration, the smaller is the resulting hindsight bias. This observation is one benchmark against which the explanatory power of the process models of hindsight bias can be measured. Can the RAFT model account for this "expertise effect"? Yes. Specifically, using computer simulations of the RAFT model, Hertwig, Fanselow, and Hoffrage observed that the more comprehensive decision makers' prior knowledge is, the smaller is their hindsight bias. In addition, they made two counter-intuitive observations: First, the relation between prior knowledge and hindsight bias appears to be independent of how knowledge is processed. Second, even if prior knowledge is false, it can reduce hindsight bias. This work was included in a special issue on the hindsight bias, which appeared 2003 in *Memory,* with Ulrich Hoffrage and Rüdiger Pohl as guest editors.

The Benefits of Cognitive Limits

The premise that human information-processing capacity is limited is usually accompanied by another assumption, namely, that these limitations pose a liability: They constrain our cognitive potential. These limitations bar us from performing feats, such as reciting the *Iliad* from memory or, for many of us, remembering the three things we were to pick up at the store. Even more sinister, though, is that these cognitive limits are also suspected of being culpable for lapses of reasoning. The link between cognitive limitations and reasoning errors, more generally, and human irrationality can be found in such disparate research programs as Piaget's theory of the cognitive development of children, Johnson-Laird's mental model theory, and Kahneman and Tversky's heuristics-and-biases program. By bringing together ideas on cognitive limits from a variety of fields, Hertwig and Todd (2004) challenge the seemingly obligatory connection between cognitive limitations and human irrationality. While not doubting that limits can exact a price, they question their exclusively negative status. First, the thesis is put forth that decision-making strategies that take limitations into account need not be less accurate than strategies with little regard for those limitations; in fact, in psychologically important contexts, simple strategies can actually outperform "unbounded" strate-

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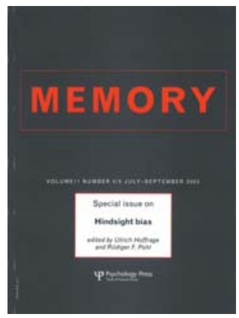

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gies. Second, it is argued that limitations in processing capacity can actually enable rather than disable important adaptive functions. Third, it is suggested that some of the reasoning errors produced by the mind's cognitive limits fulfill important adaptive functions. Finally, the assumption is challenged that simple decision-making strategies have evolved in response to the cognitive limitations of the human mind. The reverse causality is suggested and the thesis is submitted that capacity constraints may, in fact, be a byproduct of the evolution of simple strategies.

How Forgetting Aids Heuristic Inference

Forgetfulness is amongst our most troublesome cognitive limitations. Why don't we have the perfect recall of a computer memory chip? A few theorists have argued that forgetting should not be seen as a limitation, but as key to the proper working of human memory. Essentially, forgetting prevents outdated information from interfering with more recent information that is likely to be more relevant. Schooler and Hertwig (in press) propose that forgetting may, in addition, prove beneficial for inference heuristics that exploit mnemonic information, such as recognition and retrieval fluency. To explore the mechanisms that link loss of information and heuristic performance, they implemented the *recognition heuristic* (Goldstein & Gigerenzer, 2002) and the *fluency heuristic* (e.g., Jacoby & Dallas, 1981) in ACT-R (Anderson & Lebiere, 1998). The ACT-R research program strives to develop a coherent theory of cognition, specified to such a degree that phenomena from perceptual search to the learning of algebra can be modeled within the same framework. In particular, ACT-R offers a plausible model of memory that is tuned to the statistical structure of environmental events.

This model of memory was central to Schooler and Hertwig's (in press) implementation of the *recognition heuristic* and the *fluency heuristic*, both of which depend on phenomenological assessments of memory retrieval. The former operates on knowledge about whether a stimulus can be recognized, while the latter relies on an assessment of the fluency, the speed, with which a stimulus is processed. By grounding these memory-based heuristics in a cognitive architecture, they aimed to precisely define these heuristics and analyze whether and how loss of information—that is, forgetting—fosters their performance. Using computer simulations, the authors demonstrated that forgetting boosts the accuracy of the recognition heuristic (Goldstein & Gigerenzer, 2002), which relies on systematic failures of recognition to infer which of two objects scores higher on a criterion value. Similarly, simulations of the fluency heuristic, which arrives at the same inference on the basis of the speed with which the two objects are recognized, indicate that forgetting helps maintain the discriminability of recognition speeds. Thus, the ignorance that forgetting brings can, paradoxically, enhance inferences about real objects in the world.

How Emotions Aid Fast and Frugal Heuristics

Following Herbert Simon's claim that a complete explanatory account of human rationality must identify the significance of emotions for choice behavior, Muramatsu and Hanoch (in press) propose a strategy to study the significance of emotion in decision-making processes. They argue that emotions exert systematic influence on thinking and choice. They alter one's goal prioritization, determine the relative salience of aspects of a task, shape cost–benefit assessments, often tell us when to stop processing information, and render unthinkable many options for the decision maker.

Hanoch and Vitouch (2004) challenge the idea that high levels of emotional arousal are necessarily detrimental for performance, which is a common interpretation of the Yerkes-Dodson Law. In contrast to prevailing assumptions that having more information available is necessarily preferable to having less information, they show that the adaptive value of high emotional arousal stems precisely from its ability to restrict agents' attention. By this process agents are able to perform two vital functions: (i) focus their attention on the most urgent and vital information within the environment while overlooking peripheral information and (ii) mobilize the body to deal quickly with urgent problems.

Heuristics and the Law

Most lawyers would posit "heuristics and the law" to be a nonissue. In continental law, rules are generated by Parliament, and they are applied by the executive or by the courts. All these formal institutions function under complex procedural rules that do not seem open for parsimonious context-specific decision rules. On closer inspection, however, one finds legislators responding to scandal, administrators taking one-reason decisions, and courts cutting through complex cases by relying on what they perceive to be their salient features. Research in psychology has identified situations in which *fast and frugal* heuristics can lead to more accurate decisions than more elaborate strategies that use more information, time, and resources. Can a less-is-more approach be applied to law as well? When are fewer rules better than more? Should legal rules be designed so that the authorities entrusted with their application need less information? How many tax laws does a society need?

These results can provide a new perspective and stimulation for two important programs. The *law and economics* movement offered rational choice theory as a descriptive account of human behavior and social or aggregate utility maximization as

Dahlem Workshop on Heuristics and the Law

In June 2004, 40 scholars from law, psychology, economics, and related fields participated in a five-day Dahlem workshop to clarify the role of heuristics in the law. The workshop was organized by Christoph Engel, of the Max Planck Institute for Research on Collective Goods in Bonn, and Gerd Gigerenzer, and centered on four key questions: Are heuristics a problem or a solution? What is the role of heuristics in making law? What is the role of heuristics in court? How do heuristics mediate the impact of law on behavior?

As in all Dahlem workshops, the conference was not based on a series of talks. Rather, the editors asked 16 of the participants to write a paper on a specified topic, and these were distributed months before the workshop to all participants. The participants were then asked to comment on the papers whose topics they felt competent on, and these comments were also distributed before the workshop started. The five days of meetings were spent exclusively on intensive discussion and on writing the four group reports, addressing the four key questions. The revised chapters will be published by MIT Press.

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a prescriptive goal for the design of legal rules. However, many scholars in the law and economics tradition became dissatisfied with a standard of individual utility maximization that sometimes ran dangerously close to being nonfalsifiable. This had particular salience in areas such as smoking or obesity, where large portions of the policy community simply refused to accept the idea that individual choices were *not* amounting to a problem, even for the individual choosers themselves. The second project, *behavioral law and economics*, has been heavily influenced by the conceptual framework of the heuristics and biases program. This has been enormously fruitful research, but has been inclined to share the same half-empty-glass perspective displayed by the judgment and decision-making literature more generally. Behavioral law and economics scholars have tended to extrapolate from the heuristics and biases research without appreciating the way in which that research's aim of identifying "general-purpose heuristics" might not be well suited to the purpose of making domain-specific policy recommendations.

The ABC Research Group in 2004

Left to right, front row to back row: Monika Keller, Rocio Garcia Retamero, Gerd Gigerenzer, Henry Brighton, John Hutchinson; Michaela Gummerum, Tim Johnson, Benjamin Scheibehenne, Shenghua Luan; Lael Schooler, Bettina von Helversen, Anja Dieckmann, Masanori Takezawa; Ulrich Hoffrage, Nathan Berg, Jörg Rieskamp; Rui Mata, Will Bennis, Wolfgang Gaißmaier, Thorsten Pachur; Magnus Persson, Andreas Wilke, Jutta Wittig, Guido Biele, Peter Todd (not pictured: Uwe Czienskowski, Yaniv Hanoch, Konstantinos Katsikopoulos, Julia Schooler).

Ecological Rationality

Fast and frugal heuristics can perform as well, or better, than algorithms that involve complex computations. Even if humans had the mental computational power to use such complex algorithms, they would not gain much, if anything at all, by using them. The astonishingly high accuracy of these heuristics indicates their ecological rationality; fast and frugal heuristics exploit the statistical structure of the environment, and they are adapted to this structure. Our upcoming group book, the follow-up to *Simple Heuristics That Make Us Smart*, will focus on ecological rationality by exploring the ways that simple decision mechanisms fit with particular information structures in their environment. The book will cover heuristic building blocks and decision trees, social and nonsocial environments, as well as how people structure their own environments for easier cognition, and it will feature decision domains ranging from medical diagnosis to choosing a parking space. Navigating through the environment puts people into the business of making bets: Bets about the structure of the environment and about the risks they face. In this section, we highlight the costs that can be paid when people place bad bets about the risks of travel, and explore the processes that people use to assess risk.

The Risky Business of Avoiding Risks

Catastrophic events, such as the terrorist attack on September 11, 2001, in which many people are killed at one point in time, as opposed to situations where the same number of people are killed over a longer period, tend to generate great fear. These high-consequence, but low-probability events are called *dread risks.* If Americans avoided the dread risk of flying after the terrorist attack and instead drove some of the miles not flown, one would expect an increase in traffic fatalities—a second toll of lives that has apparently gone unnoticed. But has this happened?

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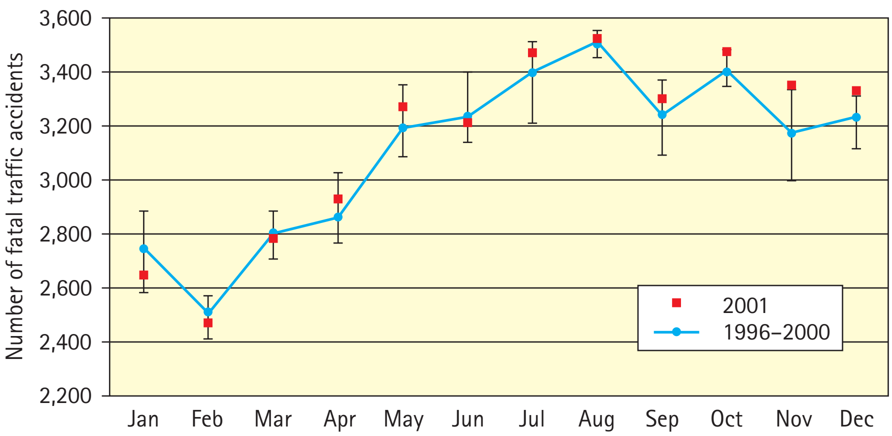

Source. Gigerenzer, 2004a.

Figure 3. Number of fatal traffic accidents in the United States in 1996 through 2000 versus 2001. The blue line represents the means for the years 1996 through 2000, the vertical black bars indicate the highest and lowest values for those years, and the red squares indicate the values for 2001. Note the increase of fatal traffic accidents in the three months following September 11. During these months an estimated 350 Americans lost their lives on the road, presumably in the attempt to avoid the risk of flying.

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After September 11, millions of Americans stopped, or reduced, their air travel. According to the Air Transport Association, the national revenue passenger miles decreased in October, November, and December 2001 by 20%, 17%, and 12%, respectively. Reports of increased vehicle miles from the American Office of Highway Policy Information suggest that a number of these Americans instead chose to drive: Compared with 2000, monthly miles driven were on average 0.9% higher before September 2001, but 2.9% higher in the three months following. In the last three months of the year, the largest traffic increase occurred on rural interstate highways (5.3%), which is consistent with the hypothesis that there was an increase in long-distance travel by car. As Figure 3 shows, the number of fatal crashes from January through August 2001 closely followed the numbers for the five preceding years, whereas from October through December 2001, it consistently rose at or above the upper range of the previous years. A more detailed analysis (Gigerenzer, 2004a) estimated that 350 people lost their lives by trying to avoid the risk of flying in the three months following September 2001. This number is higher than the total number of passengers and crew killed on the four fatal planes. Preventing terrorist attacks is difficult, but avoiding the second, psychologically caused toll of lives is possible, and should become a focus of security policy. The pictures of the planes striking the twin towers —shown again and again on TV— appealed to emotion and increased fear. In contrast, few citizens were exposed to the fact that driving a car for 12 miles is as risky as one nonstop flight (even after September 11). Thus, if one arrives safely at the airport with the car, the most dangerous part of the trip may already be past. To prevent a similar secondary toll of lives happening again in the future, the public should be better informed about psychological reactions to catastrophic events and the potential risk of avoiding risk.

Sample-Based Inferences About Risk

When trying to infer the frequency of occurrence of events in real-world environments, people cannot typically consult frequency tables that provide summary statistics. Instead, they need to make such inferences on the basis of limited information. Such information can come in two forms—either in terms of cues or in terms of samples of the event in question. Most heuristics in the adaptive toolbox embody cue-based inferences, but recently ABC has begun to consider models for sample-based inferences. Pachur, Rieskamp, and Hertwig (in press) developed and tested the social circle heuristic, a heuristic for judging which of two events (e.g., health risks) occurs more often in the population. The heuristic relies exclusively on the number of occurrences of the events in a person's social circle (i.e., self, friends, family, acquaintances), which are searched sequentially. As soon as enough occurrences of the events are recalled to discriminate between the frequencies of the events, search is stopped. The heuristic implies that frequency judgments are often made based on very small samples. In computer simulations Pachur et al. demonstrated that the heuristic is ecologically rational: That is, in particular real-world environments, it makes as accurate judgments as models that rely on much larger samples.

To what extent do people use information about the frequency of events in their social networks to make inferences about the frequency of occurrence of health risks, such as cancer, tornados, motor vehicle accidents, or tuberculosis? To investigate what mechanisms people use when judging risk frequencies, Hertwig, Pachur, and Kurzenhäuser (in press) asked participants to pick out of two health risks the more frequent one in Germany, and to estimate the number of people who are annually affected by the risks. The authors specified predictions for four different candidate mechanisms to account for these judgments. Of the four candidates, two mechanisms accounted for people's judgments best. The first, similar in spirit to the social-circle heuristic, makes frequency judgments based on the number of cases in a person's social network *(availability-by-recall)*; and the second, a mechanism that assumes that frequencies are monitored automatically and people's estimates accurately reflect actual frequencies (though slightly regressed toward the mean; *regressed-frequency*). The superior fit of these mechanisms thus suggest that people have a relatively good sensitivity to the frequencies of health risks.

Sampling-based heuristics have difficulty picking up on extremely rare events. The consequences of obtaining probabilistic information by sequential sampling rather than in a summary format was studied by Hertwig, Barron, Weber, & Erev (2004) in a context in which people are asked to decide between two lotteries (e.g., A: Get $4 with probability .8, $0 otherwise, or B: Get $3 for sure). The most prominent descriptive theory of how people decide between such lotteries is the prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992). This theory posits that, relative to the objective probabilities with which an outcome can be expected to occur, people make choices as if small-probability events receive more weight than they deserve and as if large-probability events receive less weight than they deserve. Hertwig et al. (2004) argued that—in contrast to the standard paradigm for studying decisions between gambles, in which people are provided with a symbolic, usually written descriptions about the probabilities of the outcomes of gambles *(decision by description)*—we rarely have complete knowledge of the possible outcomes of our actions and their probabilities. Instead, we rely on the experience that we have accumulated over time. Hertwig et al. referred to this kind of choice as a *decision from experience.* To find out whether people behave differently when deciding from experience opposed to deciding from description, Hertwig et al. (2004) created an experimental environment in which people had to learn the outcome probabilities associated with pairs of lotteries by sampling from either distribution as many times as they wished. After they stopped sampling, they were asked which lottery they

Key Reference

Hoffrage, U., Weber, A., **Hertwig, R.,** & Chase, V. (2003). How to keep children safe in traffic: Find the daredevils early. *Journal of Experimental Psychology: Applied, 9,* 249–260.

wanted to play for real payoffs. As it turned out, compared to the choices of respondents who received written descriptions of each option, the choices by respondents who were allowed to sample the possible outcomes freely and repeatedly suggested that rare events had less impact than they deserved (given their objective probability)—the opposite of the predictions from the prospect theory.

To account for the dramatic difference between decisions from description and decisions from experience, Hertwig and colleagues cited two factors—small samples and a recency effect. First, the experience group tended to rely on small samples of outcomes, which meant that they either never encountered the rare event or encountered it less frequently than expected on the basis of its objective probability. Second, they paid more attention to recently experienced outcomes. In contrast, having read about the rare events, the description group tend to exaggerate their importance.

Individual Differences in Risk Taking

The topic of the next three sections is individual differences with respect to risk taking, and the development of measures to predict and to assess people's willingness to take risks.

How to Identify the Young Daredevils in Traffic

We start with the youngest age group that we studied: 5- to 6-year-olds. The risky activity under consideration is crossing the street in front of oncoming vehicles. Is each young pedestrian similarly at risk? To find this out, Hoffrage, Weber, Hertwig, and Chase (2003) placed 44 children on the curb of a busy one-way street in Munich where there was no traffic light or crosswalk. They then asked them to indicate when they thought it was safe to cross the street. As expected, some children were more likely than others to say they could still cross the street when it was potentially dangerous to do so. Did children's willingness to take risks in the street correlate with their willingness to take risks in the laboratory?

The researchers played two games with the children, a gambling game and a computer game. In the gambling game, each child was presented with ten wooden boxes, nine of which contained coveted stickers; the tenth box contained a little devil. The children were told to choose and open the boxes one-by-one. If they chose the box with the devil, the game ended and they lost their stickers; but if they stopped the game before they found the devil's box, they were allowed to keep the stickers they had found. Children who stopped early were classified as risk avoiders, while those who pressed their luck were labeled risk

takers. In the computer game, the real-traffic scenario was simulated as closely as possible. Children were seated in front of a computer monitor that depicted—from an aerial view—a stream of oncoming vehicles, with gaps of varying size between them. With a key press, the children sent a pedestrian across the street. They were told that for every successful crossing they would receive a piece of candy, whereas for every accident they would lose three. The classification of risk takers versus risk avoiders was based on their accident rates in this task.

It turned out that those children who were risk takers in the gambling task made more crossing decisions, especially when the gaps between cars were of medium size—a time when it is often unclear whether a child could safely cross. Second, they tolerated shorter time intervals between initiation of the crossing decision and arrival of the next vehicle, and were more likely to cause a (hypothetical) accident. Third, they made decisions more quickly than risk avoiders. Finally, while boys were more likely than girls to make risky decisions, whether a child was a risk taker according to the gambling game was a far better predictor of their street-crossing behavior than gender. The computer game, in contrast, did not predict behavior in the real-traffic situation, which may be explained by the compensatory payoff structure: Candies lost with accidents could be compensated for with successful crossings. Finding the devil's box, however, was noncompensatory and led to loss of everything accumulated so far—as in the real-traffic situation.

Individual Differences in Risk Taking in Sports

Individual players differ in the degree to which they are willing take risky decisions. A popular view is that such risky decisions can be explained by differences in personality traits. Rather than simply identifying differences in risk-taking behavior between individuals, Raab and Johnson (2004) explored the mechanisms that may underlie such differences. A basketball task was used in which participants had four options displayed on a video screen that varied in the degree of associated risk. For example, shooting to the basket was considered a high-risk option, while passing to a play maker entails relatively little risk. Different versions of a computational model of decision making, Decision Field Theory, were compared to evaluate whether behavioral differences depend on such factors as the focus of attention, the initial preference for particular behaviors, or an approach-avoidance interpretation of the task. In basketball, risky shooting behavior can be best explained by differences in the initial preferences for risky and safe options.

Is Risk Taking a Domain-General Phenomenon?

How to adequately measure risk-taking propensity has long been debated among researchers in psychology, economics, and other fields reflecting the importance of the construct not only to researchers but also to policy making. Two of the main problems researchers have run into are that, first, people tend not to be as generally risk seeking (or avoiding) as is often assumed, but

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Johnson, J. G., **Wilke, A.,** & Weber, E. U. (2004). Beyond a trait view of risk-taking: A domain-specific scale measuring risk perceptions, expected benefits, and perceived risk attitude in German-speaking populations. *Polish Psychological Bulletin, 35,* 153–163.

Hoffrage, U., Lindsey, S., **Hertwig, R.,** & **Gigerenzer, G.** (2000). Communicating statistical information. *Science, 290,* 2261–2262.

Gigerenzer, G., & **Hoffrage, U.** (1995). How to improve Bayesian reasoning without instruction: Frequency formats. *Psychological Review, 102,* 684–704.

rather show differential risk taking across domains (e.g., a mountain climber who buys fire insurance) and second, that some typical risk–taking measurements (e.g., assessing risk propensity via choices made between monetary gambles) do not extend well to other risk domains or to behavior outside of the laboratory. Recently, Weber, Blais, and Betz (2002) overcame these limitations by hypothesizing domain-related within-individual differences in attitudes toward risk and developed a new psychometric instrument to distinguish risk-taking attitude and behavior in different domains. Now, Johnson, Wilke, and Weber (2004) translated and validated the English version of this domain-specific risk-taking scale on more than 500 German participants. This German-language scale assesses tendencies to engage in risky behaviors as well as perceptions of risks and expected benefits from such behaviors in six distinct domains of risk taking: ethical, recreational, health, social, investing, and gambling. As in the English version, risk-taking as well as perceptions of risks and benefits were domain-specific, while perceived risk attitudes were more similar across domains, thus supporting the use of a risk-return framework for interpreting risk-taking propensity. The translation has enabled cross-cultural studies on domain-specific risk. For example, one study underway explores how risk taking in different domains is used as a possible cue in human mate choice.

Information Representation

We have pursued the issue of ecological rationality in yet another way, namely, by studying the question of representation. Representational formats constitute environments for cognition. This research has practical relevance in many domains, such as diagnostic inference or risk assessment in legal cases, where the external representation of diagnostic information influences physicians', counselors', and lawyers' performances.
Probabilities and percentages are representations of uncertainty that were devised only a few hundred years ago and still cause people problems today. For instance, consider the statement: "There is a 30% chance of rain tomorrow." To investigate what this means to people, Gigerenzer, Hertwig, van den Broek, Fasolo, and Katsikopoulos (in press) surveyed citizens living in five cities of five countries: New York, Amsterdam, Berlin, Milan, and Athens, where probabilities of rain were introduced in 1965, 1975, 1990, on the Internet only, and not yet, respectively. They approached pedestrians in public squares and asked them to indicate which of three alternatives is the most and the least appropriate interpretation of the statement "There is a 30% chance of rain tomorrow." The alternatives were (i) "It will rain tomorrow in 30% of the region," (ii) "It will rain tomorrow for 30% of the time," and (iii) "It will rain on 30% of the days like tomorrow." How does the public understand a quantitative probability of rain? Figure 4 shows that two thirds of the participants in New York chose "days" as the correct reference, about one quarter chose "time," and a few "region." In contrast, in none of the European cities

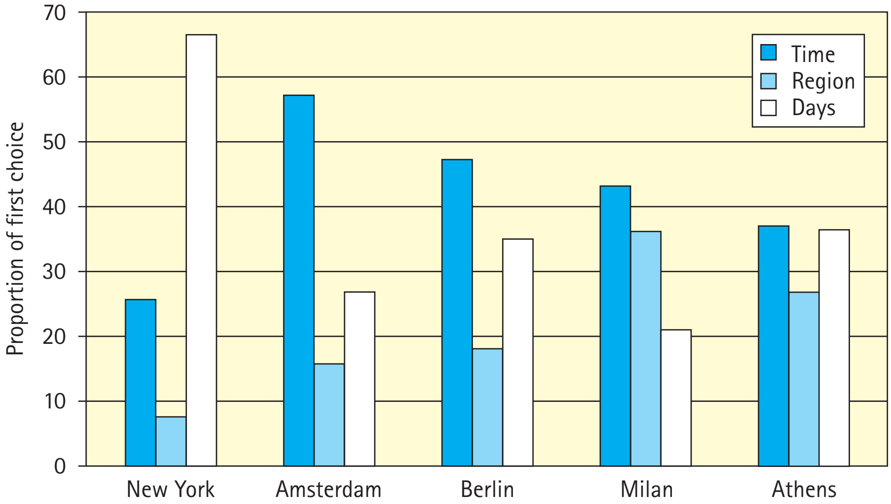

Figure 4. First Choice. People in New York (*n* = 103), Amsterdam (*n* = 117), Berlin (*n* = 219), Milan (*n* = 203), and Athens (*n* = 108) were asked what the statement "There is a 30% chance of rain tomorrow" refers to. The three alternatives were "It will rain tomorrow for 30% of the time," "in 30% of the region," and "on 30% of the days like tomorrow." Note that most Europeans misunderstood that the "30%" is intended to refer to the class of events of "days like tomorrow."

Source. Gigerenzer, Hertwig, van den Broek, Fasolo, & Katsikopoulos, in press.

did we find a majority for "days." The favored interpretation in Amsterdam, in Berlin, in Milan, and in Athens was "time."

Why does the public understand probabilities in such multipe ways? A forecast, such as "There is a 30% chance of rain tomorrow" conveys a single-event probability, which by definition leaves open the reference class (region, time, or days) to which it refers. For the National Weather Service, which defines the probability of precipitation "as the likelihood of occurrence (expressed as a percent) of a measurable amount of liquid precipitation ... during a specified period of time at any given point in the forecast region," a 30% chance of rain does not mean that it will rain tomorrow in 30% of the region or during 30% of the time. Rather, it means that it will rain in 30% of the days with similar weather constellations as tomorrow. The problem, however, is not simply the public's lack of understanding; it is the ambiguous communication of risk to the public. When meteorologists communicate risks in terms of single-event probabilities, they leave open what class of events this percentage refers to.

The ambiguity of a single-event probability in risk communication and the resulting possibility of miscommunication is not limited to probabilities of rain. The same problem occurs, for instance, when single-event probabilities are used by expert witnesses to explain DNA evidence in the court, and by medical organizations that publicize statements, such as "If a woman participates in mammography screening, she reduces her risk of dying from breast cancer by 25%," and women systematically misunderstand this percentage. Consider another medical scenario in which a physician needs to infer the probability that an asymptomatic man has colorectal cancer (C) after he received a positive hemoccult test result (pos) in a routine screening. In terms of probabilities, the relevant information (concerning a population of men aged 50) is a base rate for colorectal

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Gigerenzer, G., & **Hoffrage, U.** (1995). How to improve Bayesian reasoning without instruction: Frequency formats. *Psychological Review, 102,* 684–704.

cancer $p(C) = 0.3\,\%$, a sensitivity $p(pos|C) = 50\,\%$, and a false positive rate $p(pos|C) = 3\,\%$. Whereas the Bayesian answer is 4.7 %, typically most lay-people (and also doctors) estimate this probability at approximately 50 % or higher. This result has been interpreted as the "base-rate neglect."

To evaluate and understand the performance of the human mind, one needs to look at its environment and, in particular, at the external representation of the information. For most of the time during which the human mind evolved, information was encountered in the form of natural frequencies, that is, absolute frequencies as they result from observing cases that have been representatively sampled from a population. The same information represented in terms of natural frequencies is: "Thirty out of every 10,000 people have colorectal cancer. Of these 30 people with colorectal cancer, 15 will have a positive hemoccult test. Of the remaining 9,970 people without colorectal cancer, 300 will still have a positive hemoccult test." Natural frequencies simplify Bayesian computations and, as a consequence, help people gain insight into Bayesian reasoning. This was demonstrated both with lay-people (Gigerenzer & Hoffrage, 1995) and in different fields of professional decision making (Hoffrage,

Gigerenzer, G. (2002). *Calculated risks: How to know when numbers deceive you.* New York: Simon & Schuster.

UK edition: *Reckoning with risk: Learning to live with uncertainty.* Penguin Books, 2003

German translation: *Das Einmaleins der Skepsis. Über den richtigen Umgang mit Zahlen und Risiken.* Berlin Verlag, 2002

Italian translation: *Quando i numeri ingannano: Imparare a vivere con l'incertezza.* Raffaelo Cortina, 2003

Japanese translation: Hayakawa Publishers, 2003.

Chinese translation: CITIC Press, in press

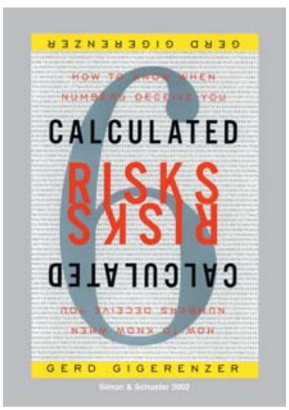
Portugese translation: Gradiva, in press.

Calculated Risks/Reckoning With Risk/Das Einmaleins der Skepsis

At the beginning of the 21st century, most children have learned to read and write, but many adults still do not know how to reason about uncertainties and risk. As this book repeatedly demonstrates, physicians or legal experts often do not understand the risks either. This problem has been called innumeracy, and this book offers a remedy.

The book provides experts and lay-people with mind tools for understanding risks and communicating these effectively to others. These tools are easy to learn, and can turn innumeracy into insight. They can help reduce the widespread uninformed consent in medical, legal, and everyday situations, from mammography screening to understanding the meaning of a DNA match in a legal trial.

The book, published by Penguin in the UK and Simon & Schuster in the US, was nominated in 2003 for the Aventis prize that recognizes science books targeted at a general readership. The German translation *(Das Einmaleins der Skepsis: Über den richtigen Umgang mit Zahlen und Risiken)* has been selected the Most Informative Book of the Year by *Bild der Wissenschaft,* a major German science magazine. Japanese and Italian translations have been published, and Chinese and Portuguese translations are underway.



Lindsey, Hertwig, & Gigerenzer, 2000). Moreover, Zhu and Gigerenzer (in press) found that even fourth, fifth, and sixth graders showed a better performance with natural frequency problems than adults with probability problems.

Representations of Risk Reduction
Natural frequencies are also beneficial for a related problem, namely, to understand the benefit of a therapy or of participation in a screening program. Consider again the statement that mammography screening reduces the risk of dying from breast cancer by 25%. Does that mean that from 100 women who participate in the screening, 25 lives will be saved? Although many people believe this to be the case, the conclusion is not justified. This percentage, in fact, means that from 1,000 women who do not participate in the screening, 4 will die from breast cancer within ten years, whereas from 1,000 women who participate, 3 will die. The difference between 3 and 4 is the 25% "relative risk reduction." Expressed as an "absolute risk reduction," however, this means that the absolute benefit is 1 in 1,000, that is, 0.1%. Cancer organizations and health departments typically inform women of the relative risk reduction, which gives a higher number—25% compared to 0.1%—and makes the benefit of screening appear larger than if it were represented in absolute risks. Kurzenhäuser (2003b) analyzed 27 brochures that informed women about mammography screening. The main result was that the relevant statistical information about risks and benefits are, for the most part, poorly explained. Even when information is provided, it is frequently given in terms of vague verbal descriptions rather than in precise numbers. It should thus not come as a surprise that there is also confusion in the normal population about the meaning of numbers describing costs and benefits of medical interventions. Hoffrage (2003) conducted a survey among 50- to 60-year-old women that has revealed substantial deficits in understanding the difference between absolute and relative risks in the context of hormone replacement therapy.

Applications in Law
Judges also must make decisions based on probabilities. Does the representation of numerical information in natural frequencies foster Bayesian reasoning in court? Professionals and law students in Germany evaluated two criminal court case files involving rape and forensic evidence of a DNA match. Expert testimony reported the statistical information of DNA profiles and the rates of technical and human mishaps leading to false-positive results. This information was presented in two different formats, one stated as probabilities and the other as natural frequencies. When these statistics were expressed as probabilities, only 13% of the professionals and less than 1% of the law students correctly inferred the probability that the defendant was actually the source of the trace. But when the identical statistics were stated as natural frequencies, 68% and 44% of these same participants made the correct inference. Perhaps more significantly, the different ways of ex-

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Kurzenhäuser, S. (2003b). Welche Informationen vermitteln deutsche Gesundheitsbroschüren über die Screening-Mammographie? *Zeitschrift für ärztliche Fortbildung und Qualitätssicherung, 97,* 53–57.

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Lindsey, S., **Hertwig, R.**, & **Gigerenzer, G.** (2003). Communicating statistical DNA evidence. *Jurimetrics, 43*, 147–163, VII–IX.

pressing the same statistical information altered the verdicts in each case. When the information was presented as probabilities, 45% of the professionals and 55% of the students rendered a verdict of guilty, but only 32% and 33% did so when the same statistics were expressed as natural frequencies (Lindsey, Hertwig, & Gigerenzer, 2003). When verdicts hinge on statistical evidence, understanding that evidence is crucial, and pursuing such simple methods of fostering statistical insight could contribute to that goal.

How to Solve the Monty Hall Problem

Base-rate neglect is an example of a so-called bias, typically revealed under conditions that differ from people's natural environments. By representing (statistical) information in a way that better fits how we encounter information in the environment, reasoning becomes not only more accurate but also more consistent with statistical or probability norms, such as Bayes' rule. Here is another example: Suppose you are on a game show and you are given the choice between three doors. Behind one door is a car; behind the others are goats. You pick, for exam-

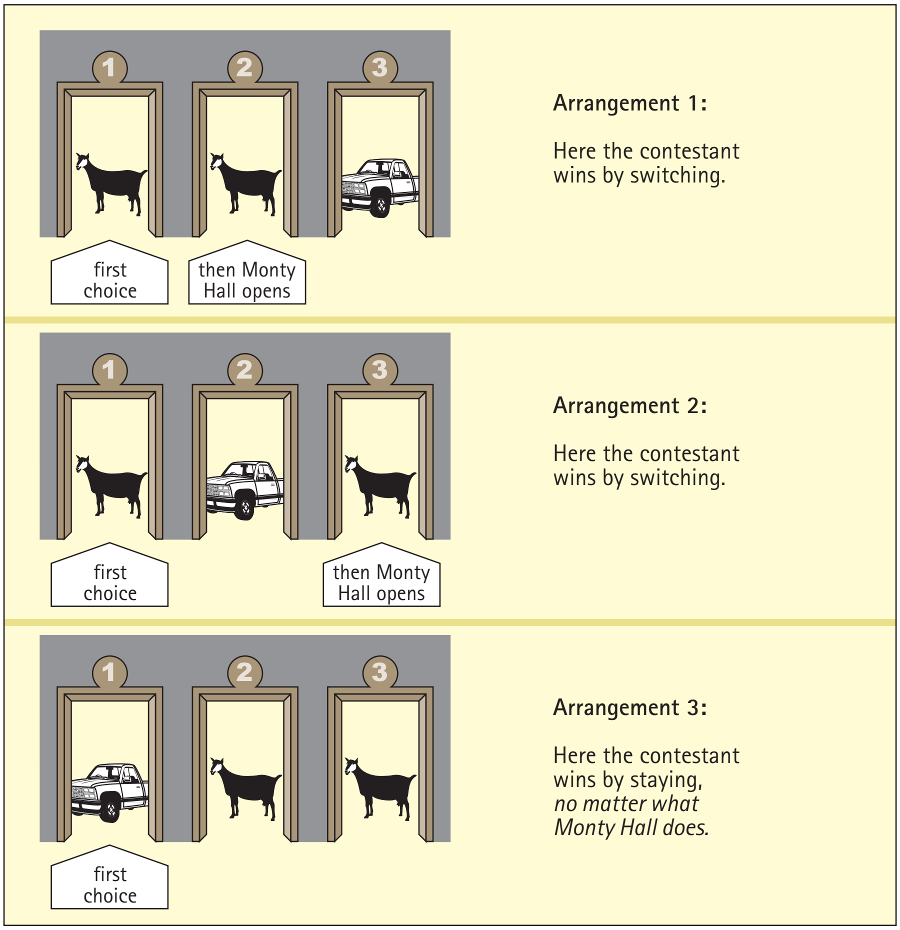

Figure 5. Explanation of the solution to the Monty Hall problem: In two out of three possible car-goat arrangements the contestant would win by switching; therefore she should switch.

ple, door number 1, and the host, who knows what is behind the doors, opens a different door, for example, door number 3, to reveal a goat. He then asks you, "Do you want to switch to door number 2?" Is it to your advantage to switch your choice? What contestants should do in this situation (known as the Monty Hall problem or the three-door problem) sparked a heated public debate. Although it is to the advantage of the contestant to switch, until now, all experimental studies on the Monty Hall problem led to similar results: The vast majority of participants believes that switching and staying are equally good alternatives.

Piattelli-Palmarini singled out the Monty Hall problem as the most expressive example of the "cognitive illusions" or "mental tunnels" in which "even Nobel physicists systematically give the wrong answer, and (...) insist on it, and are ready to berate in print those who propose the right answer."

Krauss and Wang (2003) were able to shed light into this "mental tunnel" by formulating the problem in an ecologically appropriate manner: By asking "In how many of the possible arrangements would the contestant win by switching and in how many would she win by staying?" they allowed their participants to reason in a frequentist manner (see Figure 5). By implementing further manipulations into the problem's wording (e.g., a perspective change from the perspective of the contestant to the perspective of the game show host), they could bring a substantial portion of the participants to a full understanding of the brainteasers' underlying mathematical structure.

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Social Rationality

Some of the most ambitious decisions faced by social species are those arising from an environment comprised of the decisions of conspecifics. Social environments are characterized by the speed with which they can change, and by the need to consider the decisions being made by others. These two features make social rationality an important and distinct form of ecological rationality.

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Keller, M., Lourenço, O., Malti, T., & Saalbach, H. (2003). The multifaceted phenomenon of "happy victimizers": A cross-cultural comparison of moral emotions. *British Journal of Developmental Psychology, 21,* 1–18.

Understanding Relationships and Moral Norms in a Cross-Cultural Perspective

One focus of our research is on the development of the understanding of moral obligations and interpersonal responsibilities in a cross-cultural context from childhood into late adolescence. The developmental course of understanding in China and Western countries, in particular Iceland, reveals striking similarities in conceptions and the sequence of developmental levels both in general and situation-specific reasoning about close friendship and parent-child relationship. Children of different age groups focus on different defining properties of relationships, and seem to rely on a limited number of defining relationship structures (or cues), which lead to different behavioral responses, such as moral decisions and evaluations. In spite of the general similarities, culture modulates the specific meaning of obligations and responsibilities in close relationships (Keller & Gummerum, 2003). In the transition from early into late adolescence, understanding of close friendship in both societies reveals a developmental path from relationship intimacy to autonomy. However, young Chinese see the self and friendship embedded into society, while Icelandic adolescents focus on the psychological aspects of close friendship, for example. the friend as a therapist (Keller, 2004b).

Development of Moral Emotions in a Cross-Cultural Perspective

Moral emotions, such as guilt that are associated with the consequences of moral transgressions, are important cues for the motivational acceptance of moral norms. While older children attribute guilt to a moral violator, younger children have been defined as "happy victimizers" because in spite of moral knowledge, they attribute positive feelings to moral rule violators. However, this shift in attributions has not been found consistently. We tested in a cross-cultural study whether a self-other differentiation may be an explanation for these inconsistent findings. Six- and nine-year-old German and Portuguese children had to attribute emotions to a rule violator, both in the role of self and hypothetical other (Keller, Lourenço, Malti, & Saalbach, 2003). The findings revealed a developmental shift in both roles, but moral feelings were attributed much more frequently to self as violator than to the hypothetical other. Thus, a self-other differentiation only partly account for inconsistent results in the attribution of emotions to others. We are presently analyzing Chinese data in which no emotional shift obtained for other. Thus, our research shows that not only different age groups but children from different cultures rely on different cues in the interpretation of the emotional consequences of moral transgressions. Two other studies have been performed to follow up on the phenomenon of moral emotions in different contexts. The first study interconnects deontic reasoning about contracts and contract violation with the attribution of emotions in a developmental perspective (Keller, Gummerum, Wang, & Lindsey, 2004). Already, young children from the age of 5 to 6 years on can understand contract violation from the two different perspectives of the contractors in parent-child and peer relationships. However, relationship cues influence the understanding of emotions of contract violators. In the symmetrical peer relationship, older children attributed moral feelings much more frequently than the younger children. In the asymmetrical parent-child relationship this linear increase was supported for the attribution of guilt feelings to the mother as contract violator. However, even the oldest children tended to attribute positive feelings to the child who is a violator. We concluded that moral feelings in the case of contract violation are specific to the type of relationship. Thus, we cannot conclude that there is one cheating detection device which helps identify contract violation in all kinds of relationships, but that this device has to be adapted to the domains of different relationships. This question is presently followed up in a further study controlling systematically for type of relationship and type of contract.

The Roles of Cognition and Emotion in Cooperation

The details of what cues and algorithms are involved in altruism, friendship, and general good will as well as the potential functions of emotional states in these algorithms, have been the subject of a good amount of speculation and research. For a recent Dahlem Conference volume, McElreath et al. (2003) reviewed the empirical evidence and theory about the cognitive nature of heuristics for cooperation, and the role of emotion and affect in regulating such behaviors. This literature has important implications for interpreting natural history (for animals ranging from bats to hermaphrodite fish), and for predicting the effects of institutional design on patterns of human cooperation.

Honor and the Regulation of Conflict

In many societies, people value their public standing or "honor," and other individuals recognize this standing as predictive of how others will behave when threatened or exploited. Such cultures of honor have existed in many places and times, seem to arise quickly, and have enduring properties. Yet the logic of honorable strategies is poorly understood. Social strategies of this type are impossible for individuals to decide upon rationally: When individuals pay attention to the behavior of others, the distributed effects of individual actions are very complex. A good amount of speculation and induction from historical and ethno-

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Reimer, T., & **Katsikopoulos, K. V**. (2004). The use of recognition in group decision making. *Cognitive Science*, *28*, 1009–1029.

graphic cases exists, but deductive analysis of these arguments has been lacking. Thus, the function and value of the attitudes that generate cultures of honor are unclear. McElreath (in press) analyzed a formal model of conflict management strategies that track and value personal honor, to explore the material incentives and community structures that might lead to and maintain them. The analyses indicate that, unlike models of public standing for regulating cooperation, simple honor-attentive strategies perform well even when information about the standing of others is poor. The results may also explain the persistence of cultures of honor in situations where the material incentives that may have lead to the values arising are no longer present.

Adaptive Foundations of an Egalitarian Social Norm

One of the important problems of social rationality is to explain how a social norm will emerge from the interactions among socially rational agents who adopt their behaviors and cognitions in response to current social environments. As an illustration, we focused on the emergence of an egalitarian distributive norm widely observed in primordial societies. It has been argued that communal sharing has emerged because it is a social device reducing uncertainty that is inherent in resource acquisition, but this cannot explain how the so-called free-rider problem is solved. Through a series of evolutionary computer simulations, it was shown that communal sharing norms can emerge, and are sustained when there is asynchronous uncertainty on food acquisition (Kameda, Takezawa, & Hastie, 2003). We further extended the results, and hypothesized that this environment structure may work as a cue to induce a sharing behavior: When a resource acquisition is framed as uncertain, people may tend to share such a resource with the others. This hypothesis was confirmed in different cultures under different settings (vignette and laboratory experiments in Japan and the US; Kameda, Takezawa, Tindale, & Smith, 2001). In a new project by Keller, Takezawa, and Gummerum, the sharing of resources is studied with children in the context of cooperative games.

Recognition and Group Decision Making

Reimer and Katsikopoulos (2004) studied how recognition affects group decision making, by conducting a laboratory experiment in which three individuals discussed and inferred as a group which of two cities has a larger population. First, they asked whether members who use the recognition heuristic have more, less, or equal influence in the combination of individual inferences, compared to members who do not use the heuristic. Overall, the recognition heuristic was more accurate than other cues, and users of the heuristic were more influential. For example, consider the case where one individual is partially ignorant, recognizing only city A, while two individuals recognized both cities A and B; furthermore, both more knowledgeable members inferred that B was larger. The group decided that A was larger in 59% of the comparisons. The authors found less-is-more effects in group decision making. For example, a group that recognized only 60% of the cities was correct on 83% of the comparisons, while a group that recognized 80% of the cities was correct on 75% of the comparisons. Consistently, the data revealed that lower recognition rates were correlated with higher levels of accuracy. It was formally shown that less-is-more effects are predicted by a range of ways of aggregating individual inferences.

How does group decision making compare to individual decision making? This question has been extensively studied with the "hidden-profile" paradigm. Consider the following situation: Two candidates, *A* and *B,* apply for a position, and a four-member committee has to select one of them. Overall, most arguments are in favor of candidate *A.* However, no single group member is aware of this because information is distributed among the committee members in a biased way, such that each group member has more arguments in favor of candidate *B.* Are groups able to detect the hidden profile, that is, are they able to detect that there are more arguments in favor of candidate *A* overall? Experimental evidence suggests that the answer is "no"—in the present example, most groups would decide for candidate *B.* According to the most prominent explanation for this so-called hidden-profile effect, groups fail to pool and integrate all available pieces of information. However, the question of how the information should be processed by the group has been rarely asked in this literature. In several of our own simulation studies, it turned out that a group version of Take The Best very effectively identifies concealed alternatives in the hidden-profile task, thereby demonstrating that the detection of a hidden profile does not necessarily require exhaustive information processing (Reimer & Hoffrage, in press).

Evolutionary Psychology

Evolutionary psychology lies at the heart of many research projects undertaken by the ABC research group, providing a motivation for bounded rationality, supporting the significance of the environment in ecological rationality, and emphasizing the importance of the social interactions that lead to evolutionary change in social rationality. At the same time, evolutionary psychology is grounded in ecological rationality: It assumes that our minds were designed by natural selection to solve practical problems in an efficient and effective manner. While evolutionary psychology focuses specifically on ancestral environments and practical problems with fitness consequences, ecological rationality additionally encompasses decision making in present environments without privileging problems with fitness consequences. Recently, Hoffrage and Vitouch (2002) wrote a chapter on these and other issues in evolutionary psychology for a textbook on general psychology, which is notable for being one of the first accounts of this topic in such a German textbook (see also Hoffrage, in press-a).

As Todd, Hertwig, and Hoffrage (in press) argue in a new chapter upcoming in an important handbook of evolutionary psychology, a set of broad forces operating on multiple domains can also impact on the design of specific cognitive systems. They discuss how the costs of gathering information, and of using too much information, can be reduced by decision mechanisms that rely on as little information as possible—or even a lack of information—to come to their choices. They also explore how the pressures to use small amounts of appropriate information may have produced particular patterns of forgetting in long-term memory and particular limits of capacity in short-term memory. Finally, they show how selection for being able to think about past sets of events has given us humans reasoning mechanisms best able to handle information represented as samples or frequencies of experience rather than as probabilities—another recurring theme of the ABC group's research.

Mate Choice

One of the most evolutionarily important decisions is mate choice. By definition, sexual reproduction entails combining one's own genes with another individual's genes to produce offspring. Through mate choice decisions made on the basis of perceived cues, individuals can influence the quality of the genes passed on to their offspring, and the quality of the parental care their offspring will receive (see van den Broek, & Todd, 2003, for an application of this idea to the evolution of rhythmic songs as mate quality signals; Miranda, Kirby, & Todd, 2003, for related investigations). For many species, including humans, potential mates are not encountered simultaneously, but rather sequentially. When individuals find a potential mate, they must decide whether the prospect is good enough to have offspring with. This sequential search problem can be addressed through the use of simple satisficing heuristics, which establish a threshold as-

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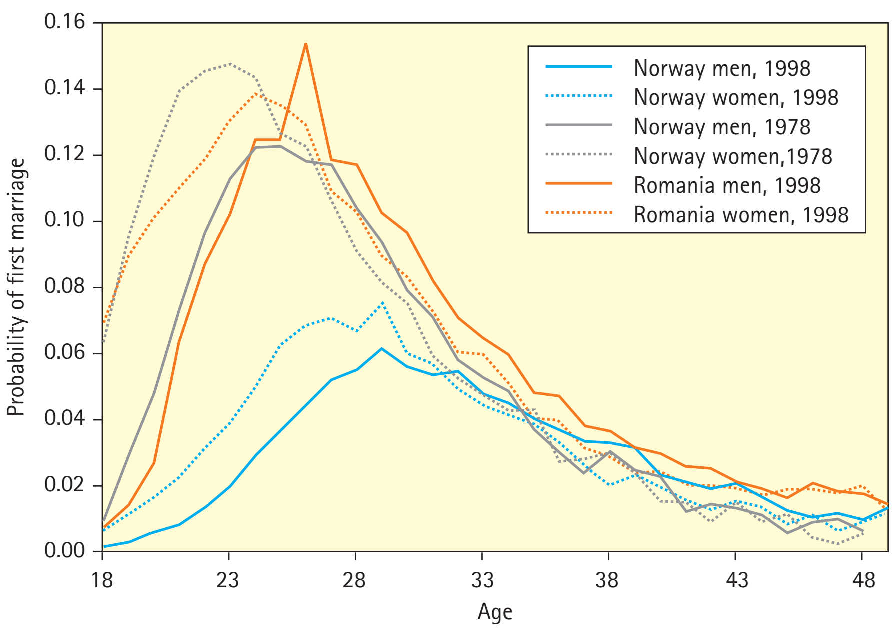
piration level that enables the straightforward judgment of the acceptability of a given potential mate. Simão and Todd (2003) have explored ways in which this aspiration level can be set, based on the experience of the individual searching for a mate, finding that simple threshold-adjustment mechanisms can outperform complex optimizing methods in this domain, as in others. The decision mechanisms that may have evolved to help us solve adaptive problems, such as mate choice, rely on the structure of the environment to make appropriate choices, and they will not work as well when the environment is different from what they expect (i.e., constantly being confronted with images of beautiful people through mass media may skew our mate preferences in ways that lead to poorer individual choices).

In modern Western societies, deciding when to get married seems like a highly personal and individual choice. We may feel that we are considering options and weighing possibilities that nobody else has ever had to think about in the same way. Furthermore, much research has pointed out the societal and economic constraints that impact on even these personal decisions. Indeed, when viewed from the aggregate level, the distribution of the ages at which people first get married shows surprising regularity across populations, following a right-skewed bell shape (see Figure 6, showing the similarly-shaped pattern across different countries and times, despite differences in overall marriage rates that affect the maximum height of the curve). Somehow, what people are doing in the mating game at the individual level seems to be following systematic rules that generate distinct patterns at the population level. But how? And how can we find out?



Source. Todd, Billari, & Simão, in press.

Figure 6. Hazard function for marriage (Number of first marriages of people who attain a given age x in a year by the number of still-unmarried individuals of age x-1 at the beginning of the year). These curves show a similar pattern across different countries and times, despite differences in overall marriage rates that affect the maximum height of the curve. Todd, Billari, & Simão (in press) demonstrate that curves like these can emerge when large numbers of simulated agents choose mates according to simple and psychologically plausible rules.

Todd, Billari, and Simão (in press) accounted for these patterns by developing agent-based models that simulate the aggregate behavior of individuals searching for marriage partners. In contrast to past models from demography and economics assuming fully rational agents with complete knowledge of the marriage market, their simulated agents use psychologically plausible simple heuristic search rules that adjust aspiration levels on the basis of a sequence of encounters with potential partners. They found that while these simple rules could indeed account for demographic-level outcomes in terms of aggregated individual behaviors, substantial individual variation had to be included in the models to account for the demographically observed age-at-marriage patterns.

This work shows that decision mechanisms not only exploit environment structure, they also initially help to create it: In this case, mate-choice mechanisms affect the population of available mates for others to choose from, which in turn can be seen in population-level measures of mating success, such as the age at which individuals mate. Studies such as this close the loop from environment structure to evolved behavioral mechanisms, back to behaviorally influenced environment structure, further strengthening the connection that evolutionary psychology focuses on, between the mind and the world.

Hutchinson and Halupka (2004) revisited the problem of sequential mate choice, introducing the realistic complication that in many species males occur in clumps. The paper first derived the optimal behavior in a simplified environment when there should be just two quality thresholds above which a male should be accepted, one when there are males left to inspect in the current patch and a lower one when inspecting new males requires moving to a patch. Optimal policies in more complex and realistic environments were derived, and their performance compared with that of the two-threshold policy and of other simple heuristics proposed in the literature. Usually the best heuristic was the simple two-threshold policy, suggesting that deriving heuristics from optima in simplified environments might sometimes be superior to more ad hoc approaches.

Methods, Metaphors, and Theory Construction

In spite of the fact that most scientists search for universal truths, scientific "truths" are contingent in important ways on the statistical and experimental tools used to discover and test them. From different starting points and based on different case studies, we converge on the same general issue in this project area, namely, the detection and understanding of the limitations and powers of scientists' tools.

Where Do Cognitive Theories Come From?

Scientific inquiry is often divided into two great domains, the context of discovery and the context of justification. Philosophers, logicians, and mathematicians claimed justification as a part of their territory and dismissed the context of discovery as none of their business, or even as "irrelevant to the logical analysis of scientific knowledge" (Popper, 1935/1959, p. 31). Discovery continues to exist in a mystical darkness where imagination and intuition reign, or so it is claimed. In earlier work, Gigerenzer (1991) argued that the mystical veil can be lifted. Specifically, new tools for data analysis (justification) can inspire new theories. This tools-to-theories thesis is twofold:

- *Generation of new theories:* The tools a scientist uses can suggest new metaphors, leading to new theoretical concepts and principles.
- *Acceptance of new theories within scientific communities:* The new theoretical concepts and assumptions are more likely to be accepted by the scientific community if the members of the community are also users of the new tools.

Examples include Fisher's analysis of variance, which provided the structure for Kelley's causal attribution theory; Neyman-Pearson's statistics, which turned into signal detection theory, multidimensional scaling turned into exemplar theories of categorization; and the digital computer, which provided the structure of Simon's mind-as-computer view (Gigerenzer, 2003). In each case, scientific practice preceded theory generation; methods of justification inspire discovery. In recent work, Sturm and Gigerenzer (in press) analyzed the implications of this work on the philosophical discussions of the discovery/justification distinction as well as on the attacks on it by Thomas Kuhn and others. If new methods inspire new theories, which in turn inspire new kinds of data, this process sets the importance of scientific practice in the foreground and provides new insights into a deep circularity in the relationship between method, theory, and data.

We Need Statistical Thinking, Not Statistical Rituals

Future historians of psychology will be puzzled by an odd ritual: the routine testing of null hypotheses, which largely eliminates statistical thinking. Textbooks and curricula almost never teach the statistical toolbox, which contains tools, such as descriptive statistics, Tukey's exploratory methods, Bayesian statistics, Neyman-Pearson's decision the-

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ory, and Wald's sequential analysis. Instead, texts tend to feature one single 3 step procedure:

The Null Ritual:

(1) Set up a statistical null hypothesis of "no mean difference" or "zero correlation." Don't specify the predictions of your research hypothesis or of any alternative substantive hypotheses.

(2) Use 5% as a convention for rejecting the null. If significant, accept your research hypothesis. Report the result as $p < .05$, $p < .01$, or $p < .001$, whichever comes next to the obtained *p*-value.

(3) Always perform this procedure.

This procedure (also called Null Hypothesis Significance Testing, NHST) is inconsistent with every existing statistical theory, including Fisher's theory of null hypothesis testing with which it is often confused (Gigerenzer, 2004e).

Gigerenzer argued that the Null Ritual undermines the theoretical progress in psychology by giving researchers no incentive to specify their hypotheses. By focusing only on significance, researchers tend to have a blind spot for effect size, power, and other relevant properties of data—and the exclusive reliance on significance tends to foster collective illusions about what significance actually means. Gigerenzer, Krauss, and Vitouch (2004) tested whether students and teachers from six German universities understand what a *p*-value means. *"Suppose you use a simple independent means t-test and your result is significant (t = 2.7, df = 18, p = .01)."*

The correct answer is that this *p*-value is the probability of the observed data (or of more extreme data points), given that the null hypothesis H_0 is true, defined in symbols as $p(D|H_0)$. The most frequent illusions include that the *p*-value specifies the probability that the null hypothesis is correct, that the alternative hypothesis is correct with 99% probability, or that if one repeated the experiment many times, a significant result would be obtained in 99% of the cases.

After successfully completing one or more statistics courses in which significance testing was taught, 100% of the students believed in at least one of these illusions ($n = 44$). But 90% of lecturers and professors of psychology ($n = 39$), and 80% (!) of statistics teachers ($n = 30$) also believed into at least one of the illusions. The ritual and its associated illusions seem to be culturally transmitted from those who teach statistics in psychology departments (who typically have no degree in statistics) to the students. Gigerenzer (in press) reviewed the attempts of statisticians, editors, and outside observers (such as the physicist Richard Feynman) to replace the existing statistical rituals by statistical thinking.

Berg (2004) proposes a constructive technique for eliciting key scientific judgments from the user. The technique addresses the question of which of two theories is better supported by a given set of data, while allowing for the possibility of drawing no conclusion at all. Procedurally similar to the classical hypothesis test, the proposed No-Decision Classification technique features three, as opposed to two, mutually exclusive data classifications: reject the null, reject the alternative, and no decision. In contrast to the classical hypothesis test, No-Decision Classification allows users to control both Type I and Type II errors by specifying desired probabilities for each. Thus, No-Decision Classification integrates judgments about the economic significance of estimated magnitudes and the shape of the loss function into a familiar procedural form.

We Need to Use the Appropriate Performance Measures

Whether a particular measure used to assess experimental data is appropriate depends on the processes that generated the data. Schooler and Shiffrin (in press) explore what happens when the measure does not match the underlying processes. Through extensive simulations, they demonstrate that such mismatches can lead to the misinterpretation of experimental results. They generated hypothetical experimental data, according to the model underlying a *d′* analysis (Green & Swets, 1966). There, the assumption is that each stimulus results in a single numerical value that is used as evidence. If this value exceeds a criterion, subjects respond "signal," and if it falls below this point they respond "noise." Many researchers, including some who hold to the *d′* model, analyze such signal detection experiments by subtracting false alarms (e.g., saying the stimulus was present, when it was not) from hits (e.g., saying the stimulus was present, when in fact it was). Such a mismatch could lead researchers to incorrectly interpret what are differences in response bias (i.e., how prone subjects are to say that a signal is present) to differences in sensitivity (i.e., the ability to detect the signal when it is present). Moreover, when the data are sparse, a *d′* analysis can also lead to incorrect interpretations of data. The authors suggest analysis methods that help to remedy these problems.

The Role of Representative Design in an Ecological Approach to Cognition

Half a century ago, Egon Brunswik stressed that psychological processes are adapted to the uncertain environments in which they evolved and function. He argued that psychology's accepted methodological paradigm of systematic design was incapable of fully examining the processes of vicarious functioning and achievement. As an alternative, he proposed the method of representative design. Representative design involves randomly sampling real stimuli from the environment or creating stimuli in which environmental properties are preserved. Thus, it departs from the tradition of systematic design endorsed in research texts. Dhami, Hertwig, and Hoffrage (2004) reviewed the development of representative design, from Brunswik's original ideas, and how they were adapted and modified by neo-Brunswikians and others.

In the second part of this paper, Dhami et al. focused on the research practices of those who have been committed to the notion of representative design. Two major findings emerged from the review of neo-Brunswikian policy-capturing research. First, most of the studies that presented participants with real cases satisfied Brunswik's recommendation of probability or non-probability sampling of stimuli. Sec-

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ond, there was a striking discrepancy between Brunswik's ideal and the research practices of most neo-Brunswikian studies that presented participants with hypothetical cases. Neo-Brunswikians often failed to represent important aspects of the ecology toward which their generalizations were intended.

In the third part, they discussed whether or not representative sampling matters for the results obtained. Unfortunately, only a small body of research has compared judgment policies captured under representative and unrepresentative conditions, and their results are mixed. Whereas some studies reported that representative conditions affected judgment policies, for instance, in terms of cue weights, others concluded that captured policies were independent of the representativeness of the stimuli. To date, the strongest evidence for the effect of representative stimulus sampling stems from research on the overconfidence effect and on hindsight bias. With regard to the former, a recent review of studies that manipulated the sampling procedure of experimental stimuli demonstrated that representative item sampling reduces, in fact, almost eliminates, the overconfidence effect—although Hoffrage and Hertwig (in press) have shown that this not only depends on the sampling procedure but also on a factor that has most often been overlooked, namely, the size of the reference class from which the stimuli are sampled.

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Experts in Science and Society

How do experts balance their commitment to science with that to society? How does a society actually determine who counts as an expert? What makes new forms of expertise emerge? These and related questions are addressed in *Experts in Science and Society* (edited by Elke Kurz-Milcke and Gerd Gigerenzer), a book based on a Schloessmann Seminar sponsored by the Max Planck Society. One recurring focus of the book is on the cultural differences of the environment in which the expert acts –social, historical, and legal. The arguments made include that in many areas, including criminal law, expertise is not wanted, and experts are mainly called in when the scientific basis is weak; and that we will witness an emerging new profession, the philosopher as a moral coach. The topics examined include experts in the fields of politics, science, medicine, and the law.

Future Directions

A major goal for the near future is to finish our collective new book on the match between heuristics and environments, thereby highlighting the interconnection between research on bounded rationality and ecological rationality. Another goal is to explore how heuristics are shaped and shape institutions. For example, what are the legal implications of (the use of) heuristics and the way information is communicated. To this end, we continue our active collaboration with the Max Planck Institute for Research on Collective Goods in Bonn. With this institute and Max Planck Institute for Research Into Economic Systems in Jena, we are developing a proposal for an international Max Planck Research School on Bounded Rationality. In collaboration with Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, we have begun to search for neural correlates of the use and application of the recognition heuristic. We hope to expand this promising avenue of research by thoroughly grounding the heuristics we study in basic cognitive and brain processes.

Summer and Winter Institutes on Bounded Rationality

The Summer and Winter Institutes on Bounded Rationality promote a view of decision making that is anchored in the psychological possibilities of humans rather than in the fictional construct of homo economicus. The third Summer Institute in 2003, in collaboration with Pompea Fabra University, Barcelona, and the University of Nottingham, UK, with support from the VW Stiftung, focused on applications in the law. In 2004, the fourth Summer Institute, supported by the Deutsche Forschungsgemeinschaft, was in collaboration with Max Planck Institute for Research Into Economic Systems, Jena, where the fifth Summer Institute is scheduled to be hosted in the summer of 2005. For the first time, members of the ABC group, with the support of *Der Deutsche Akademische Austausch-Dienst,* held a Winter Institute on Bounded Rationality in Psychology and Management at the Indian Institute of Management in Bangalore. Students and professors came together from across India for this two-week intensive course.

Winter Institute on Bounded Rationality in Bangalore, India.

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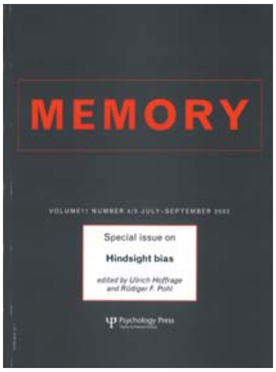

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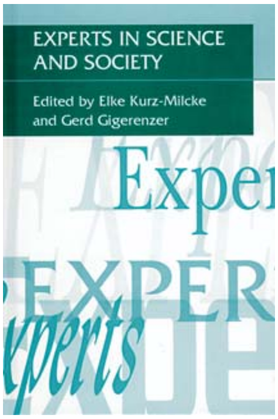

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