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1

Mathematical Rationality

IT TOO often feels like every choice in our daily experience, no matter how momentous, gets reduced to a risk analysis of chances and costs. Nutrition science tells us that a Mediterranean diet lowers the chance of heart disease, so we weigh the costs of heart attacks against what we like to eat. Worried parents meticulously plan the lives of children to maximize their chances of getting into good colleges. Polling tells us how pandering increases the chance a candidate wins an elected office, leading a candidate to decide how much to sell their conscience to maximize their chance of winning. Analysts now tell us that even sports can be distilled into raw numbers, with each play contributing to an accumulated probability of winning.

Is using risk management to guide every aspect of our lives putting us on a promising path toward happiness? I suppose it seems reasonable to say that there are some parts of life where risk analysis is important. Understanding the chances of financial assets gaining or losing value matters for retirement planning. You should estimate the risk of catastrophes when buying insurance. Statistical tests weighing genetics and risk factors inform prophylactic interventions in people at risk of developing serious diseases later in life. But going to restaurants? Raising

children? Deciding who we love? Is every decision in life actually reducible to betting on a game of chance? Certainly not! But then why has risk management permeated every aspect of our lives, from public policy to technological acceleration to health decisions? Where does this unshakable pressure to constantly optimize come from?

Central to this idea of relentless optimization is the notion of rationality. There seems to be an overarching idea today that rationality should dictate decisions—that there are right and wrong decisions independent of the ultimate outcome. The right decision is the one that maximizes the probability of winning. Winning apparently always has a cut-and-dried definition. A rational person tabulates statistics, determines the costs of outcomes, and then bets on the option with the biggest payout. A rational person is a gambler. A rational person is an insurance agent.

If this description of rationality doesn't line up with your conception of rationality, you are not alone. Digging through scholarly works, the term is hard to pin down. Someone might get at rationality by arguing that it derives from "reason." You might say a person who behaves in a reasonable way is acting rationally. Someone else might argue that rationality just amounts to having a consistent set of beliefs. The only consensus we seem to have is that rationality is good and irrationality is probably bad. Indeed, we often end up defining rationality in terms of cultural norms around irrationality. We might think it's irrational to be afraid of dogs. We deem it irrational to gamble at casinos, as the odds are stacked against you. We all know love is irrational.

The truth is that there are and should be many ways to define rationality. But the fact is, the word "rationality" has come to mean something very specific in our modern context—almost

equated with the risk-analytic mindset I've been describing. You might hear a case made like this: *Of course*, a rational person will weigh costs and benefits, estimate risks, and plan optimally. That's what it *means* to be rational. An irrational person will let emotions and personal bias influence their decisions, decisions which can easily end up being the wrong ones. If you don't want to be irrational, you'd better start doing your cost-benefit analyses, bub. Given some evidence and a set of possible actions in response to that evidence, there is always a rational way to proceed (and all other ways to proceed are thus deemed irrational). This might not lead to a win, but perhaps rationality *in and of itself* is the win.

A prime advocate for this notion of rationality is Harvard psychologist Steven Pinker. Pinker is one of the favorite intellectuals of the American elite, one of *Time* magazine's 100 Most Influential People, and frequent speaker at TED, Davos, and other hangouts of the ultra-rich and powerful. In his 2021 book, aptly entitled *Rationality*,¹ Pinker sets out to make a case for rationality and why we'd be better off if the hoi polloi was even more rational.

Pinker defines rationality as "the ability to use knowledge to attain goals." He clarifies the word knowledge to mean "justified true belief." Rather than fighting over what counts as truth,² let me drop the word "true" so we don't have to get into the philosophical morass of truth and meaning. I will use the following working definition: "Rationality is the ability to use justified beliefs to attain goals."

For Pinker and his powerful peers, rationality is defined with respect to goals. Rational agents must have goals. They also must be able to act. They decide to act based on whatever will most likely result in their desired goals. They decide on the most likely profitable action using their justified beliefs. Since

it is so centrally about quantification, algorithms, and logic, I am going to give this conception of rationality a special name: *mathematical rationality*. Mathematical rationality captures a colloquially accepted definition that undergirds all of the rational decisions I described above. It is, in short, our modern definition of rationality, the idea that guides so many of our decisions today. Build an understanding of how diets affect your chances of a long life and pick the best one. Figure out which extracurriculars maximize students' chances of getting into college and sign your kids up for those. Mathematical rationality wins the day.

Pinker's narrow view of mathematical rationality focuses on means of decision making. We choose our actions and deploy our resources in the most "rational" way to achieve our desired ends. This view is popular among Silicon Valley executives, Wall Street traders, and a growing cadre of public intellectuals like Pinker and Nate Silver, one of the most celebrated election analysts of the twenty-first century. Silver is lauded for bringing cold, analytical data to the once vibey analysis of election horse races. Since selling his wildly popular website, FiveThirtyEight, he has pivoted to being a staunch defender of mathematical rationality as the way to understand uncertainty and succeed in life. Given how much Silver praises rationality, it should come as no surprise that he began his career as a professional gambler. In his book *On the Edge*, he writes (without evidence) that "rich and powerful people" are disproportionately the mathematically rational. The ones guided by logic, not emotion. He exclaims, "Those of us who understand the algorithms hold the trump cards."³

Silver's gaming analogy touches on the most recent and culturally visible influx of risk management into everything else: the phenomenon of "analytics" in sports. You might be familiar

with the Brad Pitt vehicle *Moneyball*, which adapts Michael Lewis's 2003 telling of the statistical management of the Oakland Athletics to the big screen. More recently, analytics has taken over American football, where complex formulas are computed to select the appropriate plays to maximize odds. In football, a sport culturally associated with peak anti-intellectualism, many fans have bristled at this encroachment by the risk analytic mindset.

After a particularly consequential play backfired in a playoff game in January 2024, Greg Olsen, a former star player who had grown to be football's smartest color commentator, went on ESPN's *Pat McAfee Show* to champion analytics' role in football. Olsen declared:

The outcome doesn't make the decision right or wrong. We're going to go to Vegas here in a couple of weeks for the Super Bowl. Me and Pat are going to sit up at the blackjack table and I could be the dick that sits there and hits 18 until I get a 21. If I sit there all night, everyone on the thing is going to MF me all day. They're not going to want to play with me because I'm stupid. I'm defying all logic. But one time I'm going to pull a three, and I'm going to throw a freaking party. It doesn't mean I was right. It still means I was a dumbass.

The point is you could hit 16 all day. We've all been there. Just because you break 20 times doesn't mean it's the wrong decision. That's what's applying now to the game [of football] and they're trying to increase every percentage of win probability they can.⁴

There's so much to unpack in this quote. Olsen argues that there are decisions that are logically correct in sports. The logic of increasing probability is how the game needs to be played, regardless of outcome. This logic is the same as in the game of

blackjack, where there is an optimal strategy for winning. Football is apparently no different from a casino game. Going against the optimal strategy is “defying all logic.” It is, in his mind, *irrational*.

But the idea that there’s a right way to play blackjack is actually quite new. Blackjack has history dating back to the 1600s in Europe. You might think that someone would have written down a good strategy for the game around then. Or perhaps in the 1700s. It turns out that the first attempt at coming up with an optimal strategy for blackjack was in 1956.⁵ Why did it take so long?

Silver, Pinker, and Olsen’s ideas about rationality—their insistence on algorithms and their references to ideal strategy—also trace back to the 1940s and 1950s, when academic scholars in mathematics, statistics, and economics formalized this narrow view of the rational. It was during this same time period that the systems we’d recognize as modern computers were first designed, built, and sold. This was no coincidence. As we will see in this book, it was precisely the design and development of computers that determined the modern definition of mathematical rationality and its application to our everyday lives. In the eyes of its very first designers, the computer would become the ideal rational agent programmed to make optimal decisions. This ideal agent is an imaginary being we’ve been attempting to build, with varying degrees of success, since the 1940s. What is less clear is when we decided that we should strive to live our lives as if we were computers.

Computers have advanced to the point where the statistical analyses that enable so-called optimal decisions are easier to

run than ever. These analyses are applied all over the place, from logistics and planning of shipping goods to deciding which videos to offer you on streaming services. Internet platforms build their businesses on statistical analyses of their userbases, deploying advertisements and recommendations they deem most likely to increase engagement. With computing advances, weather prediction yields reliable 10-day forecasts that help people plan their lives. Statistical tests of personal risk factors inform prophylactic interventions against the development of serious disease later in life. This track record of successes might suggest to someone that it is worth emulating a computer when navigating their life.

Mathematical rationality, often called “normative decision theory” or sometimes, by economists, “rational choice theory,” is the rationality of computers. It is by its very nature algorithmic, strategic, and procedural. Though I only recently started calling it mathematical rationality, I’ve been studying the methodological pillars of the ideal rational agent for my entire career. These pillars are the fields of mathematical statistics, optimization, control theory, and machine learning. What unites these fields is their mathematical language for computers to rationally compute optimal decisions. This language is the bedrock of mathematical rationality and formalizes the computational components of the ideal rational agent. These are huge fields, and we can’t cover them comprehensively in a single book, but in the following pages we will learn what each contributes to mathematical rationality:

1. **Mathematical optimization.** A rational agent aims to act so that it achieves the best outcome given its model of the world. To do this, it writes down a mathematical description of how actions translate into outcomes. The

agent can then devise a computer program that computes the action that gives the best return under the assumptions of this model. This process of modeling and maximizing is called mathematical optimization.

2. **Game theory.** A particular case of mathematical optimization assumes that you are competing for resources against other rational actors. Methods for taking the potential behaviors of those other actors into account and strategizing against them are the foundation of game theory.
3. **Randomized experiments.** To inform mathematical models, a rational agent has to determine the impacts of actions via experimentation. In human-facing scenarios where predicting the outcome of action can be challenging, a popular approach is the randomized experiment. In a randomized experiment, the agent will engage in a variety of scenarios and choose random actions. By tabulating the outcomes of the various actions, they can then estimate which actions yield the best returns on average.
4. **Statistical prediction.** Finally, a rational agent needs to assess the probabilities of future outcomes. An agent might look at past experiences and compute the correlations between the previously observed actions and outcomes. If it uses these correlations to forecast future events, this is called statistical prediction, or, more commonly these days, *machine learning*.

All four of these pillars were formalized in the mid- to late 1940s, the brief window between the endgame of World War II and the creation of the first modern computer. The core algorithms developed in this period drive the automated decisions of our modern world, whether it be in managing supply chains,

scheduling flight times, or placing advertisements on your social media feeds. Even the ideas behind impressive contemporary technologies like Artificially Intelligent chatbots were formally developed in the 1940s. This period in history produced the ideas that led directly to our current obsession with optimization, in which every life decision is posed as if it were a round at an imaginary casino, and every argument can be reduced to costs and benefits, means and ends. To understand our obsession with rationality and what to do about it, we need to go back to the beginning. We need to trace mathematical rationality back to its roots.

In this book, we will explore the four pillars of mathematical rationality in depth, from their beginning in the late 1940s to the present. These pillars were pursued by a small, connected group of characters, though each pillar has an origin story and a life of its own. Together they embody the assumption made by the rationalists of today—Nate Silver, Steven Pinker, and others—that computers can make better decisions than humans. They impact on how we view, arrange, and govern our society, aimed at improving human decisions. But evidence from the past and present will show how mathematical rationality has sweet spots. It shines when it is employed in very specific, often narrow ways. But when mathematical rationality is employed outside of that sweet spot, it bumps up against very real limits and can result in us making decisions that don't serve us well. It is imperative that we figure out what those limits are, so that we can decide when to rely on computers to make decisions and when the decision is perhaps best left to a human. To that end, as we trace the history of mathematical rationality, I'll describe when these pillars succeed and when they come up short. I'll describe how people *actually* make decisions and how automated decision making and human decision making are

often in conflict. And I'll ask how humans and machines can work in tandem toward making the best decisions in the future.

This book is my attempt to answer the questions I posed at the outset of this chapter. Is mathematical rationality the right way to make decisions? Should every life decision involve distilling big data sets into simplified statistical tables? Should every decision be about profit maximization? Should mathematical rationality trump our values? Should mathematical rationality be an end in itself, justifying public policy, technological acceleration, and health decisions?

By now you will probably have guessed my answer to all of these questions: No. As the language of mathematical rationality grew more popular in the 2010s, with the rise of internet monopolies and the ubiquity of mobile computing, I increasingly realized this rational view of the world was surprisingly narrow and limited, and I wanted to understand where it came from. I wanted to explain the mathematics behind mathematical rationality. I wanted to understand how this narrow decision framework became a dominant cultural ideal. And I wanted to look to the past and future to consider possible alternative ways of approaching our lives, our governance, and our science. Writing this book prompted a foray into a critical understanding of the foundations of my field, aimed at highlighting both the sweet spots and the limits of mathematical rationality.

Cultural critic Neil Postman asserted that technology changes the meaning of our words. "It is a certainty that radical technologies create new definitions of old terms and that this process takes place without our being fully conscious of it."⁶ I want to tell you how the computer changed our meaning of the word rationality.

Let me start by setting the stage for the creation of the mathematically rational agent. Our modern notions of utility, chance, and investment all began brewing in the Enlightenment, but a solidification of these ideas would come between the two world wars. A key component of this coalescence is the formalization of modern *probability*. Such formal probability would be the foundation upon which the four pillars of mathematical rationality would be built.

Mathematical probability was first invented in the seventeenth century, but it would take three hundred years to become acceptably rigorous according to the mathematicians. Initially, the mathematics of probability was conceived to analyze odds in games of chance, such as the seventeenth-century work of Blaise Pascal and Pierre de Fermat determining how to split the betting pot appropriately in dice games. In the nineteenth century, physicists and statisticians discovered probability could be used for more than just gambling; it could help people to draw connections between the microscopic and the macroscopic.

For example, in the development of thermodynamics, physicists modeled the microscopic world as a bunch of tiny particles bouncing around. The motions of these trillions of trillions of microscopic particles appeared random. However, from far away, the blur of these tiny random particles looked *deterministic*. Physicists realized that their laboratory measurements were a blurry view of complex random activity. That is, orderly macroscopic measurements were *averages* of disordered microscopic activity.

It was during this time that we realized the world is unpredictable from certain vantage points yet highly predictable from others. For instance, I can't tell you whether a particular coin flip will land heads or tails, but I can tell you that if I flip enough

times, I should see approximately the same number of heads and tails. I can't tell you how the individual particles of gas move in a balloon, but I can tell you how big the balloon will be if I put in a certain amount of helium. I can't precisely predict the static in a radio transmission, but I can tell you roughly how loud it will be at different times of day due to atmospheric interference. This is the magic of probabilistic thinking: we trade in particulars for expectations. I can't predict specific outcomes, but I can predict general behavior.

These ideas were brewing in the physics community in the nineteenth century, and statisticians contemporaneously applied them to understand variations in plant, animal, and human populations. Individuals were random and wildly varied, but the averages of the population into statistical factoids were orderly and predictable. State bureaucrats could tabulate statistics to tell us stable facts about society, whether they be about crime, mortality, or demographics.⁷ Through statistics, chaos was aggregated into order.

Though these seminal ideas percolated for almost 300 years in various forms, it wasn't until the 1930s that we packed all of these related threads into a universal mathematical language of uncertainty. Russian mathematician Andrey Kolmogorov was the first to make probability into what mathematicians called a "rigorous theory" in 1933. Kolmogorov's axiomatization inspired a revolution in mathematics. For the first time, we could understand physical processes as *random* processes, ones whose measurements would always be unpredictable at the finest scales but whose behavior could be understood at a higher level of abstraction. If our interactions with the world were random yet predictable, maybe all uncertainty could be put on the same rigorous footing. With a rigorous calculus for the uncertain, statisticians concluded they could reason about *all* uncertainty

in the world. They could quantify uncertainty in measurements like censuses and polls. They could understand complex random processes to remove noise in communication systems and understand properties of the subatomic. There was an emerging promise of control: If we could understand uncertainty, perhaps we could use it for our purposes. Randomness itself could be *useful*. You could use random sampling to simplify quality control, looking only at a small, representative set of products on the assembly line. You could use random tests to see if one fertilizer was better than any other. You could use randomness to deceive opponents by choosing your next action at random. Statisticians began to develop means to inform decisions despite the formidable uncertainty of existence.

As the 1930s drew to a close, it seemed we were finally at a time where we could achieve the promise of Enlightenment science. We could count things, establish statistics, draw rigorous inferences, and understand our natural world through a language of mathematics. And that mathematics could inform how to make the most critical decisions even in the face of uncertainty. We could characterize all the properties of the unknown we'd need to make appropriate, informed decisions. In the 1940s, this mathematical harnessing of uncertainty would be put to the test in one of humanity's largest, deadliest conflicts.

World War II reshaped global society, discontinuously reconfiguring borders, ideologies, and technologies. The war also transformed the relationship of natural sciences and government, drafting the efforts of pure science into applied military efforts. The United States established the National Defense Research Committee in 1941. The NDRC was the brainchild of Vannevar

Bush, an electrical engineer who was MIT's Dean of Engineering in the 1930s. Bush determined hard science and engineering was necessary to advance defense logistics against the new sophisticated technology being developed by Nazi Germany. Through Bush's academic connections, World War II saw an unprecedented involvement of civilian scientists, engineers, mathematicians, and economists. Bush argued that we should gather the theoretical and technological advances of the first half of the twentieth century and make them actionable in reality to fight the greatest threat of the second half of the twentieth century. Military branches themselves established units for tabulation, statistics, and planning. The fevered war machinations tapped technological and intellectual innovations from the prior decades, advancing them for directed military applications.

Mathematicians brought two major innovations to the war effort. The first was the hardware to run large-scale computations. In the early 1930s, Bush had built a nascent computer called a "differential analyzer." This machine could add and subtract and showed the promise of automating tedious calculations to solve complex applied-mathematics problems. One of Bush's graduate students found the differential analyzer to be too temperamental because of its analog design. In his master's thesis, he proposed an alternative means of building computers with *digital* logic gates. This master's thesis would form the basis of all of our modern computer chip architectures. Its author, Claude Shannon, would become the most influential electrical engineer of all time, single-handedly creating half a dozen engineering fields.

Inspired by these early computing successes, Bush lobbied the government for massive funds for the development of digital devices to accelerate military-driven calculations. Intricate, complex computations were done by teams of people feeding

newly developed electronic calculators with punch cards, supervised by top mathematicians. These calculation efforts helped predict the behavior of complex rocket ballistics and antiaircraft weaponry and were critical to the design of the atomic bomb. Though it wouldn't be finished until after the war ended, the ENIAC, what many consider the first programmable computer, was commissioned during the war to further accelerate such calculations.⁸

A parallel contribution of mathematics to the war effort was the application of probability and statistics for logistics and planning. There were innovations in how to communicate securely and break codes. New techniques were developed to predict the behavior of enemy aircraft and determine what sorts of ships were present in noisy radar signals. Because of advances in therapies, militaries began recording the results of large-scale field trials in managing disease, infection, and wounds.

At the center of all this activity was a group of mathematicians who would become famous in the aftermath of the war. The most famous of them, Norbert Wiener, John von Neumann, and Claude Shannon, will be central to the story of this book. Before World War II, Wiener and von Neumann were well known among mathematicians for their contributions to the foundations of probability. Wiener was one of the founders of the theory of stochastic processes, and von Neumann did seminal work in quantum mechanics and what would become game theory. The war experience opened their eyes to what the abstract frameworks they built could do for concrete reality. Mathematicians saw firsthand how quantified predictions of the unknown could improve our decision-making capabilities.

Mathematicians left the war inspired by their ability to have practical impact. The world needed rebuilding, and they wanted

to be part of that rebuilding effort. They aimed to take the ideas that had shown promise in the war and apply them toward peacetime efforts. Toward defense. Toward public health. Toward governance.

The key mathematical insight of the war was linking that which could be calculated to that which could be automated. Mathematicians were tantalized by the possibility that if humans could make a decision, then that decision not only could also be made by machines, but could possibly be better made by machines. Uncertainty would still exist, of course, but quantification of uncertainty could be made methodical and rule-based. If decisions could be calculated from such quantified uncertainty, then they too could be automated. These decisions would be more “scientific.” More “rational.” The mathematicians of the day set out to build rational machines.

Inspired by the success of mathematical logistics in the war effort, this small group of talented mathematicians dedicated the decade after the war to fully automating mathematically rational decision making. This would require not only new techniques, but also new machines that did this automation. There was thus a rapid co-development of the abstraction of rational decision making and the design and construction of the architectures and circuits of the computer.

As we will see in this book, the codified mathematics of the 1930s that had proven so valuable in the war inspired the codification of an ideal rational agent. To make decisions in the face of adversity and uncertainty, uncertainty needed to be quantified. The ideal rational agent would do just that by equating the unknown with the random. Just as nineteenth-century

physicists had shown, a vast collection of unpredictable events could look predictable on average. Once uncertainty was quantified, a plan would need to be constructed to maximize the chances of a good outcome. The value of outcomes would be equated with a universal currency. A rational agent would thus assess the probability of various futures and choose its action to maximize its returns. It would be less ad hoc, temperamental, and tied to conventions than its flawed human designers. It would be mathematically rational.

Between 1945 and 1950, not only was this mathematical ideology fully developed, but the modern computer architecture was designed and built to execute it. Computers were designed to build better weapons and make better decisions in the shift from the World War to the Cold War. The rise of the Cold War administrative state, with massive investment in research, academia, and medicine, provided the ample funds and resources needed to build these first computers. And the computers would be designed to execute the four pillars of mathematical rationality: mathematical optimization, game theoretic strategy, randomized experimentation, and statistical prediction.

And though our contemporary computers are billions of times more dense and powerful than their 1950s counterparts, their internal logic, organization, architecture, and robotic ideology have remained the same.

The centering of the computer and its theoretical potential explains how mathematical rationality shaped how we conceive of rationality today. Part of the power of mathematical rationality is attributable to the unfathomable growth of computing. For a long time, computers got twice as fast every two years.

Gordon Moore, the co-founder of Intel, predicted this in 1965, and for decades the computing industry proved Moore correct. Such exponential growth meant that problems that seemed unsolvable last year became solvable the next year. From 1965 to 2015, fifty years after Moore's prophecy, computing power doubled 25 times, equal to a mind-boggling factor of over 30 million. Computers got faster, and that gave us a guiding vision. We could see how far the information age could take us.

Growth in computer "intelligence" far outgrew growth in human intelligence. And since there was so much excitement about these improved business engines, it didn't really make sense to worry too much about alternative ways to make decisions. Adding more computing and data seemed to enhance decision making at multiple points. Computers helped governments grow and manage a blooming administrative state. Computer backends help manage businesses. Computers created a globally connected financial system that has enabled unprecedentedly interconnected trading and commerce. They undergird path dependencies in our complex and confusing healthcare system. There is nothing we do anymore that doesn't touch a computer. The logic of spreadsheets, the immediacy of email, and the information of the internet all shape how we think about knowledge. We equated the booming power of our computer systems with the power of mathematical rationality to solve problems.

But if rational decision making is a hammer, every decision looks like a nail. There are sweet spots for each pillar of mathematical rationality, but it's easy to get trapped by one's tools and fail to realize that the most difficult questions are the ones the tools can't answer. Mathematical rationality is peculiar and robotic! All unforeseen occurrences are deemed conceptually equivalent to a lottery. All decision making is a proper mechanical

analysis of risk. The mathematically rational agent always identifies and chooses the least risky potential outcome. According to the inventors of computers, the truly rational agent is an actuary.

Today, the unprecedented scaling phase of the information age is ending. Access to the computing power needed to solve the most daunting contemporary calculations is concentrated among a few large tech companies. And even for these folks, exponential scaling must end too. We'll run out of data centers and electricity sooner rather than later. So what do we do next? Maybe it's time to step back and ask whether we're happy with the shortcomings of our big bureaucratic system. To ask why we're stuck with our idiosyncratic mathematically rational decision-making paradigm. To look to other ways of making decisions.

Steven Pinker and Nate Silver both claim we should strive for more mathematical rationality. I will present the case for why the future really needs less. We should use the tools of mathematical rationality only sometimes, in the sweet spot where they do make very good decisions—but the rest of the time, we need a human touch. Sure, humans aren't mathematically rational, but some decisions can't be reduced to numerical calculations. Sometimes our ingenious human qualitative irrationality is precisely what a situation needs. In the pages that follow, I'm going to show you how the four pillars of mathematical rationality came to such power and ubiquitousness—but also how they can only get us so far.

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