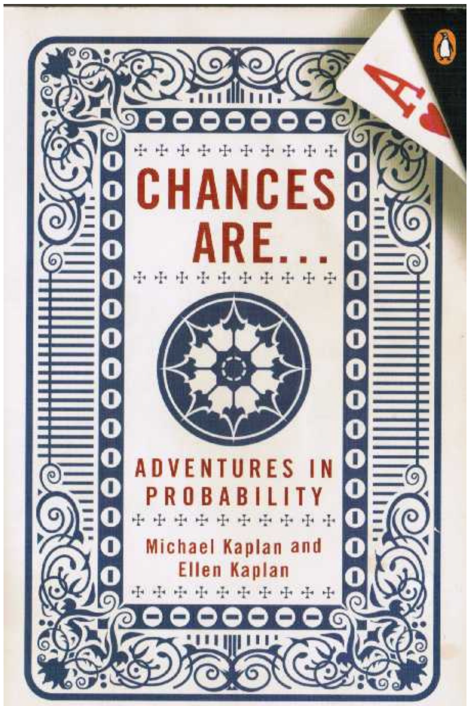
Concluding passage from



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The book begins by arguing that until the 17th Century, there were only two ways of understanding the world: ***inductively****, by example; and* ***deductively****, by axiom. Then came the development, often by clerics, philosophers and others (often mathematically inclined), of the science of* ***probability.***

The book engages that history and illustrates the use and misuse of statistics in many fields, including gambling, insurance, medicine, the law, science, war, weather, etc.

This excerpt concludes the book in what I regard a rather theological fashion. Even though it refers to material earlier in the book, the theological description of the human condition in "the world's casino" as "the endless struggle against randomness" has precedent, I think, in the wisdom of Ecclesiastes, quoted on page 2 here, "Time and chance happeneth to them all."

—Vern Barnet

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In 1877, Boltzmann extended this idea to explain mechanically how entropy tended toward its maximum value for any given state of an isolated system, a feat he achieved by relating the overall state of the system to the sum of all its possible micro-states.

Consider a system with a given total energy. There are many different ways that energy could be distributed: equally among all particles, for example, or with all the energy vested in one hyperactive molecule while all the rest remained in chilly immobility. We can call each of these possibilities a micro-state. Each is equally probable—in the same sense that each of 36 throws is equally probable with a pair of dice. But, you'll remember, the *totals* you get from the throws are not equally probable: there are more ways of making 7, for instance, than of making 12. Let a vast room full of craps players throw dice simultaneously, and you will find a symmetrical distribution of totals around seven, for the same reason that you find a normal distribution of velocities in a gas at equilibrium: because there are proportionally more ways to achieve this distribution than, say, all boxcars on this side of the room and all snake eyes on that. The maximum entropy for a physical system is the macro-state represented by the highest proportion of its possible micro-states. It is, in the strictest sense, "what usually happens."

Boltzmann's linking of microscopic and macroscopic showed how the countless little accidents of existence tend to a general loss of order and distinction. Things broken are not reassembled; chances lost do not return. You can't have your life to live over again, for the same reason you can't unstir your coffee.

But, objected Boltzmann's contemporaries, you *can* unstir your coffee—at least in theory. Every interaction in classical physics is reversible: if you run the movie backward all the rules still apply. Every billiard-ball collision "works" just as correctly in reverse as it does forward. True, we live in a mostly dark, cold and empty universe, so we don't see, for instance, light concentrating from space onto a star, as opposed to radiating out from it. Yet if we *were* to see this, it would merely be surprising, not impossible. Our sense of the direction of time, our belief that every process moves irreversibly from past to future, has no clearly defined basis in the mechanics of our cosmos.

So how could Boltzmann suggest that, although time has no inherent direction at the microscopic scale, it acquires direction when one adds up all the micro-states? How could a grimy steam boiler hold a truth invisible in the heavens? The objections were formal and mathematically phrased, but you can hear in them the same outrage that warmed the proponents of Free Will when they argued against Quetelet's statistical constants.

Yet there was more-than moral outrage at work: there was genuine puzzlement. Poincare's conclusions from studying the three-body problem had included a proof that any physical system, given enough time, will return arbitrarily close to any of its previous states. This is not quite the Eternal Return with which Nietzsche used to frighten his readers—the hopelessness to which the Hero must say "yes"—since only the position, not the path, is repeated: this moment (or something very like it) will recur but without this moment's past or future. Even so, Poincare's proof seems to contradict the idea of ever-increasing entropy, because it says that someday—if you care to wait—the system will return to its low-entropy state: the cream will eventually swirl out from the coffee.

Boltzmann, surprisingly, agreed. Yes, he said, low entropy can arise from high, but low entropy is *the same as* low probability. We can imagine the state of our system moving through the space representing all its

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possible states as being like an immortal, active fly trapped in a closed room. Almost every point in the room is consistent with the maximum entropy allowed just one or two spots in distant corners represent the system in lower entropy. In time, the fly will visit every place in the room as many times as you choose, but most points will look (in terms of their entropy) the same. The times between visits to any one, more interesting point will be enormous. Boltzmann calculated that the probability that the molecules in a gas in a sphere of radius 0.00001 centimeter will return to any given configuration is once in 3 X 10^{57} years—some 200,000,000,000,000,000,000,000,000, 000,000,000,000,000,000,000 times the age of the universe so far. As comparatively vast a system as a cup of coffee would be more than cold before it spontaneously separated.

Time's arrow, then, is not an intrinsic fact of nature; it is something defined by the prevalence of the more probable over the less probable. It is part of what usually happens but need not. Nothing in physics requires that we live from past to future; it's just a statistical likelihood. Somewhere in the universe now, physics may indeed be behaving like the movies shown backward at the end of children's parties: water leaps back into buckets and cream pies peel from matrons' faces to land on the baker's cart. But its highly improbable. “Time and chance happeneth to them all,” says Ecclesiastes—because time is chance.

Boltzmann's discoveries created the modern field of statistical mechanics—the general theory of which thermodynamics is the special case. It studies, as the quiet, brilliant Yale bachelor Josiah Willard Gibbs put it, how “the whole number of systems will be distributed among the various conceivable configurations and velocities at any required time, when the distribution has been given for one time.”

Gibbs' vision was panoramic; his proposal of a universal, probabilistic relation between micro-states and macro-properties has proved extremely fruitful. Think of the ways we describe low-entropy states mechanically: as having steep energy gradients, or clear distinctions of position or velocity. In general, we are talking about ordered situations, where, instead of a uniform mass of particles moving randomly, we see a shape in the cloud, something worthy of a name.

A cup on a table has a distinct identity: cup. Let it fall on the floor, and it becomes *15 irregular shards of china, 278 fragments, dust, some heat, and a sharp noise.* The difference in length of description is significant. Claude Shannon (he of the roulette computer) worked both at MIT and Bell Labs on the problems of telephone networks. He saw, in his own domain, another physical process that never reversed: loss of meaning. The old joke tells how, in World War I, the whispered message from the front “Send reinforcements—we're going to advance,” passed back man to man, arrived at company headquarters as “Send three-and-fourpence; we're going to a dance.” All communications systems, from gossip to fiber optics, show a similar tendency toward degradation: every added process reduces the amount of meaning that can be carried by a given quantity of information.

Shannon's great contribution, contained in a paper written in 1948, is the idea that meaning is a statistical quality of a message. Shannon had realized that information, although sent as analog waves from radio masts or along telephone wires, could also be considered as particles: the "bits" that represented the minimum transmissible fact: yes or no, on or off, 1 or 0. A stream of information, therefore, was like a system of particles, with its own probabilities for order or disorder: 1111111111111 looks like a well-organized piece of information; 1001010011101 appears less so. One way to define this difference in degree of order is to imagine how you might further encode these messages. The first you could describe as "13 ones"; the second, without some yet higher-order coding system, is just thirteen damn things one after another; there's no way to say it using less information than the message itself.

Communication, therefore, has its own version of entropy—and Shannon showed it to be mathematically equivalent to Boltzmann's equation. From low-entropy epigram to high-entropy shaggy dog story, every meaning is associated with a minimum amount of information necessary to convey it, beyond which extra information is redundant, like energy not available for work.

The connection between meaning and energy, nonsense and entropy goes even deeper. In fact, the eventual solution to the paradox of Maxwell's demon was an understanding of their equivalence. The rea-

soning goes like this: for the demon to run its system of favoritism, accepting some particles and turning away others, it would have to store facts about these particles—which is in itself a physical process. Eventually, the demon would run out of space (since the system is finite) and would have to start to erase the data it held. Erasing data reduces the. ratio of ordered to random information and so is a thermodynamically irreversible process: entropy increases. The perpetual motion machine remains impossible because its control system would absorb all the useful energy it generated.

The rules of the information system, the constraints within which its entropy tends to a maximum, are the conventions—the symbols, codes, and languages—through which we choose to communicate. These constraints can, themselves, have a great effect on the apparent order or meaning in a message.

For instance, Shannon showed how we can move from total gibberish (XFOML RXKHRJFFJUJ) to something that sounds like drunken Anglo-Saxon (IN NO IST LAT WHEY CRATICT FROURE) by requiring no more than that each group of three letters should reflect the statistical likelihood of their appearance together in written English; It takes only a few further statistical constraints on vocabulary, grammar, and style to specify the unique state of our language in our time. Shannon calculated the average entropy of written English to be 64 percent that is, most messages could convey their meaning in a little more than a third their length. Other languages encode different degrees of randomness or redundancy; you can determine the language a document is written in using nothing more than a computer's file compression program. Since compressibility is itself a sensitive measure of information entropy, the average ratio between compressed and uncompressed file sizes for a given language is an instant statistical identifier for that language.

David Ruelle suggests that this idea can be taken even further: since one important aspect of statistical mechanics is that the overall constraints on a system leave their mark on every part of it (if you make your boiler smaller or hotter, the pressure goes up everywhere within it), then *authorship* is also a constraint with statistical validity. Shakespeare's aver-

age entropy should not be the same as Bacon's; Virgil's concision is not Ovid's. Perhaps this explains why we seem to recognize the hand of the maker even in an unfamiliar work: we don't confuse a previously unseen van Gogh with a Gauguin; Bach is indisputably Bach within the first few bars; a glance distinguishes classical architecture from neoclassical. The judgment that leads a reader to recognize an author is not the conscious, point-by-point examination of the expert: it is a probabilistic decision based on observing a statistical distribution of qualities. An Israeli team recently produced a word-frequency . test that claims to determine whether a given passage was written by a man or a woman—we wonder what it would make of this one.

Our technologies shape our analogies: as steam was the preoccupation of the nineteenth century, and telephones of the early twentieth, so computers provided a philosophical reference point for the late twentieth. Kolmogorov extended Shannon's information entropy into what is now called *algorithmic complexity:* taking the measure of randomness in a system, message, or idea by comparing the length of its expression with the length of the algorithm or computer program necessary to generate it. So, for instance, the decimal expansion of π, although unrepeating and unpredictable, is far from random, since its algorithm (circumference over diameter) is wonderfully concise. Most strings of numbers have far higher entropy—in fact, the probability that you can compress a randomly chosen string of binary digits by more than *k* places is 2^{-k}: so the chance of finding an algorithm more than ten digits shorter than the given number it generates is less than one in 1,024. Our universe has very little intrinsic meaning.

Kolmogorov's idea brings us back to the probabilistic nature of truth. What are we doing when we describe the world but creating an algorithm that will generate those aspects of its consistency and variety that catch our imagination? "Meaning," "sense," "interest," are the statistical signatures of a few rare, low-entropy states in the universe's background murmur of information. Without the effort made (the energy injected) to squeeze out entropy and shape information into meaning (encoding experience in a shorter algorithm), the information would

settle into its maximum entropy state, like steam fitting its boiler or a dowager expanding into her girdle. Life would lose its plot, becoming exactly what depressed teenagers describe it as: a pointless bunch of stuff.

So what we can *expect* from the world? Boltzmann showed that we can assume any physical system will be in the state that maximizes its entropy, because that is the state with by far the highest probability. Shannon's extension of entropy to information allows us to make the same assumptions about evidence, hypotheses, and theories: That, given the restraint of what we already know to be true, the explanation that assumes maximum entropy in everything we do not know is likely to be the best, because it is the most probable. Occam's razor is a special case of this: by forbidding unnecessary constructions, it says we should not invent order where no order is to be seen.

The assumption of maximum entropy can be a great help in probabilistic reasoning. Laplace happily assigned equal probabilities to competing hypotheses before testing them—to the annoyance of people like von Mises and Fisher. You will recall how, when we thought of applying Bayes' method to legal evidence, we tripped over the question of what our *prior* hypothesis should be—what should we believe before we see any facts? Maximum entropy provides the answer: we assume what takes the least information to cover what little we know. We assume that, beyond the few constraints we see in action, things are as they usually are: as random as they can comfortably be.

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Slowly, by accretion, we are building up an answer to the quizzical Zulu who lurks within. Before, we had been willing to accept that probability dealt with uncertainty, but we were cautious about calling it a science. Now, we see that science itself, our method for casting whatever is out there into the clear, transmissible, falsifiable shape of mathematics, depends intimately on the concepts of probability. "Where is it?" is a question in probability; so are "How many are they?" "Who said that?" and "What does this mean?" Every time we associate a name or measure with a quality (rather than associating two mathematical concepts with each other) we are making a statement of probability. Some conclusions look more definite than others, simply because some states of affairs are more likely than others. As observers, we do not stand four-square surveying the ancient pyramids of certainty, we surf the curves of probability distributions.

Immanuel Kant's essential point (in glib simplification) is that reality is the medal stamped by the die of mind. We *sense* in terms of space and time, so we *reason* using the grammar imposed by that vocabulary: that is, we use mathematics. So if our sense of the world is probabilistic, does that also reflect an inescapable way of thinking? Are we, despite our certainties and our illusions, actually oddsmakers, progressing through life on a balance of probabilities? Should we really believe *that?*

When we've tried to believe it, we haven't always been very successful. The guilty secret of economics has long been the way people's behavior diverges from classical probability. From the days of Daniel Bernoulli, the discipline's fond hope has always been that economic agents—that's us—behave rationally, in such a way as to maximize subjective utility. Note that the terms have already become "utility" and "subjective"; money is not everything. Nevertheless, we are assumed to trade in hope and expectation, balancing probability against payoff, compounding past and discounting future benefits. In the world's casino—this palace of danger and pleasure we leave only at death— we place our different wagers, each at his chosen table: risk for reward, surplus for barter, work for pay (or for its intrinsic interest, or for the respect of our peers). Utility is the personal currency in which we calculate our balance of credit and debit with the world: loss, labor, injury, sadness, poverty are all somehow mutually convertible, and the risks they represent can be measured collectively against a similarly wide range of good things. Thanks to von Neumann and Morgenstern, economists have the mathematical tools to track the transfer of value around this system—the satisfaction of altruism, for instance, is as much part of the equation as the lust for gold. No one is merely a spectator at the tables: currency trader or nurse, burglar or philanthropist, we are all players.

And yet we don't seem to understand the rules very well. One of von Neumann's RAND colleagues, Merrill Flood, indulged himself by proposing a little game to his secretary: he would offer her $100 right

away—or $150 on the condition that she could agree how to split the larger sum with a colleague from the typing pool. The two women came back almost immediately, having agreed to split the money evenly, $75 each; Flood was not just puzzled, he was almost annoyed. Game theory made clear what the solution should be: the secretary should have arranged to pass on as little as she thought she could get away with. The colleague, given that the choice was something against nothing, should have accepted any sum that seemed worth the effort of looking up from her typewriter. Yet here they came with their simplistic equal division, where the secretary was actually worse off than if she had simply accepted the $100.

The secretaries were not atypical: every further study of these sharing games shows a greater instinct for equitable division—and a far greater outrage at apparent unfairness—than a straightforward calculation of maximum utility would predict. Only two groups of participants behave as the theory suggest, passing on as little as possible: computers and the autistic. It seems that fairness has a separate dynamic in our minds, entirely apart from material calculations of gain and loss. Which makes it ironic that communism, the political system devised to impose fairness, did it in the name of materialism alone.

Nor is this the only test in which *Homo sapiens* behaves very differently from *Homo economicus*. The relatively new windows into the working brain—electroencephalography, positron emission tomography, functional magnetic resonance imaging—reveal how far we are from Adam Smith's world of sleepless self-interest. For example, we willingly take more risks if the same probability calculation is presented as gambling than as insurance. We seem to make very different assessments of future risk or benefit in different situations, generally inflating future pain and discounting pleasure. Our capacity for rational mental effort is limited: people rarely think more than two strategic moves ahead, and even the most praiseworthy self-discipline can give-out suddenly (like the peasant in the Russian story who, after having resisted the temptation of every tavern in the village, gave in at the last saying, "Well, Vanka—as you've been *so* good..."). Emotion, not logic, drives many of our decisions often driving them right off the road: for every impulsive wastrel there is a compulsive miser; we veer alike into fecklessness and anxiety.

These functional studies suggest that the brain operates not like a single calculator of probabilities, but like a network of specialist submitting expert probability judgments in their several domains to our conscious, rational intelligence. A person does indeed behave like an economic unit, but less like an individual than like a corporation, the conscious self (ensconced in its new corner office in the prefrontal cortex) as chief executive. It draws its information not from the outside world, but from other departments and regions, integrating these reports into goals, plans, and ambitions. The executive summaries come into the conscious mind, like those from department heads, can often seem in competition with one another: the hypothalamus I putting in requests for more food, sleep, and sex; the occipital cortex respectfully draws your attention to that object moving on the horizon; the amygdala wishes to remind you that the last time you had oysters, you really regretted it.

In the best-organized world, all departments would work in cooperation for the greater good of the whole personality: emotion and judgment, reflex and deliberation would apportion experience, each according to its ability, leaving the rational mind to get on with strategic initiatives and other executive-corridor matters. But have you ever worked for such a smooth-running organization? Most of us, like most companies, muddle along at moderate efficiency. Memos from the affective system usually get priority treatment, automatic responses remain unexamined, and the conscious mind, like a weak chief executive, tries to take credit for decisions that are, in fact, unconscious desires or emotional reflexes: "Plenty of smokers live to be 90." "He's untrustworthy because his eyes are too close together." There may be a best way to be human, but we haven't all found it—which is why, like anxious bosses, our conscious minds often seek out advice from books, seminars, and highly paid consultants.

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If we must abandon the classical idea of the rational mind as an individual agent making probability judgments in pursuit of maximum utility,

we have to accept that its replacement is even more subtle and remarkable: our minds contain countless such agents, each making probability judgments appropriate to its own particular field of operation. When, say, you walk on stage to give a speech, or play the piano, or perform the part of Juliet, you can almost hear the babble of internal experts offering their assessments: "You'll die out there." "You've done harder things before." "That person in row two looks friendly." "More oxygen! Breathe!"—and, in that cordial but detached boardroom tone: "It will all seem worthwhile when you've finished."

How do they all know this? How do our many internal agents come to their conclusions—and how do they do it on so little evidence? Our senses are not wonderfully sharp; what's remarkable our ability to draw conclusions from them. Such a seemingly straightforward task as using the two-dimensional evidence from our eyes to master a three-dimensional world is a work of inference that still baffles the most powerful computers.

Vision is less a representation than a hypothesis—a theory about the world. Its counterexamples, optical illusions show us something about the structure and richness of that theory. For we come up against optical illusions not just in the traditional flexing cubes or converging parallel lines, but in every perspective drawing or photograph. In looking, we are making complex assumptions for which there are almost no data; so we can be wrong. The anthropologist Colin Turnbull brought a Pygmy friend out of the rain forest for the first time; when the man saw a group of cows across a field, he laughed at such funny-shaped, ants. He had never had the experience of seeing something far off, so if the cows took up such a small part of his visual field, they must be tiny. The observer is the true creator.

Seeing may require a complex theory, but it's a theory that four-month-old infants can hold and act upon, focusing their attention on where they *expect* things to be. Slightly older children work with even more powerful theories: that things are still there when you don't see. them, that things come in categories, that things and categories can both have names, that things make other things happen, that we make things happen—and that all this is true of the world, not just of me and my childish experience.

In a recent experiment, four-year-olds were shown making sophisticated and extended causal judgments based on the behavior of a "blicket detector"—a machine that did or did not light up depending on whether particular members of a group of otherwise identical blocks were put on top of it. It took only two or three examples for the children to figure out which blocks were blickets—and that typifies human cognition's challenge to the rules of probability. If we were drawing our conclusions based solely on the frequency of events, on association or similarity, we would need a *lot* of examples, both positive and negative, before we could put forward a hypothesis. Perhaps we would not need von Mises' indefinitely expanding collectives, but we would certainly need more than two or three trials. Even "Student" would throw up his hands at such a tiny sample. And yet, as if by nature, we see, sort, name, and seek for cause.

Joshua Tenenbaum heads the Computational Cognitive Science Group at MIT. His interest in cognition bridges the divide between human and machine. One of the frustrations. of recent technology, otherwise so impressive, has been the undelivered promise of artificial intelligence. Despite the hopes of the 1980s, machines not only do not clean our houses, drive for us, or bring us a drink at the end of a long day; they cannot even parse reality. They have trouble pulling pattern out of a background of randomness: The thing about human cognition, from 2-D visual cognition on up, is that it cannot be deductive. You aren't making a simple, logical connection with reality, because there simply isn't enough data. All sorts of possible worlds could, for example, produce the same image on the retina. Intuitively, you would say—not that we know the axioms, the absolute rules of the visual world—but that we have a sense of what is likely: a hypothesis.

"In scientific procedure, you are supposed to assume the null hypothesis and test for significance. But the data requirements are large. People don't behave like that: you can see them inferring that one thing causes another when there isn't even enough data to show formally that

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they are even *correlated*. The model that can explain induction from few examples requires that we already have a hypothesis—or more than one-through which we test experience." The model that Tenenbaum and his colleagues favor is a hierarchy of Bayesian probability judgments.

We first considered Bayes' theorem in the context of law and forensic science, where a theory about what happened needed to be considered in the light of each new piece of evidence. The theorem lets you calculate how your belief in a theory would change depending on how likely the *evidence* appears, given this theory—or given another theory. Bayesian reasoning remains unpopular in some disciplines, both because it requires a prior opinion and because its conclusions remain provisional—each new piece of evidence forces a reexamination of the hypothesis. But that's exactly what learning feels like, from discovering that the moo-cow in the field is the same as the moo-cow in the picture book to discovering in college that all the chemistry you learned at school was untrue. The benefit of the Bayesian approach is that it allows one to make judgments in conditions of relative ignorance, and yet sets up the repeated sequence by which experience can bolster or undermine our suppositions. It fits well with our need, in our short lives, to draw conclusions from slight premises.

One reason for Tenenbaum and his group to talk about *hierarchical* Bayesian induction is that we are able to make separate judgments about several aspects of reality at once, not just the aspect the conscious mind is concentrating on. Take, for instance, the blicket detector. "It is an interesting experiment," says Tenenbaum, "because you're clearly seeing children make a causal picture of the world—'how it works,' not just `how I see it.' But there's more going on there—the children are also showing they have a theory about how detectors work: these machines are deterministic, they're not random, they respond to blickets even when non-blickets are also present. Behind that, the children have some idea of how causality should behave. They don't just see correlation and infer cause—they have some prior theory of how causes work in general." And, one assumes, they have theories about how researchers work: asking rational questions rather than trying to trip you up—now, if it was your older sister . . . .

This is what is meant by a Bayesian hierarchy: not only are we testing experience in terms of one or more hypotheses, we are applying many different *layers* of hypothesis. Begin with the theory that this experience is not random; pass up through theories of sense experience, emotional value, future consequences, and the opinions of others; and you find you've reached this individual choice: peach ice cream or chocolate fudge cake? Say you decide on peach ice cream and find, as people often claim, that it doesn't taste as good as you'd expected. You've run into a counterexample—but countering what? How does this hierarchy of hypothesis deal with the exception? How far back is theory disproved?

“In the scientific method, you're supposed to set up your experiment to disprove your hypothesis,” says Tenenbaum, "but that's not how real scientists behave. When you run into a counterexample, your first questions are: `Was the equipment hooked up incorrectly? Is there a calibration problem? Is there a flaw in the experimental design?' You rank your hypotheses and look at the contingent ones first, rather than the main one. So if that's what happens when we are *explicitly* testing an assumption, you can see that a counterexample is unlikely to shake a personal theory that has gone through many Bayesian cycles.”

Even the most open-minded of us don't keep every assumption in play, ready for falsification; as experience confirms assumptions, we pack our early hypotheses down into deep storage. We discard the incidental and encode the important in its minimum essential information. The conscious becomes the reflex; the hypothetical approaches certainty. Children ask "Whassat?" for about a year and then stop; naming is *done*—they can pick up future nouns automatically, in passing. They ask "Why?" compulsively for longer—but soon the question becomes rhetorical: "Why won't you let me have a motorcycle? It's because you want to *ruin my life,* that's why."

This plasticity, this permanent shaping of cognition by experience, leaves physical traces that show up in brain scans. London taxi drivers have a bigger hippocampus—the center for remembered navigation—

than the rest of us; violinists have bigger motor centers associated with. the fingers of the left hand. The corporation headquartered in our skulls behaves like any company, allocating resources where they are most needed, concentrating on core business, and streamlining repetitive processes. As on the assembly line, the goal seems to be to drain common actions of the need for conscious thought—to make them appear automatic. In one delightfully subtle experiment, people were asked to memorize the position of a number of chess pieces on a board. Expert chess players could do this much more quickly and accurately than the others—but only if the arrangement of pieces represented a possible game situation. If not, memorizing became a conscious act, and the experts took just as long as duffers to complete it.

This combination of plasticity and a hierarchical model of probabilities may begin to explain our intractable national, religious, and political differences. Parents who have adopted infants from overseas see them grow with remarkable ease into their new culture—yet someone like Henry Kissinger, an immigrant to America at the age of 15, still retains a German accent acquired in less time than he spent at Harvard and the White House. A local accent, a fluent second language, a good musical ear, deep and abiding prejudice—we develop them young or we do not develop them at all; and once we have them they do not easily disappear. After a few cycles of inference, new evidence has little effect.

As Tenenbaum explains, Bayesian induction offers us speed and adaptability at the cost of potential error: “If you don't get the right data or you start with the wrong range of hypotheses, you can get causal illusions just as you get optical ones: conspiracy theories, superstitions. But you can still test them: if you think you've been passing all these exams because of your lucky shirt-and then you start failing—you might say, Aha; maybe it's the socks.' In any case, you're still assuming that *something* causes it.” It's easy, though, to imagine a life—especially, crucially, a childhood—composed of all the wrong .data, so that the mind's assumptions grow increasingly skew to life's averages and, through a gradual hardening of expectation, remain out of kilter forever.

It is a deep tautology that the mad lack common sense—since common sense is very much more than logic. The mentally ill often reason too consistently, but from flawed premises: After all, if the CIA were indeed trying to control your brain with radio waves, then a hat made of tinfoil might well offer protection. What is missing, to different degrees in different ailments, is precisely a sense of probability: Depression discounts the chance of all future pleasures to zero; mania makes links the sense data do not justify. Some forms of brain damage separate emotional from rational intelligence, reducing the perceived importance of future reward or pain, leading to reckless risk-taking. Disorders on the autistic spectrum prevent our gauging the likely thoughts of others; the world seems full of irrational, grimacing beings who yet, through some telepathic power, comprehend one another's behavior.

One of the subtlest and most destructive failures of the probability mechanism produces the personality first identified in the 1940s by Hervey Cleckley: the psychopath. The psychopath suffers no failure of rational intelligence; he (it is usually he) is logical, often clever, charming. He knows what you want to hear. In situations where there are formal rules (school, the law, medicine) he knows how to work them to his advantage. His impulsiveness gets him into trouble, but his intelligence gets him out; he is often arrested, rarely convicted. He could tell you in the abstract what would be the likely consequences of his behavior—say, stealing money from neighbors, falsifying employment records, groping dance partners, or running naked through town carrying a jug of corn liquor; he can even criticize his having done so in the past. Yet he is bound to repeat his mistakes, to "launch himself" (as the elderly uncle of one of Cleckley's subjects put it) "into another pot-valiant and fatuous rigadoon." The psychopath's defect is a specific loss of insight: an inability to connect theoretical probability with actual probability and thus give actions and consequences a value. His version of cause and effect is like a syllogism with false premises: It works as a system; it just doesn't mean anything.

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We have pursued truth through a labyrinth and come up against a mirror. It turns out that things seem uncertain to us because certainty is a quality not of things but of ideas. Things seem to have particular ways of being or happening because that is how we see and sort experience: we

are random-blind; we seek the pattern in the weft, the voice on the wind, the hand in the dark. The formal calculation of probabilities will always feel artificial to us because it slows and makes conscious our leap from perception to conclusion. It forces us to acknowledge the gulf of uncertainty and randomness that gapes below—and leaps are never easy if you look down.

Such a long story should have a moral. Another bishop (this time, in fact, the Archbishop of York), musing aloud on the radio, once asked: "Has it occurred to you that the lust for certainty may be a sin?" His point was that, by asserting as true what we know is only probable, we repudiate our humanity. When we disguise our reasoning about the world as deductive, logical fact—or, worse, hire the bully Authority to enforce our conclusions for us—we claim powers reserved, by definition, to the superhuman. The lesson of Eve's apple is the world's fundamental uncertainty: nothing outside Eden is more than probable.

Is this bad news? Hardly. Just as probability shows there are infinite degrees of belief between the impossible and the certain, there are degrees of fulfillment in this task of being human. If you want a trustworthy distinction between body and soul, it might be this: our bodies, like all life forms, are essentially entropy machines. We exist by flattening out energy gradients, absorbing concentrations of value, and dissipating them in motion, heat, noise, and waste. Our souls, though, swim upstream, struggling against entropy's current. Every neuron, every cell, contains an equivalent of Maxwell's demon—the ion channels—which sort and separate, increasing local useful structure. We use that structure for more than simply assessing and acting, like mindless automata. We remember and anticipate, speculate and explain. We tell stories and jokes—the best of which could be described as tickling our sense of probabilities.

This is our fate and our duty: to search for, devise, and create the less probable, the lower-entropy state—to connect, build, describe, preserve, extend ... to strive and not to yield. We reason, and examine our reasoning, not because we will ever achieve certainty, but because some forms of uncertainty are better than others. Better explanations have more meaning, wider use, less entropy.

And in doing all this, we must be brave—because, in a world of probability, there are no universal rules to hide behind. Because fortune favors the brave: the prepared mind robs fate of half its terrors. And because each judgment, each decision we make, if made well, is part. of the broader, essential human quest: the endless struggle against randomness.

BACK COVER

A compelling journey through history, mathematics, and philosophy, charting one of humanity's most ambitious and poignant endeavors—the struggle against randomness.

Our lives are played out in the arena of chance. We are always riding the odds, seeking for certainty but settling for likelihood, building our beliefs on the shadowy props of probability. CHANCES ARE. . . tells the story of our millennia-long search for the tools to manage the unpredictable, to parry the random blows of disaster, disease, and injustice. These pages introduce the brilliant individuals who developed the first abstract formulations of probability, as well as the intrepid visionaries who recognized their practical applications—from gamblers and forensic scientists to military strategists and medical researchers, from blackjack to our own mortality.

"[Michael and Ellen Kaplan] have hit on a great subject, and they explore it, down through the centuries and across the globe, with an enthusiasm that borders on glee.... A dizzying, exhilarating ride." —William Grimes, The New York Times

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