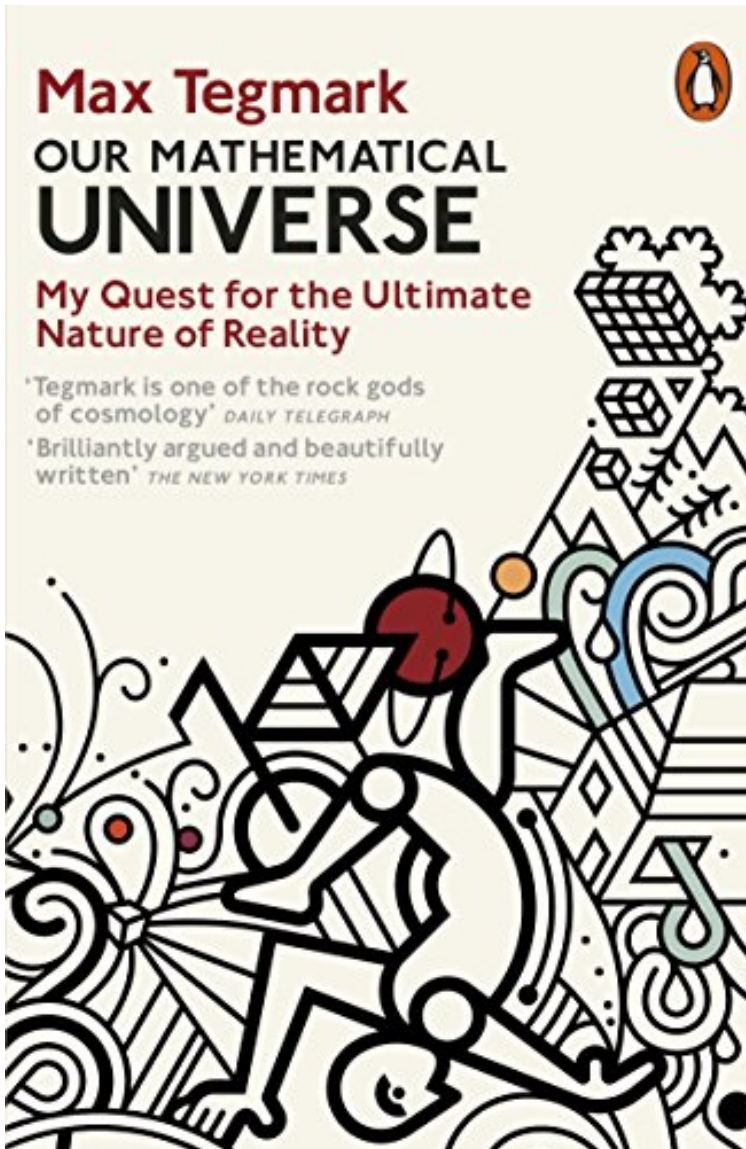


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Our Mathematical Universe: My Quest for the Ultimate Nature of Reality



Par Max Tegmark
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Description :

Prsentation de l'diteurMax Tegmark leads us on an astonishing journey through past, present, and future, and through the physics, astronomy, and mathematics that are the foundation of his work, most particularly his hypothesis that our physical reality is a mathematical structure and his theory of the ultimate multiverse. In a dazzling combination of both popular and groundbreaking science, he not only helps us grasp his often mind-boggling theories, but he also shares with us some of the often surprising triumphs and disappointments that have shaped his life as a scientist. Fascinating from first to last - here is a book for the full science-reading

spectrum. Max Tegmark is author or co-author of more than 200 technical papers, twelve of which have been cited more than 500 times. He has featured in dozens of science documentaries, and his work with the SDSS collaboration on galaxy clustering shared the first prize in Science magazine's "Breakthrough of the Year: 2003". He holds a Ph.D from the University of California, Berkeley, and is a physics professor at MIT.

Chapter 9: Internal Reality, External Reality and Consensus Reality

Sweet exists by convention, bitter by convention, color by convention; atoms and void [alone] exist in reality. Democritus, ca. 400 B.C.

Nooooo! My suitcase! They were already boarding my flight from Boston to Philadelphia, where I was supposed to help with a BBC documentary about Hugh Everett, when I realized that my hand wasn't holding a suitcase. I ran back to the security checkpoint. Did someone just forget a black roll-on bag here? No, said the guard. But there it is! That's my suitcase, right there! That's not a black suitcase, said the guard. That's a teal suitcase. Until then, I'd never realized how color-blind I was, and it was quite humbling to realize that many assumptions I'd previously made about reality and my wardrobe were dead wrong. How could I ever trust what my senses told me about the outside world? And if I couldn't, then how could I hope to ever know anything with certainty about the external reality? After all, everything I know about the outside world and my untrustworthy senses, I've learned from my senses. This puts me on the same shaky epistemological footing as a prisoner who's spent his whole life in solitary confinement, whose only information about the outside world and his untrustworthy prison guard is what his prison guard has told him. More generally, how can I trust what my conscious perceptions tell me about the world if I don't understand how my mind works? This basic dilemma has been eloquently explored by philosophers throughout the ages, including titans such as Plato, René Descartes, David Hume and Immanuel Kant. Socrates said: The only true wisdom is in knowing you know nothing. So how can we make further progress in our quest to understand reality? So far in this book, we've taken a physics approach to exploring our external physical reality, zooming out to the transgalactic macrocosm and zooming in to the subatomic microcosm, attempting to understand things in terms of their basic building blocks such as elementary particles. However, all we have direct knowledge of are instead qualia, the basic building blocks of our conscious perception,* (* For introductions to the vast literature on consciousness by psychologists, neuroscientists, philosophers and others, I recommend the books about the mind in the Suggestions for Further Reading section.) exemplified by the redness of a rose, the sound of a cymbal, the smell of a steak, the taste of a tangerine or the pain of a pinprick. So don't we also need to understand consciousness before we can fully understand physics? I used to answer yes, thinking that we could never figure out the elusive theory of everything for our external physical reality without first understanding the distorting mental lens through which we perceive it. But I've changed my mind, and in this brief interlude chapter, I want to tell you why.

External Reality and Internal Reality

Perhaps you're thinking, Okay, Max, but I'm not color-blind. And I'm looking at the external reality right now with my own eyes, and I'd have to be paranoid to think it's not the way it looks. But please try these simple experiments:

Experiment 1: Turn your head from left to right a few times. **Experiment 2:** Move your eyes from left to right a few times, without moving your head. Did you notice how the first time, the external reality appeared to rotate, and the second time, it appeared to stay still, even though your eyeballs rotated both times? This proves that what your mind's eye is looking at isn't the external reality, but a reality model stored in your brain! If you looked at the image recorded by a rotating video camera, you'd clearly see it move as it did in Experiment 1. But your eyes are a form of biological video camera, so Experiment 2 shows that your consciousness isn't directly perceiving the images formed on their retinas. Rather, as neuroscientists have now studied in great detail, the information recorded by your retinas gets processed in highly complex ways and is used to continually update an elaborate model of the outside world that's stored in your brain. Take another look in front of you, and you'll see that, thanks to this advanced information processing, your reality model is three-dimensional even though the raw images from your retinas are two-dimensional. I don't have a light switch near my bed, so I'll often take a good look at my bedroom and all the obstacles littering the floor, then turn off the light and walk to my bed. Try it yourself: put down this book, stand up, look around, and then walk a few steps with your eyes closed. Can you see/feel the objects in the room moving relative to you? That's your reality model being updated, this time using information from your leg movements rather than from your eyes. Your brain continuously updates its reality model using any useful information it can get hold of, including sound, touch, smell and taste. Let's call this reality model your internal reality, because it's the way you subjectively perceive the external reality from the internal vantage point of your mind. This reality is internal also in the sense that it exists only internally to you: your mind feels as if it's looking at the outside world, while it's actually looking only at a reality model inside your head which in turn is continually tracking

whats outside your brain via elaborate but automatic processes that youre not consciously aware of. Its absolutely crucial that we dont conflate this internal reality with the external reality that its tracking, because the two are very different. My brains internal reality is like the dashboard of my car: a convenient summary of the most useful information. Just as my cars dashboard tells me my speed, fuel level, motor temperature, and other things useful for a driver to be aware of, my brains dashboard/reality model tells me my speed and position, my hunger level, the air temperature, highlights of my surroundings and other things useful for the operator of a human body to be aware of. The Truth, the Whole Truth and Nothing but the Truth Once my cars dashboard malfunctioned and sent me to the garage with its CHECK ENGINE indicator illuminated even though nothing was wrong. Similarly, there are many ways in which a persons reality model can malfunction and differ from the true external reality, giving rise to illusions (incorrect perceptions of things that do exist in the external reality), omissions (nonperception of things that do exist in the external reality) and hallucinations (perceptions of things that dont exist in the external reality). If we swear under oath to tell the truth, the whole truth and nothing but the truth, we should be aware that our perceptions might violate all three with illusions, omissions and hallucinations, respectively. So metaphorically speaking, the CHECK ENGINE incident was my car hallucinating or experiencing phantom pain. I recently discovered that my car also suffers from an illusion: based on its speedometer reading, it thinks its always driving two miles per hour faster than it really is. Thats not bad compared to the vast list of human illusions that cognitive scientists have discovered, which afflict all our senses and distort our internal reality. If your version of this figure is in color rather than black and white, youll probably see the lower dot in the left panel as orange and the upper dot as somewhat brown. Figure 9.1 (in the book) shows two examples of optical illusions, where our visual system creates an internal reality different from the external reality. In the external reality, the light from both of them has identical properties, with a wavelength around 600 nanometers. If a spotlight beamed out such light, it would be orange light. What about brown? Have you ever seen a spotlight or a laser pointer produce a brown beam? Well, you never will, because theres no such thing as brown light! The color brown doesnt exist in the external reality, but only in your internal reality: its simply what you perceive when seeing dim orange light against a darker background. For fun, I sometimes compare how the same news story is reported online by MSNBC, FOX News, the BBC, Al Jazeera, Pravda and elsewhere. I find that when it comes to telling the truth, the whole truth, and nothing but the truth, its the second part that accounts for most of the differences in how they portray reality: what they omit. I think the same holds for our senses: although they can produce hallucinations and illusions, its their omissions that account for most of the discrepancy between the internal and external realities. My visual system omitted the information that distinguishes between black and teal suitcases, but even if youre not color-blind, youre missing out on the vast majority of the information that light carries. When I was taught in elementary school that all colors of light can be made up by mixing three primary colors red, green, and blue, I thought that this number three told us something fundamental about the external reality. But I was wrong: it teaches us only about the omissions of our visual system. Specifically, it tells us that our retina has three kinds of cone cells, which take the thousands of numbers that can be measured in a spectrum of light (see Figure 2.5 in Chapter 2) and keeps only three numbers, corresponding to the average light intensity across three broad ranges of wavelengths. Moreover, wavelengths of light outside of the narrow range 400-700 nanometers go completely undetected by our visual system, and it came as quite a shock when human-built detectors revealed that our external reality was vastly richer than wed realized, teeming with radio waves, microwaves, x-rays, and gamma rays. And vision isnt the only one of our senses thats guilty of omissions: we cant hear the ultrasound chirping of mice, bats and dolphins; were oblivious to most faint scents that dominate the olfactory inner reality of dogs, and so on. Although some animal species capture more visual, auditory, olfactory, gustatory or other sensory information than we humans do, theyre all unaware of the sub-atomic realm, the galaxy-spangled cosmos, and the dark energy and dark matter that, as we saw in Chapter 4, makes up 96% of our external reality. Consensus Reality In the first two parts of this book, weve seen how our physical world can be remarkably well described by mathematical equations, fueling the hope that one day equations can be found for a theory of everything, perfectly describing our external reality on all scales. The ultimate triumph of physics would be to start with the external reality from the bird perspective of a mathematician studying these equations (which are ideally simple enough to fit on her T-shirt) and to derive from them her internal reality, the way she subjectively perceives it from her frog perspective inside the external reality. To accomplish this would clearly require a detailed understanding of how consciousness works, including illusions, omissions, hallucinations and other complications. However, between the external

reality and the internal reality, there's also a third and intermediate consensus reality, as illustrated in Figure 9.2 (in the book). This is the version of reality that we life-forms here on Earth all agree on: the 3-D positions and motions of macroscopic objects, and other everyday attributes of the world for which we have a shared description in terms of familiar concepts from classical physics. Table 9.1 summarizes these reality descriptions and perspectives and how they're interrelated. Each of us has our own personal inner reality, perceived from the subjective perspective of our own position, orientation and state of mind, and distorted by our personal cognitive biases: in your inner reality, dreams are real and the world turns upside down when you stand on your head. In contrast, the consensus reality is shared. When you give your friend driving directions to your place, you do your best to transform your description from one involving subjective concepts from your inner reality (such as here and in the direction I'm facing) to shared concepts from the consensus reality (such as on 70 Vassar Street and north). Since we scientists need to be precise and quantitative when we refer to our shared consensus reality, we try extra-hard to be objective: we say that light has a 600-nanometer wavelength instead of orange color and that something has $\text{CH}_3\text{COOC}_5\text{H}_{11}$ molecules instead of banana flavor. The consensus reality isn't free from some shared illusions relative to the external reality, as we'll elaborate on below: for example, cats, bats and robots also experience the same quantum randomness and relativistic time dilation. However, it's by definition free from illusions that are unique to biological minds, and therefore decouples from the issue of how our human consciousness works. The internal reality may feel teal deficient to me, black and white to a seal, iridescent to a bird seeing four primary colors, and still more different to a bee seeing polarized light, a bat using sonar, a blind person with keener touch and hearing, or the latest robotic vacuum cleaner, but we all agree on whether the door is open. This is why I've changed my mind: although understanding the detailed nature of human consciousness is a fascinating challenge in its own right, it's not necessary for a fundamental theory of physics, which need only derive the consensus reality from its equations. In other words, what Douglas Adams called the ultimate question of life, the universe and everything splits cleanly into two parts that can be tackled separately: the challenge for physics is deriving the consensus reality from the external reality, and the challenge for cognitive science is to derive the internal reality from the consensus reality. These are two great challenges for the third millennium. They're each daunting in their own right, and I'm relieved that we need not solve them simultaneously. Chapter 9 is continued in the book.

Revue de presse This is science writing at its best: dynamic, dramatic and accessible. . . . Our Mathematical Universe is nothing if not impressive. Brilliantly argued and beautifully written, it is nevertheless thought-provoking about the greatest mysteries of our existence. Amir Alexander, *The New York Times*

Cosmologist Max Tegmark has written an engaging and accessible book, *Our Mathematical Universe*, that grapples with this multiverse scenario. He aims initially at the scientifically literate public, but seeks to take us to and, indeed, beyond the frontiers of accepted knowledge. . . . This is a valuable book, written in a deceptively simple style but not afraid to make significant demands on its readers, especially once the multiverse level gets turned up to four. It is impressive how far Tegmark can carry you until, like a cartoon character running off a cliff, you wonder whether there is anything holding you up. Andrew Liddle, *Nature*

Our Mathematical Universe is a fascinating and well-executed dramatic argument from a talented expositor. Peter Woit, *The Wall Street Journal* "An informative survey of exciting recent developments in astrophysics and quantum theory [...] Tegmark participated in some of these pioneering developments, and he enlivens his story with personal anecdotes. [...] Tegmark does an excellent job explaining this and other puzzles in a way accessible to nonspecialists. Packed with clever metaphors Edward Frenkel, *The New York Times Sunday Book* The book is an excellent guide to recent developments in quantum cosmology and the ongoing debate over theories of parallel universes. . . . Perhaps this book is proof that the two personalities needed for science: the speculative and the sceptic can readily exist in one individual. Mark Buchanan, *New Scientist*

Our Mathematical Universe boldly confronts one of the deepest questions at the fertile interface of physics and philosophy: why is mathematics so spectacularly successful at describing the cosmos? Through lively writing and wonderfully accessible explanations, Max Tegmark, one of the world's leading theoretical physicists, guides the reader to a possible answer, and reveals how, if it's right, our understanding of reality itself would be radically altered. Brian Greene, physicist, author of *The Elegant Universe* and *The Hidden Reality*

Daring, Radical. Innovative. A game changer. If Dr. Tegmark is correct, this represents a paradigm shift in the relationship between physics and mathematics, forcing us to rewrite our textbooks. A must read for anyone deeply concerned about our universe. Michio Kaku, author of *Physics of the Future*

Tegmark offers a fresh and fascinating perspective on the fabric of physical reality and life itself. He helps us see ourselves in a

cosmic context that highlights the grand opportunities for the future of life in our universe. Ray Kurzweil, author of *The Singularity is Near* "Our Mathematical Universe" is a delightful book in which the Swedish-born author, now at MIT, takes readers on a roller coaster ride through cosmology, quantum mechanics, parallel universes, sub-atomic particles and the future of humanity. It is quite an adventure with many time-outs along the way. . . . Our Mathematical Universe gives keen insight into someone who asks questions for the pure joy of answering them." Stephen Hirtle, *The Pittsburg Post-Gazette* Readers of varied backgrounds will enjoy this book. Almost anyone will find something to learn here, much to ponder, and perhaps something to disagree with. Prof. Edward Witten, physicist, Fields Medalist Milner Laureate This inspirational book written by a true expert presents an explosive mixture of physics, mathematics and philosophy which may alter your views on reality. Prof. Andrei Linde, physicist, Gruber Milner Laureate for development of inflationary cosmology Galileo famously said that the universe is written in the language of mathematics. Now Max Tegmark says that the universe IS mathematics. You don't have to necessarily agree, to enjoy this fascinating journey into the nature of reality. Prof. Mario Livio, astrophysicist, author of *Brilliant Blunders* and *Is God a Mathematician?* Scientists and lay aficionados alike will find Tegmark's book packed with information and very thought provoking. You may recoil from his thesis, but nearly every page will make you wish you could debate the issues face-to-face with him. Prof. Julian Barbour, physicist, author of *The End of Time* In *Our Mathematical Universe*, renowned cosmologist Max Tegmark takes us on a whirlwind tour of the universe, past, present and other. With lucid language and clear examples, Tegmark provides us with the master measure of not only of our cosmos, but of all possible universes. The universe may be lonely, but it is not alone. Prof. Seth Lloyd, Professor of quantum mechanical engineering, MIT, author of *Programming the Universe* A lucid, engaging account of the various many-universes theories of fundamental physics that are currently being considered, from the multiverse of quantum theory to Tegmark's own grand vision. Prof. David Deutsch, physicist, Dirac Laureate for pioneering quantum computing Tegmark offers a fascinating exploration of multiverse theories, each one offering new ways to explain quantum weirdness and other mysteries that have plagued physicists, culminating in the idea that our physical world is a giant mathematical object shaped by geometry and symmetry. Tegmark's writing is lucid, enthusiastic, and outright entertaining, a thoroughly accessible discussion leavened with anecdotes and the pure joy of a scientist at work. *Publishers Weekly* (starred review) Lively and lucid, the narrative invites general readers into debates over computer models for brain function, over scientific explanations of consciousness, and over prospects for finding advanced life in other galaxies. Though he reflects soberly on the perils of nuclear war and of hostile artificial intelligence, Tegmark concludes with a bracingly upbeat call for scientifically minded activists who recognize a rare opportunity to make our special planet a force for cosmic progress. An exhilarating adventure for bold readers. Bryce Cristensen, *Booklist* (starred review) Max Tegmark is a professor of physics at MIT and a leading expert on theories of the Universe. But he's also arguably the nearest we have to a successor to Richard Feynman, the bongo-playing, wise-cracking physicist who proved it is possible to be smart, savvy and subversive at the same time. [Now `Mad Max has been given the freedom of an entire book. And he hasn't wasted it. Around half of it is a lucid tour d'horizon of what we know about the Universe. The rest is an exhilarating expedition far beyond conventional thinking, in search of the true meaning of reality. Don't be fooled: Tegmark is a very smart physicist, not a hand-waving philosopher, so the going gets tough in parts. But his insights and conclusions are staggering and perhaps even crazy enough to be true. Robert Matthews, *BBC Focus* magazine Just a few years ago, the idea of multiple universes was seen as a crackpot idea, not even on the margins of respectability. . . . But now, thanks in large part to Tegmark and his pursuit of controversial ideas, the concept of multiple universes (or a multiverse) is considered likely by many experts in the field. . . . Tegmark's clear, engaging prose style can take you down these exciting and unexpected pathways of thought without making you feel lost. . . . In *Our Mathematical Universe*, we meet a revolutionary cosmology physicist who is hell bent on figuring out if that theory is true, how to prove it, how to use it, and what it means for the world as we know it. Nathan Gelgud, *Biographile* Nathan Gelgud, *Biographile* Today multiple universes are scientifically respectable, thanks to the work of Tegmark as much as anyone. [...] Physics could do with more characters like Tegmark. He combines an imaginative intellect and a charismatic presence with a determination to promote his subject [...] enough will be comprehensible for non-scientific readers to enjoy an amazing ride through the rich landscape of contemporary cosmology. There are many interesting diversions from the main argument, from an assessment of threats to human civilisation (such as a 30 per cent risk of nuclear war) to the chance of intelligent life elsewhere in our galaxy (lower than astrobiologists like to think). Written in a lively and

slightly quirky style, it should engage any reader interested in the infinite variety of nature. Clive Cookson, *Financial Times* "In Our Mathematical Universe, Max Tegmark distinguished cosmologist gives a lucid rundown of the current state of knowledge on the origin, present state, and fate of the universe(s). [...] It is immensely illuminating on the reach of current cosmological theories. [...] From time to time, Tegmark engagingly admits that such ideas sound like nonsense, but he makes the crucial point that if a theory makes good predictions you have to follow all of the consequences. [...] His concluding chapter on the risks humanity faces is wise and bracing: he believes we "are alone in our Universe" but are capable of tackling terrible threats from cosmic accidents, or self-induced nuclear or climatic catastrophes. He doesn't cite poets but his philosophy adds up to an updated 21st-century version of Thomas Hardy's 'If only to the better there be, it exacts a full look at the worst.'" Peter Forbes, *The Independent* [M]ind-bending book about the cosmos. . . Tegmark's achievement is to explain what on earth he is talking about in language any reasonably attentive reader will understand. He is a professor at MIT, and clearly a fine teacher as well as thinker. He tackles the big, interrelated questions of cosmology and subatomic physics much more intelligibly than, say, Stephen Hawking." Giles Whittell, *The Times* "Max Tegmark's doorstopper of a book takes aim at three great puzzles: how large is reality? What is everything made of? Why is our universe the way it is? Tegmark, a professor of physics at MIT, writes at the cutting edge of cosmology and quantum theory in friendly and relaxed prose, full of entertaining anecdotes and down-to-earth analogies." Brian Rotman, *The Guardian*