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INTRODUCTION

There we were, my wife and I, standing in front of a gorgeous house we were about to call our own. We'd been house-hunting for a while, and on the face of it, this one seemed to satisfy almost all of our criteria. It was perfect. But somehow, we were not happy. For some mysterious reason, we got a bad feeling when we visited the house. Something was wrong, but we could not figure out what it was.

We soon discovered that the reason behind our negative feelings was more unexpected and deeper-seated than I could have anticipated.

I was only two years old when the war started—an eight-year-long war that eventually claimed the lives of more than half a million people. Air raids and missile attacks on my hometown were common. I remember the terrifying sounds of bombs and missiles striking seemingly random areas of the city, sometimes close enough to my neighborhood to shake buildings and shatter windows. I grew up holding my breath and waiting for the next blast.

Many of us who grew up with memories of war have an understandably unfavorable feeling about any sound that reminds us of rockets, bombs, or bullets. As it turned out, there was a shooting range near that perfect house we intended to purchase. Standing in front of the house, we could barely hear the gunshots. The low level of noise was almost nonexistent for the residents of the neighborhood. But apparently not to us. I theorized that our dislike for the house stemmed from the noise from the shooting range subconsciously putting us in a bad mood whenever we visited. We did not even realize the cause until someone casually mentioned the shooting range, and we finally understood where those bad feelings were coming from.

We ended up not buying the house. Was this a good decision? Well, there are several aspects of uncertainty, randomness, and decision-making we can consider in this story.

Let's start with my initial bombing experience. Is it rational to be so worried when living in a city under siege? On the surface, if you were in this situation, it is quite unlikely that you would be directly impacted by an incoming bomb. Say your city has several million residents, and each attack directly impacts a few hundred people or so. The probability of a direct impact right where you're standing at any given moment is less than 1 in 1,000. However, you probably agree that this situation—where lives could be lost in the blink of an eye—is more complicated than a simple probability calculation.

The story of my wife and I deciding not to buy the house exemplifies the idea that our decisions are

impacted by a variety of factors, many of which we might not even be aware of. Often we cannot accurately assess the quality of our decisions, even after we make them. Was the nearby shooting range the true reason for our bad feelings about the house? Could other factors have played a role without our knowledge?

Interestingly, even if I had a crystal ball that could have shown me what would have happened had we purchased the house, I still would have had difficulty accurately assessing the quality of our decision not to buy the house due to factors such as hindsight and outcome biases.

Life is messy and full of uncertainty, risk, opportunities, and randomness. Human decision-making is too complex to be addressed with a few general rules. So how do we make sure we are making good decisions under uncertainty? In other words, what can we do to gain an edge in our decision-making processes? This was the question I set out to explore more than a decade ago, and it is the question at the center of this book.

WHAT THIS BOOK IS ABOUT

Practical Uncertainty combines what I found to be the most useful concepts and ideas in uncertainty, risk, randomness, and decision-making; presents them in a coherent, practical, and usable way; and offers intuitive insights to better help you internalize these concepts. It also aims to provide you with an understanding of machine learning (ML) and artificial intelligence (AI) decision-making through the lens of uncertainty.

Randomness and uncertainty are all around us, and they impact us in surprising ways. This book is

intended as a practical and educational manual that will help you understand and internalize useful tools for risk-taking and decision-making under uncertainty, both by humans and AI.

WHY I WROTE THIS BOOK

Over the course of two decades in my career as a researcher, in my research, I have heavily used tools from probability, statistics, information theory, and related fields. I even published a textbook on probability. However, over a decade ago, I became seriously interested in how these often-abstract tools can be used in personal and social life. I realized that risk, uncertainty, and randomness are vital parts of business, sports, politics, and almost every personal or societal decision we encounter.

I began researching and attending seminars and workshops on uncertainty and randomness in real life. After a while, I started teaching various university courses on uncertainty, risk, and decision-making that were mostly based on the vast available literature on the subject. I also became interested in using AI decision-making in engineered systems as a part of my research agenda.

Then, to validate my teaching methods, I started to keep track of how I was using the tools I was teaching in my own personal decision-making. The result surprised me: after two years of teaching the course, I could attribute very few of my decisions to my new “expertise” in decision-making, and I realized that very little of what I was teaching now would have helped me make better decisions in the past. What was going on? Did I have it all wrong?

The realization that few of the tools I was teaching my students had proved useful in my own life was a wake-up call for me. If I was not able to use most of these concepts, how useful could they really be to my students? How could I remove the less consequential stuff and focus on the most fundamental and useful concepts for real-life decision-making? That became my primary objective.

I began to notice that a large part of the content I was using in my courses and seminars, although academically interesting, was not usually applicable in practice (at least to my personal decision-making experience). In the end, I stripped away anything that wasn’t directly relevant to our daily lives, leaving only those lessons that I or the students in my classes had found helpful.

Slowly, interesting patterns emerged. Finally, I was able to combine these useful but somewhat disparate ideas into a coherent whole and present them in a practical and actionable way. It turned out that it was the *intuitive understanding* of uncertainty and how it impacts our lives that was particularly useful.

I also noted that this foundational look at uncertainty is at the core of machine learning (ML) and AI decision-making. This topic fit very well with the other remaining core content and thus was added to the course (and now to this book). For those unfamiliar with ML, the presentation in this book should be self-contained; for those already familiar, I hope my approach can provide new insights and better understanding.

During this period, on several occasions, I had to make tough life-and-death decisions, which helped

a lot in practically evaluating the decision-making strategies described in this book. At the same time, my research group and I were building autonomous systems whose purposes were to make high-impact decisions. For example, we designed a group of autonomous drones that could help in search and rescue operations. A good decision by such autonomous agents could save lives, while a bad decision could have catastrophic consequences.

To develop my research further, I also tried to take all opportunities to gain practical experience with randomness and uncertainty such as engaging in finance and entrepreneurial activities. For example, financial markets are a good place to experience randomness and uncertainty, so I opened an investment account and started to manage my own small portfolio. This was shortly after the 2008 financial crisis, so there was a lot to learn. While I had been familiar with theories of finance for years, taking risks with a sizable portion of my own money was certainly a fruitful experience.

This book is thus the result of my exploration, teaching, and research on decision-making under uncertainty. Everything discussed within it is some concept or trick that my students or I found personally useful in some respect, either directly or by helping to better understand and internalize other useful concepts.

HOW THIS BOOK CAN HELP

There are many admirable books and articles relating to the fields touched upon in this book: chance, uncertainty, risk, decision-making, psychology, and machine learning.

I have greatly benefited from and been influenced by many of these resources. Many of them, combined with my own research, experiences, and research, have shaped the content of this book. However, my hope is that this book can benefit even the readers familiar with the existing excellent body of work for the following reasons.

First, the focus here is mostly on the question “How can I use this in my own personal and work life?” One reason the courses I taught were less effective in the beginning years was that I tried to cover too much. With this in mind, my goal for this book was to identify the most useful concepts and ideas surrounding decision-making under uncertainty, then present them in a concise and usable way.

Second, some insights and techniques in this book might be novel or barely covered elsewhere. For example, I will discuss some practical applications of information theory in decision-making, privacy, and finance that I do not believe have been adequately covered before for the general audience. The combined presentation of human decision-making and machine learning under the umbrella of uncertainty and randomness is similarly uncommon and, I hope, insightful.

One surprising finding from my teachings is that it is easy to misinterpret or misunderstand the implications of some influential works on the topic of uncertainty. For example, I often saw my students drawing gloomy messages from certain readings: that our intuition is hopeless when it comes to randomness and we cannot do much to improve it, or that success is largely determined by luck and we have little influence on our

trajectory. I found this extremely frustrating. This kind of thinking was the exact opposite of what I had in mind when sharing this knowledge.

I strongly believe that we *can* work to improve our decision-making. We can better understand uncertainty, and we can use this understanding to increase our chances of achieving our goals. That's why another focus of this book is to reinforce this important conclusion by providing applicable ideas and strategies. Thus, you will find out that this book is written with a somewhat positive outlook in mind. It is not all doom and gloom!

As I mentioned above, a large number of resources that I used over the years, combined with my own research, experiences, and observations, have shaped the content of this book. You'll find a list of relevant resources in the Recommended Reading section at the end. Anything useful in this book should be mostly attributed to the people I learned from, and any shortcomings should be assumed mine.

HOW TO APPROACH THIS BOOK

Practical Uncertainty begins with simple, well-known concepts and gradually moves toward those that are less covered in the existing literature. This structure is intended to make the book easy to read for all audiences. What does that mean for you? If the beginning of the book seems somewhat elementary or even a bit boring, please read on! More exciting topics are soon to come. Even if you are an informed reader on the subject, I recommend reading the entire book, as some treatments of the material might be insightful.

On a related note, a brief word of warning (or perhaps assurance): this is not a rigorous academic science or math book. If you are expecting frequent references to academic journals, discussions on historical data, and so on, this is not the book for you. Instead, I have focused on providing applicable insights and takeaways for life and work.

The book is intended to stimulate pondering as you read. I do not try to sugarcoat or oversimplify anything. Some of the ideas can only be internalized after thinking deeply about them and putting them into practice. That is why I hope you read this book more than once.

Some ideas in the book are based on mathematical arguments. In the interest of making the book accessible, practical, and to the point, I have focused on building intuition and insight rather than providing mathematical or scientific proofs. That said, I have tried hard not to sacrifice useful concepts or mislead readers by oversimplifying things. This means there is, indeed, some minimal but inevitable math in the book. I do briefly explain mathematical concepts as they relate to the topics at hand, but for those readers who dislike math, my hope is that you still find the material useful.

Throughout *Practical Uncertainty*, I have utilized my personal experience, feedback from my students, and my research and observations over the years to continuously improve the presentation of this material. I hope the resulting book is effective and helpful to readers and, hopefully, enjoyable to read.

Now let's get started!



CHAPTER 1:

A WARM-UP: UNLUCKY STREAKS AND MARGINS

A few months into the COVID-19 pandemic, some large organizations and companies found themselves in dire situations and began planning for layoffs, while others in the same industries fared relatively well throughout the pandemic. What was the secret of the companies that managed to stay strong? Well, there are many factors at play here, but a certain property of uncertainty can help us partially answer this question. We will return to this concept shortly, but first, let's start with a quick overview of randomness and uncertainty.

THE BASICS: UNCERTAINTY VIEWED AS RANDOMNESS

This book is about understanding randomness and uncertainty. What do I mean by randomness? I simply

mean a lack of certainty. For example, when you start a business, you cannot be sure what your first-year sales will be. Thus, this first year of business is an example of a random experiment. With this view, randomness and uncertainty are essentially the same.

A random experiment doesn't have to be a future event; the event in question could have happened in the past. However, as long as we have uncertainty about the event, we can treat it as a random experiment. For example, the jury in a murder trial is interested in the probability of the defendant's guilt during a past event. Even though the event has already happened, jurors cannot be certain either way of the defendant's guilt.

To summarize this point, any time there is uncertainty or a lack of information about an event, we can consider it a random experiment—and we may be able to use the tools discussed in this book to enhance our decision-making in such scenarios.

A SIMPLE YET INSIGHTFUL RANDOM EXPERIMENT

What is the simplest random experiment? Consider a basic coin toss: you flip a coin, and the outcome is either heads or tails. This simple experiment will be our guide to understanding uncertainty.

You might point out that life is not like tossing a coin or rolling a die. It is not even like poker or any other structured game. And you would be absolutely right. That is why the title of this book is not *How to Live* or something like that. That topic would be too general and too complicated.

So why am I starting with a coin toss example if it does not reflect real life? The simplicity of a coin toss and its limited outcomes can help us develop intuition about randomness and uncertainty that *can* be useful in real-life decision-making. We will build on this intuition throughout the book.

Our discussion on randomness and coin tosses provides a natural way to discuss luck. In anything we do, the outcome is due partly to skill and partly to luck. In this view, a chance occurrence could be interpreted as luck, so we may be able to gain insight by tossing some coins. Our first insight relates to random patterns.

PATTERNS AND LUCK

Every morning when I make my latte, I manage to create a new pattern or shape in the foam. One day it might be a flower, the next day a famous person, and so on. I never practiced this art; I have never worked at a coffee shop. So what is my secret? It's easy: I pour the milk foam randomly over the coffee, and after I am done, I try to identify a pattern. Sure enough, I always find one.

Of course, if you ask me beforehand to create a certain shape, you will be disappointed. Randomness tends to create patterns, and we humans are masters of identifying patterns. Let's investigate this issue more carefully and see how we can effectively use it in our decision-making. To do so, we use our coin-tossing experiment to gain intuition.

PATTERNS IN COIN TOSSES: RUNS AND STREAKS

Let's toss a coin 100 times and observe the sequence of heads and tails to look for patterns. The easiest patterns we might perceive are streaks (or runs) of heads or tails. More specifically, a streak is a sequence of consecutive identical outcomes. For example, HHH is a streak length of three,¹ since it represents three heads in a row.

Consider the result of our 100 coin tosses. How likely is it that somewhere in that sequence we observe a streak length of six—that is, six heads in a row or six tails in a row? Many of us might guess this probability to be less than 50%, but it happens more often than you'd think; the correct answer is more than 80%. What does this tell us? It simply says that streaks resulting from randomness are more likely than what we might naturally expect. See figure 1.1.

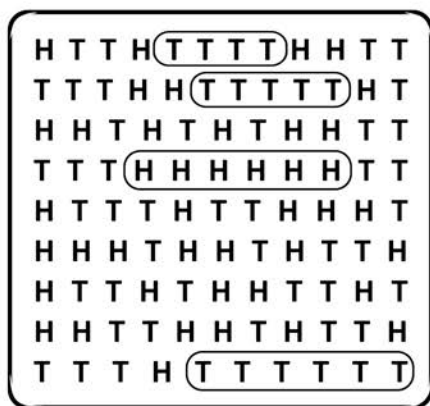


Figure 1.1. The result of 100 coin tosses. A typical random sequence could contain long streaks or runs, i.e., consecutive heads or consecutive tails.

¹ Here H represents the coin landing heads up.

According to psychologists, if you were to ask a person to write down a random sequence of heads or tails, they would likely not produce a long streak of consecutive heads or tails. In reality, though, such *clustering*—long random sequences of similar events—does happen. Now, how can we use this observation in real life?

This prevalence of clustering implies that streaks of good and bad luck are inevitable in life and business, but we tend to underestimate their likelihood and length. We need to be prepared to handle this phenomenon and even take advantage of it.

If we can expect certain bad events to sometimes occur consecutively, we should not be surprised or disappointed when they do. We know these clusters of unlucky events simply happen at random. Just by understanding this, we can significantly toughen ourselves against such misfortunes. Rather than becoming depressed after a series of unfortunate events, expecting and planning for these situations can help us cope with them.

One caveat, though: we should make sure we do not mistake bad luck (randomness) with bad planning or bad strategy (unpreparedness). For example, I had a high school friend who never studied for his exams. Instead, he prayed to God to help him *cheat* on the exams! Needless to say, God did not respond to his absurd prayers. My friend's poor results were the consequence not of bad luck but of his lack of preparation.

Although most of us have better judgment than my friend, I share this example as a reminder. We should make sure the misfortune we occasionally experience is

not because of our own misguided strategies. Psychologists have observed that we tend to overestimate the role of bad luck in our failures and, at the same time, underestimate the role of good luck in our success. Being aware of these tendencies helps us better manage our situations.

The fact is, bad luck does occasionally cluster, and knowledge of this fact is the first helpful tool we can use to cope with streaks of negative events. In fact, tough times are usually opportunities for improvement. Channeling our frustration into overcoming obstacles and finding new opportunities seems to be a helpful strategy for weathering bad times.

You have probably heard stories of people turning bad luck into great success, so I won't bore you with them here. Instead, let's talk about the next tool for dealing with unlucky streaks. I believe it is one of the most effective tools we can use to deal with bad luck and uncertainty in our lives.

THE VALUE OF MARGINS AND SOME MISCONCEPTIONS

An important strategy in dealing with randomness and uncertainty is including enough margin when planning our days, projects, and business endeavors. Here *margin* refers to any redundancy, extra capacity, buffer, or leeway that helps to soften the blow when unfortunate events occur.

An important point here is that we tend to underestimate the required margin for a situation in the same way we tend to underestimate the length of streaks in

the coin toss example. During the COVID-19 pandemic, many large organizations quickly ran into insurmountable problems, in part because they did not implement enough margin in their plans. When running a business, it is a good idea to investigate how the business would survive a few unexpectedly bad months, then take actions to increase buffers and margins to increase your ability to survive.

Here is another important point about uncertainty: we are most vulnerable to events that we do not see coming. These unpredictable outlier events could appear out of nowhere and have big consequences. Nassim Taleb, mathematical statistician and essayist, refers to these events as Black Swans and points out how important they are in our lives. Things that have never happened in the past and of which we are completely oblivious do indeed happen, and they can hurt us.

Sounds horrible, right? Well, implementing margins is one of our best defenses against negative Black Swans. For example, financial advisers always suggest building a sizable emergency fund and limiting debt, both examples of incorporating margins into personal finance. We cannot accurately predict what sort of emergencies we might face in the future, but we can know that significant savings can potentially help us weather such storms.

It is also a good idea to include a decent margin when planning for projects by scheduling more time than we think we'll need. As another everyday example, if you are traveling somewhere or you have an appointment, it's always good to leave early in case your car

breaks down, your train is late, or you run into bad traffic. This margin gives you space to take care of the situation and continue about your day without missing important plans or appointments.

Unsurprisingly, margins can also help reduce stress in our lives. If you start studying for an exam a week in advance, you will be less panicked about it than if you try to cram the night before. Stress can lead to poor decision-making, so reducing your stress can have positive ripple effects.

All this being said, most of us are busy and have many different responsibilities; we cannot build margins for everything. Margins could indeed be costly in some situations. There are two times when it makes sense to build margins: when the thing in question is important and when the cost of building the margin is reasonably low. For example, when I need to fly, I usually leave for the airport much earlier than necessary. This is a combination of an important event and a low cost: missing the plane could have major consequences, and because I can easily work while waiting for boarding, I can implement this margin with almost zero cost. Why risk it?

STREAKS OF GOOD LUCK

Now what about streaks of good luck? They happen too—hooray! I personally believe the best approach to such situations is humility. I need to make sure I do not get cocky or arrogant in good times as hubris can lead to mistakes. Instead, take advantage of the opportunities good luck can bring by building margins for Black Swans and bad times.

Borrowing again from finance literature, let's say times are good, and you are making good money. Great! While you are enjoying your wealth, it is a good idea to increase your contributions to your saving, and investing accounts. If you get a 20% raise or a significant bonus, for example, it is a good idea to save or invest at least half of the amount. As figure 1.2 demonstrates, this gives you an extra boost and helps to offset the times when things aren't so good.

This all might seem obvious and basic, but the truth is that many of us fail to follow these simple actions. Even intelligent business managers sometimes make big mistakes in this regard. This is one of the reasons many businesses fail every year: many of them simply do not implement margins in the good times to help them survive the bad times. So how can we get better at implementing margins?

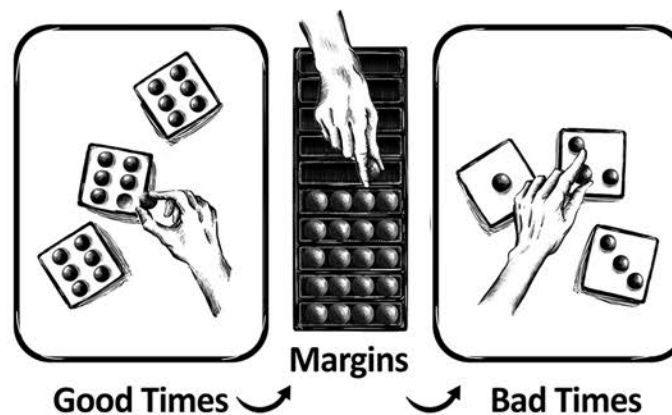


Figure 1.2. Taking advantage of lucky streaks. Increasing your margins during the good times can help offset the bad times.

One problem is that we might think building margins necessarily implies inefficiency. This is not true. For example, you could be very productive by being the kind of person who plans well and finishes most of their projects early.

One way to internalize the margin concept is to look at our past failures and develop contingencies to address those failures. Any time I have difficulty meeting a deadline, I know that it's because I have failed to build enough margin into my schedule. When another difficult deadline comes up, I look back and try to learn what I did wrong the last time so that I can prevent the same thing from happening again.

OUTCOME BIAS AND THE LAW OF SMALL NUMBERS

Here is another useful insight from our coin-tossing experiment: We discussed that in the short term, randomness can create all kinds of patterns. This implies that we should be careful not to read too much into such patterns. To help internalize this idea, let's consider a few questions.

Here is the first question: I tossed a coin twice, and it handed heads up both times. Do you think there is something wrong with the coin? You will probably say, "Most likely not." You are right. Indeed, we just discussed that streaks are quite common in random sequences.

Now, let's look at another question: I tossed a coin fifty times, and it landed heads up every time. What do you think now? You will probably say, "I am guessing this is a double-headed coin." Great; your intuition is spot-on.

What is the difference between the two cases? In the second case, you have a very large sample, so it makes sense for you to draw conclusions based on your observation. But in the first case, it could be very dangerous to draw conclusions from such a small sample. In the short term (i.e., when the sample size is small), it is usually difficult to separate luck and skill. Let's look at a few applications of this point.

Once, when I was at a party, I heard someone claim, "I don't believe in the healthy-living crap advertised by the media. My aunt, who had a very healthy lifestyle, died of cancer at the age of 55, while my uncle, who never exercised, smoked heavily, and was drunk all the time, is still alive at the age of 94." The flaw in his argument was that he could not conclude much from a sample size of two, the same way you could not infer much when you observed two heads in the coin toss example above.

This mistake is usually called belief in the "law of small numbers."² Note that this law of small numbers is not really a law; it is a fallacy. I was once burned by the law of small numbers. As a graduate student, I attended many conferences and workshops to present my work. I once slacked off on putting a good effort into practicing my presentation. To my surprise, it turned out to be one of my best presentations; everyone loved it. "Learning" from my experience, I showed up unprepared to the next event—and failed miserably.

My conclusion based on one sample was completely irrational. After that lucky talk, I came up with all kinds

² The law of small numbers was explained by Amos Tversky and Daniel Kahneman in their 1971 paper, "Belief in the Law of Small Numbers," published in *Psychological Bulletin*, 76, no. 2.

of crazy theories to justify why unpreparedness is good for a speaker. But as I soon learned, my success in the first presentation was primarily due to luck.

In general, it would be a mistake to think a single good outcome implies that you have made a good decision. Psychologists refer to this mistake as the *outcome bias*. Again, the danger here is that we learn the wrong lesson when we evaluate a small number of decisions based on their outcome.

To further combat outcome bias, we should evaluate the quality of a decision based on the information available at the time it was made rather than the eventual outcome. We should consider alternative possible outcomes. For instance, if a decision yielded a positive result, we want to look for the factors that could have led to an unfavorable outcome. Conversely, if a decision resulted in a negative outcome, we want to consider the unpredictable factors that may have played a role.

A WARNING AND A MYSTERY

Let's end this short chapter with a warning and a mystery. First, the warning.

WARNING: THIS WAS A SIMPLIFIED VIEW

Admittedly, the above coin-tossing experiment provides a simplified view. Among other simplifications, it mostly ignores the magnitude of lucky or unlucky events, and it assumes lucky or unlucky events happen independently, i.e., they don't impact each other. None of these assumptions are accurate in real life.

(These issues will be discussed in later chapters.) Nevertheless, even this simplified coin toss example can provide some insights and lessons, and that's why we started here.

I would also like to emphasize the power of our simple coin-tossing process. Almost any complicated random process can be constructed mathematically using our simple coin toss example. Thus, this simple example can be thought of as a building block of much more sophisticated and more realistic random experiments we might face in real life.

This leads us to the mystery, which is related to the story of how I was first attracted to randomness and uncertainty.

THE MYSTERY OF RANDOM CODES

Suppose an engineer wants to design a car. She suggests the following method: select a random collection of car parts (wheels, engines, seats, etc.) and attach them to each other randomly. The designer claims this method will give you the best possible car. Do you take her claim seriously?

I am guessing you do not. I would agree with you—and that is why I was completely surprised when an instructor of mine made a similar claim during a college lecture I was attending. I was a third-year electrical engineering student attending a somewhat dull lecture on telecommunication systems. From my studies, I knew that since any form of data transmission could suffer from transmission errors, engineers need to design error control mechanisms (referred to as *error-correcting codes*).

Here is the weird part: the lecturer claimed that the best error-correcting codes can be designed by random construction. This was the part that shocked me. How can a random design be the best design? In fact, this method of random construction of error-correcting codes is a famous discovery by Claude Shannon, the father of information theory. I was excited by the power of such random codes, and this is indeed how my fascination with randomness and uncertainty started.

A few years later, I chose a modern version of such random codes as my doctoral research topic. In the years since, different versions of these random and pseudo-random codes have evolved to become new standards for communication devices. You have probably used them yourself when connecting to the internet, talking on your phone, and making video calls.

Now, why did I tell you this story? As it turns out, the construction of these random codes essentially boils down to a process not unlike our simple coin toss. The coin toss is, indeed, a very powerful operation.

In this book, we are concerned more with everyday applications of randomness than with technical or engineering applications. However, as we explore other practical applications of uncertainty in the next chapter, we will also be able to partially explain the mystery behind the power of random codes.

Indeed, exploiting randomness is a well-known strategy in computer science. Randomized algorithms are used extensively in data algorithms, which we all benefit from when we use the services of companies like Google, Facebook, and Amazon. A vital question for us

is whether we can implement some of the ideas from randomized algorithms in our personal, business, and societal decisions. We will explore such questions in the upcoming chapters.

CHAPTER TAKEAWAYS

- It is useful to look at randomness as the lack of certainty. In this view, the concepts of uncertainty and randomness are practically the same.
- Due to randomness, we might all experience streaks of misfortune in our lives. Just knowing and expecting these streaks make them easier to deal with.
- Another useful point of view is looking at bad times as opportunities to improve and discover new opportunities.
- We tend to underestimate the lengths of our streaks of bad luck. They could, in fact, last much longer than we expect.
- We tend to overestimate the role of bad luck in our failures and underestimate the role of good luck in our success.
- Implementing margins, cushions, and redundancies is an effective way to deal with uncertainty and randomness. This also provides peace of mind, which can be priceless.
- We should build margins when the consequences of negative events could be significant and the cost or effort of implementing margins is reasonably small.

- Good luck streaks happen too. We should take advantage of them to increase our resilience and build capacity, for example, by reducing debt, increasing savings, and completing tasks ahead of schedule.
- Margins do not necessarily imply inefficiency. In fact, guarding against unpredictable events can keep us from losing efficiency.
- We can use our past failures to practice the habit of building margins into plans.
- The tendency to draw conclusions from small amounts of data is usually referred to as the law of small numbers. We should be careful not to read too much into short-term patterns, as such patterns might be the result of randomness.
- Outcome bias refers to the tendency to judge a decision by its outcome instead of basing it on the quality of the decision given what was known at that time. The danger here is that we might learn the wrong lessons, which can adversely impact our future decisions.

CHAPTER 2:
**THE IMPACT OF LOW-
IMPACT EVENTS**

Ronald Read worked as a janitor and a gas station attendant. When he died in 2014, he had accumulated a fortune of almost \$8 million.³ Given his low salaries over the years, this is quite an impressive feat! What was his secret? Well, aside from being frugal, he benefited from two powerful mathematical concepts.

The first one is *exponential growth* (also called *compounding effect*), which you are probably familiar with. The second one is related to the convergence rules in probability, one example of which is the *law of large numbers*. This related concept is less commonly discussed, but as we will learn, it can have significant real-life implications.

In this chapter, we will strive to better understand the law of large numbers (LLN) and see how we can take advantage of this concept to make decisions in our daily lives that could lead to significant benefits over time.

³ Ronald Read's story was featured in Morgan Housel's informative book, *The Psychology of Money*.