

The background of the cover is a composite image. The upper portion shows a view of Earth from space, with the planet's horizon and a bright sun or star in the center, creating a lens flare effect. The lower portion shows a sunset or sunrise over a landscape with trees and water, with the sun low on the horizon, casting a golden glow. The overall color palette is dominated by blues, purples, and oranges.

ANDREW MAYNARD, PHD

Foreword by Cady Coleman, NASA Astronaut

# FUTURE RISING

A Journey from the Past  
to the Edge of Tomorrow

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***To my parents,  
without whom none of this would be possible***

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# FOREWORD

My world collided with Andrew's when we were asked to join forces to host a podcast for the Interplanetary Initiative at Arizona State University. Both of us seem to share an excitement about the possibilities that exist at a place like ASU, where reimagining the future and making education accessible are the first steps to engaging students and helping them find their paths in the world.

While recording interviews for the podcast, I was struck by how illuminating his questions were, bringing perspectives from science fiction to physics to philosophy. Those perspectives permeate *Future Rising*.

The structure of this book is one of its delights. Through these short but always engaging chapters, Andrew creates a path for us to follow—and it is a trip worth taking: from light to movement, from imagination to curiosity, from possibility to hope. Each chapter reveals a new way to think about the possibilities in the world around us.

Andrew opens his book with the famous Earthrise photo, taken in 1968, an image that had a profound impact on my generation. As an astronaut who has flown in space twice on the shuttle and lived on the International Space Station, I was privileged to see our Earth from space every day for almost six months. That perspective is startling.



The Earth from space does not look fragile—the rock itself will survive long after we do. But there is a sense of our vulnerability, made palpable on my mission when we viewed the aftermath of the 2011 tsunami in Japan, only days after working with Japanese colleagues on the ground to berth their supply ship to the space station. It was comforting for us as a crew to be able to gather data about the flooding to send back to Earth. We also folded origami white cranes and sent videos of them floating in space, which played on billboards during the rebuilding to represent hope for the Japanese people.

From that vantage point, it is also clear that all of us come from one place. One planet. One home. We are the crew of Spaceship Earth and it falls on us to find a way to continue to thrive on our precious and beautiful planet. From space, it is clear that there are no borders, and nothing to stop us from being the best of collaborators, to form the best teams, to collectively bring our imaginations to bear to solve the critical problems of our times.

Imagination, as it should, underpins everything in *Future Rising*. Coupled with a sense of hope and possibility, it's what took us to space in the first place, and it is a key tool in solving the problems we face. Every section in his book gives us a different lens through which to see ourselves and others, and to explore the past, the present and what the future might hold.

To paraphrase Andrew's introduction, reading *Future Rising* really does help us "hit the metaphorical reset button to think afresh about the future." The most resounding feeling I'm left with after reading this book is hope, because in every section, Andrew shines a light and shows a path toward a future that could be ours.

CADY COLEMAN, retired NASA Astronaut

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# INTRODUCTION

We live in a world in turmoil. As I write, we are grappling with a future-changing global pandemic, refugees are being held in less-than-human conditions as they strive to build a better future, a growing wave of populism and nationalism is sparking another type of global epidemic—this one of mean-spirited inhumanity, and people the world over are being denied the futures they aspire to because of the narrow-mindedness of others. And over everything, there's the looming disaster of climate change, as we sacrifice long-term sustainability for short-term gain.

It's a picture of the present that doesn't bode well for the future. Yet, dire as the outlook seems, it is not inevitable. Despite appearances, our collective ability to imagine and build the future we aspire to has never been greater. With advances in science and technology, we are on the cusp of mastering biology, of creating machines that think, and of conquering seemingly-incurable diseases. Our understanding of people and society is revealing pathways toward more equitable and just futures. And we're beginning to figure out ever-more-effective ways of living sustainably within the constraints of the planet we inhabit.

And yet, unless we better understand our relationship with the future and our responsibility to it, there will remain a gaping chasm between what we are capable of and what we

achieve. As a species, we are profoundly talented architects of our own future. But to do the job well, we need to get a much better grip on where we're heading, and how to ensure it's a better place than the one we came from. This is a responsibility we all face. And as we do, we each need to find our own personal threads that tie together past and future, and learn how to weave them together into a bigger picture of what humanity could become.

This, though, is no mean task. Every day, we're bombarded with information and advice in a cascade of news, commentary, and opinion that conspires to hide and tangle these threads—often leaving us feeling dazed and confused. And sometimes, we simply need to take time out—to find a still, quiet place, where we can begin to piece together a picture of the future that makes sense.

But finding such a quiet place isn't easy. We're obsessed with the future, to such an extent that it can threaten to overwhelm us. We avidly suck up news feeds and forecasts to get a glimpse of what's coming down the pike. We immerse ourselves in social media to keep up with what's on trend, and what's not. We consume book after book about the future that tells us what we're doing to destroy it, how technology will transform it, how our wrong-headedness is hampering it, and how our intelligence is manufacturing it. And we surround ourselves with science fiction stories that guide and color our ideas of how the future *might* pan out.

And yet, despite all of this, we rarely take the time to hit the reset button and think afresh about what the future is, where it came from, why it's so integral to our lives, and what our responsibilities to it are.

It's this metaphorical reset button that I set out to hit in this series of short reflections. My aim was to make them long enough to help carve out a quiet space for reflection, but short enough that they don't add to the noise. Through them, I hope to take you on a journey into what the future is, why it matters, and how we can collectively navigate toward one we aspire to as we live our lives together.

What emerges is a journey into our understanding of the future that spans history, starting at the very beginning of all things, with the celestial "big bang," and ending with our responsibility to ensure that coming generations inherit a better future than the one passed on to us. It's a journey of twists and turns, of unexpected insights, and serendipitous delights. And it's one that, step by step, builds a picture, not only of what the future is, but what our roles and responsibilities are in crafting and creating it.

Like all pictures, of course, this is one that tells a story that is far from complete. Look closely, and there are broad brushstrokes where you might expect fine detail, and curious omissions where you might expect deep insights. Yet step back, and a unique portrait of the future emerges

that sheds new light on its relationship to us, and our responsibility to it.

It's also a portrait that, despite the turmoil we see around us in the present, gives us hope for a future that could far exceed our expectations—as long as we all play our part in building it.





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PART 1

# A JOURNEY INTO THE PAST

*"No sensible decision can be made any longer  
without taking into account not only the world as  
it is, but the world as it will be."*

—Isaac Asimov

# 1

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## EARTHRISE

On December 24, 1968, William Anders took one of the most influential photographs of the past hundred years. The picture was taken from the Apollo 8 mission as it orbited the moon, and it showed a startling image of the Earth, suspended in space above a bleak lunar landscape.

Anders's *Earthrise* photo captured a growing sense of our planet as a precious object that, despite its stunning beauty, was in danger of being systematically destroyed by short-sighted consumerism and greed. And it galvanized a generation to protect and preserve a future that was increasingly seen as being under threat.

In the intervening decades since Anders's photograph was first published, our ability to exploit the Earth and, with it, our future, has only escalated. As the Earth's population climbs toward eight billion, with many people still facing poverty, hunger, and substandard living conditions, we are polluting the planet and stripping it of its resources faster than ever. Climate change that's being driven by human activity is now one of the greatest threats we face. At the same time, we are beginning to overstep other environmental boundaries that help keep the world we

live in on an even keel, from decreasing biodiversity to increasing ocean acidification. And this seeming disdain for the future is only being exacerbated by a growing fascination with powerful and potentially destructive new technologies.

Yet within this seemingly dystopian vision of the future, there is room for hope. Since Anders took his photograph in 1968, we've seen profound advances in potentially beneficial science and technology. As a result, more of us are living longer, healthier lives than ever before. We can now treat and manage diseases that were once considered unmanageable. The digital revolution and the internet have put more information, knowledge, and power into the hands of more people than at any previous point in history. Emerging technologies from gene editing to artificial intelligence are opening the door to potential futures that were once little more than science fiction. And threading through all of these advances, social norms and expectations are evolving around how we should behave, and what our responsibilities to future generations are.

Collectively and individually, we have more control now over how our future unfolds than ever before. But our ability to envision and engineer the future comes with almost unimaginable levels of responsibility as, together, we grapple with what we want it to look like, and how to avoid costly and potentially catastrophic mistakes.

Anders's 1968 photograph set us on a path toward powerful new ways of imagining our future. As well as showing us the majesty of our planetary home from space, he encouraged us to think of the future as an "object," something real and precious that we can and should aspire to, and to imagine the possibility of a vibrant home we would gladly bequeath to generations to come. It's a metaphor for what lies ahead that has the power to tear our eyes from the present and focus them on a future that we have a hand in designing and creating. But for it to truly transform how we think about the future, we need to go on a journey that starts billions of years in the past, when the distinction between what was and what is to come was little more than a spark in the cosmos's eye.

# 2

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## ORIGINS

Around 13.8 billion years ago, the universe as we know it came into existence. Before this, there was no future, no present, and no past, just a pinprick of potential that existed outside what we now experience as space and time.

Prior to what we think of as the “big bang,” time did not exist. There was no sense of what had just happened, or what might happen next. What we think of as the future was only made possible as our present universe popped into existence, much as the cascading, irresistible flow of a flooding lake is unleashed when a dam collapses.

Because of the way our minds work, it’s almost impossible for us to wrap our heads around that point of compressed space-time that existed just before the universe came into existence. And yet, over the past hundred years, scientists have, quite remarkably, been able to reconstruct those earliest moments. As a result, we now know that what we think of as “past” and “future” are merely the byproducts of the laws of physics that emerged after the big bang took place—those laws that we often take for granted, yet which govern everything from the behavior of subatomic particles to the movements of the largest galaxies.

It's sobering to think that, had some unfathomable cosmic tick not triggered the big bang, we wouldn't have a future. And yet, because of an event that scientists are still trying to understand, 13.8 billion years ago, time and space came into being and the future was born. The cosmos belched, and the scene was set for creatures like us to emerge—creatures so trapped in the resulting flow of space-time between past and future, that we can't imagine life any way.

Of course, it's easy to get mystical at this point and start to imagine what it would be like to exist outside of time. Maybe the defining essence of humans is a soul that, somehow, escaped the physics of the big bang. Or perhaps our lives are guided by celestial beings that transcend the limitations of everyday reality.

Sadly, intriguing as these ideas are, everything we currently know about the universe indicates that there is no plane of existence that transcends space and time. Every ounce of our existence, it seems, is trapped in this irresistible flow from past to future. With that cataclysmic event that started everything, the die was cast for a universe where, in practical terms, everything has a past and a future that are irrevocably tied together by the present.

It is, of course, disappointing that we can't just step in and out of time at will. But the more we understand this one-way river of intertwined space and time that we're being swept along by, the more we can learn how to nudge the

future in a direction we'd like to go in, rather than the one that fate hands us. That is, if we can see where we're going.



# 3

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## LIGHT

Light, in all its forms, is such a basic part of life for most of us that it's sometimes easy to take it for granted. Light from the sun is what powers the Earth, from its geological evolution over vast timescales to its weather, the energy we rely on, and ultimately, life itself. Light has physically and metaphorically guided our planetary and evolutionary history for billions of years. And it continues to illuminate our future.

Walk into a darkened room and flick the light switch and, in most cases, what was invisible immediately becomes visible. And with it, different possible futures are revealed. These may be as mundane as avoiding stubbing a toe on a protruding piece of furniture, or as profound as—quite literally—being *enlightened* by what you can now see.

Light reveals a pathway between where we are now and where we're heading. It enables us to develop new knowledge as it illuminates the world around us. It allows us to explore how the past influences the future by observing the relationships between cause and effect. It even provides the illumination for many scholars to capture their ideas in writing, and for their students to read and

benefit from these—even if that illumination is sometimes the light of a computer screen. More than this, though, light infuses our thinking about what is coming next, as we talk about “seeing” into the future, or “envisioning” it.

Yet, even before humans were on the map in the cosmic scheme of things, light was playing the role of arbiter between past and future.

As the initial maelstrom of the big bang settled down into something approaching the normality we’re now familiar with, the cosmos was flooded with the fundamental particles that act as the building blocks that make up the universe and the glue that keeps it together. We’re perhaps most familiar with those particles that represent visible light—the photons that are emitted from fires, light bulbs, computer screens, and, of course, the sun. But these represent just a small slice of the spectrum that scientists think of as “light.” This spectrum extends all the way from intense, destructive gamma rays to long, lazy radio waves, with visible light sandwiched into a narrow band somewhere in between.

All of these forms of light form connections between the past and the future. This is perhaps most famously seen in Einstein’s theory of relativity, which depends on the speed of light in a vacuum remaining the same, wherever you are and whatever you’re doing.

Because light travels at a finite speed, we're still, quite remarkably, receiving signals from the very earliest moments of the universe. Incredibly, we can actually detect the afterglow of the big bang in the form of cosmic microwaves that have taken nearly fourteen billion years to reach us. These signals from the universe's past are deeply revealing of where we come from on a cosmic scale, and they help us better understand where we're ultimately heading.

But there's an aspect of light that's even more fundamental to our understanding of the future.

Light is emitted when charged particles oscillate back and forth. This is how transmitters emit radio waves. It's also why atoms emit light as the negatively charged electrons in them move between energy states.

This connection between the electrons in atoms and light turns out to be deeply relevant to the passage of time between past and future. For every oscillation, every turn of the atom-electron spinning top, emitted light waves slice like a metaphorical knife between what has just been and what's to come. Without light, there is no past and no future. And without past and future, there is no light.

Fittingly, we actually measure time using the frequency of light emitted by oscillating electrons. A single second is defined as the time it takes for nine billion, one hundred and ninety-two million, six hundred and thirty-one

thousand and seven hundred and seventy oscillations of an electron transitioning between two energy orbits in a cesium atom. It's a frequency that is, sadly, too slow to be seen as visible light. But it can be picked up by a high-frequency radio receiver. And thus, light becomes the metronome that keeps time as the past transitions to the future.

But as light ticks the seconds away, it reveals yet another important aspect of the transition from past to future: movement.

# 4

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## MOVEMENT

Knock a glass off a tabletop, and there's a moment when time slows. You see the glass tumbling slowly toward the hard floor, and you know that in a split second it will be transformed into a thousand shards. Or not, if your reflexes are fast enough to intervene between the future you see unfolding and the one you imagine could play out.

When it comes to the future, movement is paramount. We're constantly talking about the future in terms of movement. We "move toward" the future, we take "steps" to change it, or avoid what we imagine it might contain. We even "speed" toward the future, albeit sometimes unwillingly.

These metaphors for how we think about what's to come reflect the reality that movement is part of the natural transition from past to future.

This connection between movement and future is clearly illustrated by the falling glass. It represents a transition between what was and what, in a few seconds, is going to be. Yet the connection goes far beyond this.

As we saw previously, light results from the movement of charged particles. But movement is even more deeply

embedded in the physics of the universe. In the esoteric world of particle physics, the building blocks of everything around us—protons, neutrons, electrons, quarks, and more—are held together by other particles that shuttle back and forth between them. These form the cosmic glue that holds everything together. It's a game of catch at an infinitesimally small scale, where stuff sticks together because of the constant movement of elementary particles between the basic building blocks of the universe. Stop the motion, and everything falls apart.

The same applies to the largest objects in the cosmos. The Earth is in motion around the sun, which is in motion within the galaxy, which in turn is wending its own way between a myriad other galaxies. All are tied together by a gravitational pull that scientists increasingly suspect is governed by gravitational particles—gravitons—shuttling back and forth between celestial bodies.

All of this may sound far removed from a glass falling from a table. But without this continuous and irresistible movement from past to future, neither the glass, the knock, the fall, or its ultimate future, would be possible.

Movement—whether the oscillation of an electron, the passing of a light beam, or the falling of a glass—marks the transition between past and present, and points toward the future. Yet movement can only occur because of that

intangible yet ever-present essence that envelops us all:  
time.

# 5

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## TIME

In 1988, the late British scientist Stephen Hawking published what is possibly the most successful book never to be read. Although *A Brief History of Time* sold like hotcakes, it's tough going for most readers. Yet the book tapped into our near-insatiable fascination with time, and how it both constrains our lives and opens up new possibilities.

Time dominates our lives. With very few exceptions, we are deeply aware of its passing, and the ways that it guides and molds us. The Earth marks out time in its orbit around the sun with every passing day and year. We wake, work, and sleep to a given rhythm of time. We're obsessed with what we did with our time in the past, and what we're going to do with it in the future. We celebrate birth as a new chapter in our time-driven lives. We worry about death as the end of a chapter, along with what—if anything—comes next. And we surround ourselves with devices that remind us of the inexorable passing of time, from our watches and clocks, to our phones, laptops, fitness trackers, and every conceivable manner of internet-connected device.



We are, at every level, creatures of time, immersed in it, obsessed by it, yet unable to control it.

This, not surprisingly, deeply colors our visions of the future. How we experience time allows us to imagine what the future *might* be like. But it also throws up an opaque veil between us and the future. It offers us tantalizing glimpses of what might occur in the future, while holding us back from experiencing it until we get there.

Unlike the many time-related fantasies explored in science fiction, we sadly cannot move back and forth in time, beyond the second-by-second movement forward to which everyone is subject.

Of course, there's an exception to every rule, and the exception here is that, at near-light speeds and in the presence of massive gravitational fields (a black hole for instance), time no longer ticks along at the same rate. But for the vast majority of us, we're stuck on a one-way trip into the future, with all of us on the same track.

And yet, the same science that prevents us from flitting back and forth through time occasionally allows us to see—albeit darkly—what might potentially occur in the future. This has nothing to do with us mystically overcoming the shackles of time. Rather, it's based on how the laws of physics allow us to predict what's likely to happen, based on what's occurred in the past.

And one of the more intriguing of these predictions involves how the passage of time is causing the universe and everything in it to slowly run down, through the accumulation of “entropy.”

# 6

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## ENTROPY

In a 2018 ranking of US states by road quality, Florida and Hawaii did pretty well, but my former state of Michigan did not. In fact, the report confirmed Michigan's dubious status as the pothole capital of the country—something my bones can vigorously attest to!

Potholes may seem a far cry from the future of the universe, yet they are both tied together by a natural tendency that threads through the cosmos: entropy.

Entropy is one of those concepts that people often invoke when they try to explain life, the universe, and everything, yet is rarely understood—much to the chagrin of physicists the world over. Despite this, it plays an important role in determining how and why the universe behaves as it does, as it slips from past to future.

Entropy is related to the amount of usable energy in a system—the energy that you can actually put to work to achieve something. The greater the entropy, the less usable energy there is. The idea goes that, if you have an imbalance in energy between one object and another—say, for instance, between a cool Earth orbiting a searing hot sun, or

a really hot cup of coffee and a pair of cold hands—you can make that energy work for you by moving it from one place to another. But when the imbalance has been eliminated, you're done. You can no more make use of energy when any energy difference has gone than you can make water flow uphill. As energy is used, imbalances are reduced, and entropy increases. And potholes, it turns out, are a symptom of this.

Potholes are, unfortunately, part of the natural future state of roads. They're what roads aspire to, if only people would leave them alone. And they are an inevitable outcome of entropy. To make sense of this, think of roads as objects that represent massive amounts of stored energy in the form of the work that goes into making them straight, smooth, and durable. As a result, there's an energy imbalance between them, the environment, and the tires that they're constantly being pounded by. As that energy difference is evened out, with a little help from the elements and daily wear and tear, cracks and crevices form and ultimately turn into potholes. And as they do, entropy increases.

Without regular repairs, our roads would simply get more and more potholed until they become impossible to use. It's a very real and frustratingly tangible example of entropy as it acts as the inexorable "arrow of time." And it's one that reminds us that, not only is the future inevitable, but when left to its own devices, it's likely to be rougher than the past.

This is the same process that many scientists believe is leading to the universe winding down. Experts are still uncertain whether we're ultimately heading for a big crunch—a fitting mirror to the big bang, where everything contracts back into a pre-big-bang singularity—or a big freeze, where the universe simply slows down and stops. Many scientists suspect that increasing entropy will ultimately lead to what they refer to as “heat death,” where all the usable energy in the universe has been, not to put too fine a point on it, used up.

It's the celestial equivalent of the universe becoming so potholed that it's impossible to drive on it any more.

In the grand scheme of things, this is one future that the laws of physics indicate is likely to occur—a predictable pathway toward a dead universe, where increasing entropy has sucked the marrow out of every atom and every molecule. It's a default future that has little time for the complexity of living organisms. Yet, far from slipping toward heat death, Planet Earth has somehow spawned organisms that can seemingly reverse the universe-wide flow of entropy. And because of this, we have emerged as creatures that can not only imagine the future, but also intentionally alter it.

# 7

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## EMERGENCE

In 2014, the Massachusetts Institute of Technology physicist Jeremy England shook the scientific world with an audacious new explanation for the emergence of life on Earth. And in doing so, he opened the door to an intriguing explanation for how we might have gotten here, and why we're so obsessed with understanding and changing the future.

One of the side effects of entropy is that things generally get more disorganized as the universe ages and usable energy decreases. It's the celestial equivalent of a kitchen that becomes increasingly messy if no one's putting in the effort to clean it, or the degradation of roads if road crews aren't constantly fixing them.

According to the laws of physics, the universe's future should be getting increasingly chaotic. And yet, life seems to fly in the face of this conventional wisdom. Compared to the primordial soup that existed billions of years ago, humans are an exquisite manifestation of organization and complexity. Our bodies and minds are fantastically intricate biological entities that are not only incredibly complex, but are also able to create order out of chaos. We are, in

effect, localized anti-entropy machines that have the ability to change the future from its default mode to something entirely different.

Life's ability to buck this celestial arrow of time has puzzled scientists for decades. There are, as you would expect, plenty of explanations that scientists weave around this seeming anomaly. For instance, most scientists would argue that, while net entropy always increases, there's nothing to stop temporary decreases at a more local level—such as the emergence of living organisms on a favorable planet. And yet, life as we know it still seems to lie so far from the apparent comfort zone of the universe that it sometimes feels like our explanations of how we came to be here are, at best, long shots.

In contrast, England came up with a possible explanation for this seeming anomaly which suggests that living organisms could be a feature of the universe we live in, rather than an exception. And, if right, his ideas could fundamentally alter our understanding of life, intelligence, and the future.

England argues that the universe is “programmed” to reach its ultimate future of heat death as fast as possible—that point where increasing entropy has eliminated all usable energy. Under normal circumstances, the speed with which this journey occurs would be limited by relatively conventional physics. But what if there were shortcuts that

could accelerate this celestial decline, and get the universe to where it's going even faster?

According to England, the emergence of life may well be one of these shortcuts.

Living organisms have an amazing ability to convert energy into less usable forms, as they suck in high-energy resources, and leave behind lower-energy "excretions" (usually in the form of heat). In this way, plants and animals are entropy-accelerating machines as they burn through the energy they receive from the sun and their surrounding environment. And humans, with their creativity and inventiveness, take this to a whole new level.

To get a sense of the scale of the entropy-acceleration we're capable of, you only need to look at how a global population approaching eight billion is stripping the world of its usable energy resources, and leaving a trail of chaos and destruction behind it. And when you factor in our ability to invent ever more powerful and rapid ways of creating chaos, from guns and explosives to hydrogen bombs, you have to begrudgingly admire the universe for coming up with such an ingenious shortcut for accelerating the rate at which entropy increases.

England's ideas are controversial and as yet unproven. Yet they are compelling. They grapple with the physics of systems that are a long way from thermal (or energy) equilibrium. And in doing so, they are hinting at how the



laws of the universe might throw up pockets of order that seem to defy the flow of entropy, because they ultimately accelerate the journey toward its inevitable future. They also begin to create a framework that may help us better understand the emergence of life and human intelligence, and even our tendency to cause chaos in the name of progress.

If England is right, we may all be part of a celestial shortcut that is nudging the universe ever faster toward its ultimate fate. It's a shortcut that began, however, long before humans appeared on the scene, with the earliest emergence of living organisms.

# 8

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## EVOLUTION

Four billion years ago, the Earth was a barren planet circling an undistinguished sun in a backwater of an unremarkable galaxy. Then something changed.

Whatever sparked that initial series of events, a hole was punched in the universe's slow, measured amble toward heat death. As organic molecules formed and coalesced, and the first living organisms began to appear, there was no conscious sense of past and future. And yet, the stage was set for a remarkable journey, as life was driven along toward a future that was always slightly better than what had gone before.

We now know that a large part of this driving force was natural selection. Those earliest organisms inherited a unique adaptability that was encoded within a quite remarkable molecule—the DNA that is part and parcel of all living creatures. Across generations, those organisms that were able to survive and adapt in a harsh and changing environment passed the genetic secrets of their success onto their offspring. And as circumstances changed, so did their DNA, whether through natural mutations, interbreeding, or other ways of exchanging and coopting genetic advantages.

DNA turned out to be an incredibly powerful entropy accelerator. Fed by heat, chemical energy, and ionizing radiation, it became the defining base code of increasingly advanced organisms that were ever more adept at making use of the energy around them and discarding it in a slightly less-usable form.

Through natural selection and genetic mutation, DNA began to encapsulate the blueprints of organisms that were increasingly complex and sophisticated. It's a process that is startlingly elegant in its simplicity: randomly tweak the code, naturally select the organisms with the traits that increase their chances of survival, multiply, and repeat.

In this way, evolution appears to reverse the universal flow of entropy locally, as organisms and the environments they inhabit become increasingly ordered and complex. But in the grand scheme of things, it accelerates the conversion of energy from usable forms to unusable ones, and in doing so, it speeds up the rate at which universal entropy increases.

If things were different, this might have been the end of the story. The world could have been filled with constantly evolving plants and animals that were finely tuned to accelerate the rate of increase in entropy, but were no more aware of their future than the microbes in your gut.

Yet the universe had another trick up its sleeve, and this was the emergence of creatures that had the unique

ability to anticipate the future, and to adjust their behavior accordingly.

# 9

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## ANTICIPATION

In 2010, Paul the octopus shot to fame for his uncanny ability to seemingly predict the outcome of World Cup soccer games. A resident at Sea Life Oberhausen in western Germany, Paul correctly predicted the outcomes of all seven of the German team's games, including their loss to Spain in the semifinals.

It's hard to see Paul's success as anything other than a complete fluke. As a tank-bound cephalopod, he simply didn't have the relevant data at his tentacle-tips, or the mental acuity to process it even if he did. And yet, in a curious way, Paul's story captures just how important anticipation is to how we think about the future, and how we end up responding to what we foresee.

Anticipation of the future is something that's typically seen in higher-order organisms. It's an evolved capacity that reflects an awareness that there's a future beyond the present where potentially good or bad things can happen. And it is part of a suite of abilities that lay the foundations that enable organisms to not only envision the future, but to plan for it as well.

In Paul's case, his anticipation was, disappointingly, more to do with food than football. Before each game, he was presented with two clear boxes, each with a tasty mussel in it. Each box sported the flag of a different soccer team. Despite the beliefs of his fans, Paul was simply smart enough to anticipate the future satisfaction of eating the food he could see, and everything else was sheer luck.

This may seem trivial in the broader scheme of things, but the evolutionary progression from organisms that lived random lives, then died, to those that could anticipate the future and act accordingly, was a profound one. It changed how animals acquired their food, and it altered the behavior of those that were valued as food. Anticipation became an essential part of the evolutionary survival toolkit, as it allowed organisms to peer into the near future and work out what their best course of action was to either avoid it, or embrace it.

This future-looking evolutionary trait is seen in most higher-order animals, and even in some communities of social insects, such as bees and ants. And of course, it's a defining feature of humans. We're constantly anticipating the future and imagining how it's going to affect us. Whether we're driving, putting in a day's work, working out, or simply working out how we're going to get to the end of the week, we're anticipating the future and adapting our behavior accordingly. It's what keeps us moving forward. And it's what leads to our obsession with sports among

other things, as we eagerly anticipate the tangible outcomes of clashes between opposing players.

Paul may not have actually been able to anticipate the outcomes of soccer games, but it was anticipation of the results that led his fans to suspend their belief and accept his “predictions.” This anticipation, though, was also due to another biologically inherited “future-sense” that we all have, and one that leads to us sometimes favoring views of the future that aren’t always grounded in reality: instinct.

# 10

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## INSTINCT

People who write and talk about risk perception for a living often tell a story that goes something like this: Someone is walking along a path, and they see a long, sinuous shape on the ground in front of them. Their instinctive response, before any rational thought or logical analysis has kicked in, is to freeze, fight, or run away...until they discover to their embarrassment that what their subconscious interpreted as a snake is, in fact, just a stick.

Eons ago, our primitive brain developed responses to avoid things that might harm us, snakes being one of them. Through the process of natural selection, animals that were predisposed to avoid dangers, such as objects that looked like snakes, lived long enough to pass on their genetic predisposition to the next generation. And so on.

As we've moved up the evolutionary ladder, we've retained many of these inbuilt responses. And thankfully so—these biological instincts provide us with a brilliant survival mechanism that enables our subconscious brain to peer into the near future and avoid potential dangers it sees there.



Our instinctive behaviors are both complex and nuanced. They're a combination of genetically programmed responses—a biological tendency to adopt certain ways of behaving—and the ability of our brains to assimilate conscious learning into unconscious behavior. Behavioral scientists refer to these as system 1 and system 2 thinking. But at its heart, instinct is our innate ability to foresee possible futures, and to act on them without conscious thought.

Much as we like to think of ourselves as rational creatures, our lives are still deeply influenced by instinct. We even take pride in “going with our gut,” or “following our intuition.” Both are part of our built-in “future-senses,” those bits of us that make us feel that we can see beyond the present and peer around the corner of time. And thank goodness we have these, as there are times when our conscious brain does an appallingly bad job of making sense of signals that our unconscious brain is screaming at us to take note of.

And yet, when it comes to navigating the future, our instinct can be a liability. Instinct relies on the future being similar to the past, and predictable based on what's happened time and time again. But humans have put a huge wrench in this biological master plan as we've developed the ability to change the future faster than any evolutionary process can accommodate.

Over the past two hundred years, the rate of technological change has been accelerating at breakneck speed. We've invented steam power, electricity generation, mass production, synthetic chemicals, computers, the internet, social media, gene editing, artificial intelligence, space flight, even the ability to "geoengineer" the entire planet. And in doing so, we've created a world that our instincts are increasingly poorly equipped to handle.

These instincts, which have their roots in an evolutionary provenance that long predates the Enlightenment or the Industrial Revolution, make us predisposed to believe things that *feel* right, yet aren't necessarily supported by evidence. This is not to say that feelings-based decisions are wrong—far from it. But when they run counter to evidence, or reinforce deep biases in how we use evidence, they can derail our ability to achieve what we set out to.

Impressive as they are, our gut instincts—our evolutionarily honed future-senses—are easily dazed and confused by the future we're creating. One way out of this conundrum is to kick our finely evolved conscious mind into gear as we develop a clearer understanding of how the past, present, and future are connected. And this means learning to draw lines between how future effects are linked to past causes.

# 11

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## CAUSALITY

Causality forms the bedrock of how the universe works. Putting aside the first tumultuous moments after the big bang and some of the more esoteric oddities of quantum physics, the future largely looks the way it does because of events that happened in the past. No matter how convoluted and complex the threads tying the past, present, and future become, each past action sends ripples into the future that spark a cascade of sympathetic reactions.

We learn this pretty quickly growing up. Grab a hot pan, and it will burn. Eat putrid meat, and you'll get sick. Needlessly insult people, and you'll get the cold shoulder treatment.

This line between cause and effect means the future is molded and crafted by what's happened in the past. Understanding this, we can begin to plan for what's heading our way, and even begin to entertain the idea of influencing it. That is, if we can work out which "cause" levers in the present lead to desired future "effects."

Making use of these threads between cause and effect is, of course, what underpins modern science and engineering. Scientists are remarkably good at asking "what if" questions

that begin to unpack what the results of a set of actions or events might be, and using these to create theories and models that enable the future to be predicted. This is what scientific theories like Newton's laws of motion and Einstein's theory of relativity do.

But consciously understanding, measuring, modeling, and theorizing about cause and effect is only half the story. The other half is what we do with this knowledge. And this is where science and engineering enable us to use our conscious understanding of cause and effect to not only predict the future, but take a stab at changing it. It's this ability to make causality work for us that is enabling us to feed a growing population, to control and eradicate devastating diseases, and to elevate the quality of life for billions of people.

On the flip side, it's also what has enabled us to devise increasingly effective ways of harming the environment, and abusing and killing people. We should never assume that our mastery of cause and effect is, by default, benign.

Yet, while our ability to utilize causality has had a profound impact on humanity's capacity to predict and control the future, this ability depends on something even more basic: our ability to remember and recall what happened in the past.

# 12

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## MEMORY

Imagine not being able to remember what happened yesterday, an hour ago, or even a minute ago. Your life would exist in a small sliver of the present, with no understanding of where you've come from or where you're going. As a result, your sense of the future, and your agency over it, would be limited to the point of being almost nonexistent.

Unlikely as this might sound, this is the situation that British musician Clive Wearing found himself in after contracting *Herpes simplex* encephalitis in 1985. The infection led to highly unusual damage to his hippocampus, making him incapable of forming new memories.

Wearing's case is an extreme example of anterograde amnesia. While he can remember some things from his previous life, current memories only last for a matter of seconds. Because of this, he is stuck between past and future, always in the present, but never able to move on.

Wearing's story is a sobering reminder of the importance of memory in how we see the future, and how we begin to think about ways to navigate toward it, or even change

it. If we have no memory of what's happened in the near past, we have no way of connecting effects we observe to what caused them. And this in turn means that we cannot begin to understand how our actions potentially influence the future.

This can be seen through a hypothetical example of learning a seemingly simple task in the absence of memory: learning for the first time how to open a door.

A door stands as both a metaphorical barrier and an opportunity along the pathway between the past and the future. Closed, it bars the way to what lies on the other side. But when opened, it reveals new possibilities.

First, though, you need to open the door.

Imagine for a moment that you have no concept of what a doorknob is or what it does, and you have no short-term memory retention. You're faced with a smooth surface with a circular protrusion sticking out of it. You may have previously been shown how this works, but you don't remember.

You might try a few things—pushing it, pulling it, sliding it, even turning it. But here's the kicker: Whatever you do, you immediately forget. And so, even if you begin to turn the knob, and the latch begins to open, the next second you'll be trying something else, oblivious to the fact that, if you could remember what you were doing, you'd have cracked the problem.

And it gets worse. Even if you do manage to open the door, you will have no recollection of how to do it again, because you have no memory of the cause that led to the effect.

It's a somewhat simple example, but it does demonstrate that, even in the smallest tasks, memory is essential to the way we think about and navigate toward the future. It's what allows us to build models in our mind of how the past and present are connected to what lies ahead of us. Memory is an amazing evolutionary gift that has given us the ability to chart a pathway toward futures we desire, while avoiding those we don't. Without it, we are helplessly caught in a present that we are powerless to control.

And yet, memory on its own takes us only so far toward navigating and designing the future. It gives us the capacity to construct visions of the future, and pathways to get there. But this capacity is redundant unless we have the ability to fill it with useful information, together with the skills necessary to make use of it.

# 13

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## LEARNING

I was in my mid-thirties when I moved with my family from England to the US. And because of this, I was blissfully unaware of the dangers of one of the country's more ubiquitous plants—poison ivy. Yet it only took one painful encounter to teach me the wisdom of avoiding it.

Our ability to learn is one of the most transformative skills evolution has bestowed on us. This ability to not only remember, but to associate an event with an outcome and to anticipate the consequences of our actions, uniquely equips us to imagine a future that is different from the present, and to work toward creating it.

Learning is what begins to carry us beyond instinct and allows us to start intentionally crafting the future. It's what enabled me to ensure a future that did not involve me blundering into poison ivy, and one where I learned how to identify and avoid the offending plant. And on a much grander scale, it's what's driven along every invention that's propelled humanity into the future over the past ten thousand years, from taming fire to the latest advances in space flight.



Learning is what ties together anticipation, causality, and memory, as we shrug off the shackles of instinct in our quest to build the future. And it encompasses an incredibly powerful and diverse set of evolved skills that, in turn, color our perception of the future.

Perhaps one of the most familiar tools in this learning skill set—and the one that taught me the evils of poison ivy—is learning by trial and error. Anyone who’s watched a young child learn knows how effective the process of trying, failing, and trying again is in developing new skills. It’s this form of learning that fueled the Industrial Revolution, as inventors persevered in trying different ways to harness the power of water, steam, and later, electricity. It’s what enabled scientists like Michael Faraday to harness the power of electromagnetic induction. It underpinned the tenacity of Edison as he strove to invent a viable electric light bulb. And it’s deeply embedded in the entrepreneur’s mantra of “fail fast, fail forward.”

Learning by trial and error is one of the ways we close the gap between how we *think* the world works and how it actually works, as we strive to create a future that’s different from the past. It’s not the only form of learning, by any stretch of the imagination. And to be effective, it needs to be accompanied by the ability to predict what might happen in the future, based on previous experience. But it is foundational to many of the ways in which we develop and apply new knowledge.

And yet, for learning in any form to be useful, it has to involve more than simply developing new knowledge. To work for us in crafting the future, the knowledge that comes from learning needs to be applied. But first, there needs to be intent, and the conscious resolve to bring about change through what we know, and how we imagine things might be different.

# 14

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## INTENTIONALITY

The question of whether the future is set in stone, or is malleable and designable, is as old as human civilization itself. And it's one that provides rich pickings for science fiction, including the 1984 sci-fi movie *The Terminator*.

The original *Terminator* movie takes place in a future where super-intelligent robots are at war with humanity, and in a bid to finally stamp out their adversary, they send a “terminator” robot back in time to eliminate the future leader of the human resistance.

As time-warping sci-fi movie plots go, it's as convoluted as it is implausible. Yet, beneath the rather fantastical storyline, the movie grapples with the conundrum of whether the future is set, or whether we somehow have the ability to alter it by what we do in the present.

Not surprisingly, the movie's overarching message—and one that is reinforced in the 2019 sequel *Terminator: Dark Fate*—is that we have the power to change the future. In the words of John Connor, who Arnold Schwarzenegger's Terminator was sent back to eliminate, “The future is not set. There is no fate but what we make for ourselves.”

Yet there's a catch—both in the film and in real life—in that we can only change the future for the better if we consciously decide to do so. There has to be an intentionality to our actions if we want to see a future emerge that fits our dreams and aspirations.

Intentionality is the connective tissue between learning and outcomes. It's the link between observing which levers in the present can be used to nudge the future in different directions, and having the wherewithal to actually pull them. Intentionality is the difference between watching people starving on news feeds, or being aware of the scourge of cancer, and actually doing something about it. And it depends critically on the realization that the future is, indeed, not set.

Intentionality draws on an awareness of what the future might look like, and leads to responses designed to nudge the future closer to what we would like it to be. But because intentional acts represent an investment of time, energy, and reputation, we have to be pretty sure of ourselves before we commit. We have to believe that the future we hope for is possible, and that we have some ability to influence it. Few people are willing to make sacrifices to bring about a future that, in their mind's eye, isn't a real, concrete likelihood.

But what if our visions of the future and how to get there are so flawed that they inadvertently lead to a place filled

with pain and suffering? Or worse, do so because of malicious intent?

Sadly, there will always be those who set out to intentionally create a future for themselves that is built on the pain and suffering of others. Yet I have to believe that, for most people, there is a willingness to try to build a future that benefits as many others as possible. The problem is, if our collective vision is misguided and our understanding of the tools we have at our disposal is misinformed, we can easily do more harm than good, no matter how intentional we are.

The challenge, then, is how we narrow the gap between what we hope for and what we end up getting. How do we better ensure that we are the masters of our collective fate? Here, evolution has given us one of our most precious gifts: our intelligence.

# 15

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## INTELLIGENCE

Imagine the scenario: A salesperson cold-calls you and persuades you to listen to their pitch. They present you with three visions of the future, and tell you that, for a small donation, you can be a part of building the one that most appeals to you.

The first future is one where everyone lives in harmony with nature, where there's no pollution, no sickness, and no unhappiness. The second is a future where the streets are quite literally paved with gold, and everyone's a millionaire. And in the third, all political differences have been put aside for the greater good, and everyone's pulling together to make the world a better place. All you have to do is pick the future of your dreams and commit \$10 per month for the rest of your life, and watch your investment grow. The futures are beautiful, the price is right, so why would you *not* sign the contract?

I'd like to believe that most people would see through such a scam because they're smart enough to understand the impossibility of what's being offered, as well as the underlying intent of the salesperson to deceive them. But

obvious as it seems, such insight is only possible because of our intelligence.

Intelligence is possibly one of the most important attributes evolution has imbued us with. It's what enables us to come up with creative schemes to build the future we desire, just as it helps us avoid scams designed to rob us of our future. Intelligence is what allows us to solidify in our mind a vision of the future as something that can be crafted, designed, engineered, and valued. And it's what helps us ensure that intentionality and learning carry us in the direction we want, without leading to too many unexpected surprises.

Yet, essential as our intelligence is to imagining and building the future, it's surprisingly hard to pin down precisely what we mean by it.

On one hand, it's easy to think of intelligence as a combination of memory, learning, and application that, together, enable us to solve problems. It's this type of intelligence that lies behind many of the inventions we rely on. An inventor, for instance, may remember that round objects roll, and learns that placing something on top of a round object helps move it from point A to point B. Before you know it, you have bicycles, trains, cars, and an epidemic of e-scooters.

This practical, problem-solving form of intelligence underpins much of modern science and engineering. And as

something that helps us design and build new futures, it's a powerful one. But there are many other types of intelligence that are relevant to future-building. These include intelligence that leads to the creation of music and other art forms which reveal insights and possibilities that would otherwise remain hidden. Or intelligence that enables us to understand and respond to each other emotionally and socially.

Because what we think of as intelligence is so multifaceted and elusive, how we define it is still surprisingly contentious. This tension arises in part because our notions of intelligence are deeply tied to our personal visions of the future and how to get there. So, if you value a technology-enabled future, your idea of intelligence will more likely be one that's grounded in logic, rationality, and science. Or, if you are fixated on a future dominated by economic growth, you'll likely value concepts of intelligence that are rooted in translating knowledge into power and profit.

On the other hand, if you value a future that's environmentally sustainable, or one where health and happiness are more important than power and profit, you're more likely to think of intelligence as a complex mix of empathetic, artistic, and inspirational traits that help transform your aspirations into reality.

Despite these differences, intelligence emerges as that special something, the "secret sauce" if you like, that gives us



the tools and ability to transform what we can imagine into the future we hope for. It's an engine of change that helps us craft and create the future. But like all engines, it needs fuel. And a vital ingredient in that fuel is the knowledge that comes from learning.

# 16

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## KNOWLEDGE

In 1962, John F. Kennedy galvanized a nation into creating a future that had previously been the stuff of science fiction, as he inspired Americans to “...go to the moon in this decade and do the other things, not because they are easy, but because they are hard.” His vision was realized seven years later as, on July 20, 1969, the Apollo Lunar Module Eagle landed on the moon and Neil Armstrong took “one small step for man, one giant leap for mankind.”

Kennedy, and everyone who worked on the Apollo mission, took a bet on changing the future and setting humanity on a new course. But when Apollo 11 blasted off, how did they know that there was a high chance of its occupants not only walking on the moon, but returning safely to Earth? One thing that’s certain is that they didn’t just say, “We don’t know that it won’t work, so let’s just try it and see.”

Memory and learning reveal to us that it’s possible to change the future, while intentionality provides us with an impetus to act on this possibility. Yet if we don’t know what we’re doing, the chances of breaking something along the way are pretty high.

Intelligence is what helps us better understand the path between the present and the future. But it's knowledge—generated through learning—that helps us to move safely and effectively down this path. When combined with our intelligence, knowledge helps us begin to connect cause with effect, and to create the models and tools that allow us to make use of these connections. It's what makes the difference between actions that have unpredictable and possibly damaging consequences, no matter what the intent, and those that help move us toward the future we are trying to build. And, just like intelligence, it comes in many shapes and sizes.

In the case of the space program of 1960s America, technical knowledge was the currency of success. Scientists and engineers worked tirelessly to develop and test materials, devices, and systems that could safely deliver a crew to the moon and back. Lives depended on knowledge that not only connected myriad causes to a plethora of effects, but extended to events that had never previously been experienced. What emerged was a deep and powerful intertwining of intelligence and knowledge that enabled mission leaders to predict the future of a journey into the unknown with impressive accuracy. But this projected future—this possibility made real in the mind's eye of the American people—also had a profound impact on the type of knowledge that was developed.

Much of this knowledge was technical in nature, but not all. As the space program progressed, we learned about ourselves as individuals and as a society. We developed new ways of thinking about the future and our place in it. We were inspired to imagine what it would be like to travel to other planets and beyond, and not only what it might take to get there, but how we might be changed in the process.

The ways our visions of humanity's presence in space have unfolded since Kennedy's 1962 speech encapsulate many different forms of how we "know"—how we make sense of where we've come from and where we're going, and how we navigate our journey along this path. But underpinning much of this is our ability to identify and fill important gaps in our knowledge. And one of the more powerful attributes we have as a species to achieve this is our ability to reason.

# 17

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## REASON

One of the most profound aspects of being human is our ability to predict the future. Of course, there are deep limits to our capacity to see into the future. Chance and randomness tend to throw a wrench into our skill at peering into the unknown, as do the boundaries of our intelligence and knowledge. Yet, every day, we use our reason to anticipate the twists and turns life throws at us, and to adroitly navigate them.

Reason, unlike instinct or intuition, is the culmination of our ability to observe, learn, recognize gaps in our knowledge, fill them, and develop an understanding of how the past and present are connected. It gives us a window into the future that not only enables us to predict what happens next in many cases, but to prepare for what's unfolding, and even to alter it.

This capacity to think about and respond to what the future may hold is not unique to humans. There's growing evidence that a number of animals are able to reason their way through solving simple problems. Yet it's something that has become so advanced in us that it sets us apart from other species.

Our ability to reason is what helps us imagine the possible outcomes of events and actions, and to focus on the more plausible ones. It's a combination of observation, learning, and mental gymnastics, all tied together by our intelligence, that enables our brains to construct future-predicting "if-then" statements that keep us alive and kicking as we move forward.

This ability to peer into the future through the power of reason is so enmeshed in our everyday lives that it's easy to overlook how astounding it is. Its roots lie in the survival mechanisms we've evolved and inherited—a side effect of our biologically encoded instinct to stay alive. But over time, our capacity for reason has grown to the point where it now enables us to envision the future we want, and to work out, step by step, how to build it.

Reason lies at the heart of modern science, as we systematically learn how the universe works, and use this to predict what it's going to do next. It enables us to begin mapping out the consequences of our actions, even if those consequences take time to show themselves, as in the case of human-caused climate change. And it allows us to translate our wildest dreams into concrete realities, whether these entail going to Mars, creating new virtual worlds, or building a better society.

And yet, stupendously powerful as this attribute is, reason can be blind to the future. Reason is what tells us that 2 +

2 will always equal 4, and that the sun will always rise in the east and set in the west. But it can lead to us struggling when we don't have all the information necessary to predict the future, or when the threads tying the present to the future are so complex and convoluted that they defy analysis. And it most definitely runs into difficulties when all of our wonderful human idiosyncrasies are thrown into the mix, and it becomes clear that the past and future are tied together by more than reason alone.

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## ABOUT THE AUTHOR

Dr. Andrew Maynard is an author, former physicist, and leading expert on the socially responsible development of emerging and converging technologies. His PhD is in Physics from the University of Cambridge, UK. For over twenty years he has worked closely with experts from around the world on the challenges and opportunities presented by technologies ranging from nanotechnology and genetic engineering, to artificial intelligence and self-driving cars.

He was previously Chair of the World Economic Forum Global Agenda Council on Emerging Technologies, and continues to work closely with the Forum on beneficial and responsible technology innovation. In addition to his academic work, Andrew is a prolific writer, communicator, and sought-after speaker. He writes about technology and society on platforms ranging from Medium OneZero and Slate Future tense, to *The Conversation*, produces the YouTube channel *Risk Bites*, and is active on Twitter as @2020science. Dr. Maynard is currently a professor in the School for the Future of Innovation in Society at Arizona State University. He spends more time than any sane person should watching sci-fi movies. His first book is *Films from the Future*.



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