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Cosmological Koans

A Journey to the Heart of Physics

Anthony Aguirre

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COSMOLOGICAL KOANS

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ANTHONY AGUIRRE

Cosmological Koans

A Journey to the Heart of Physical Reality



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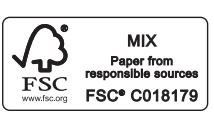
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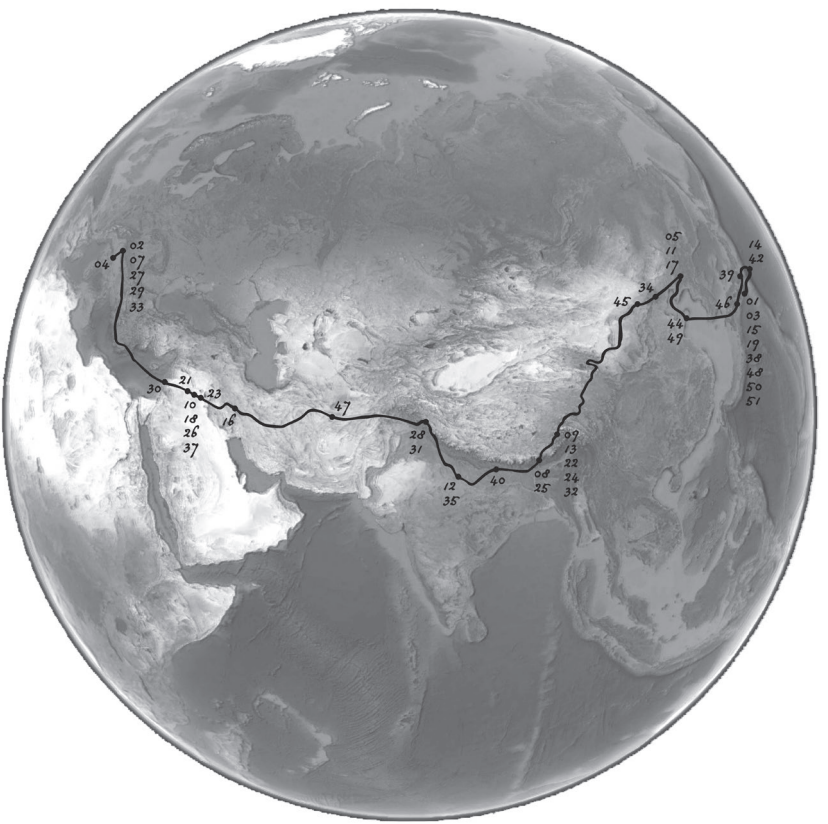
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A MAP OF THE JOURNEY



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INTRODUCTION

One afternoon some years ago, I was walking through the snow and thinking about other universes. This goes a bit beyond the minimal job description of a professional cosmologist, but pondering at least *our* universe is definitely a requirement, and on this particular day I was thinking about other ones. More specifically, I was turning over in my mind the fact that the hospitality provided by our universe depends on many extremely special things. For example, if the electric repulsion between protons in the nuclei of atoms were just a bit stronger, then those atoms, and hence chemistry, and hence *life itself*, could not apparently exist. And there are many other such "coincidences." I had convinced myself that there were four—and pretty much only four—possible explanations for the fact that the laws of physics seem to be carefully chosen to allow us living, conscious beings to be here.

First, perhaps the laws of physics really were designed for us: when the universe began, it (or some superbeing that created it) had us—or at least life—in mind. Second, perhaps it was just an immense coincidence: there was one "roll of the dice" that specified, among other things, the force between protons, and we just got colossally lucky. Third, it could be that *many* "universes" exist with different laws of physics, and we are perforce in one of the universes that

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allow life. Fourth, perhaps the coincidences are illusory: perhaps life would somehow find a way to arise in *any* universe, with any possible set of physics.

This bit of thinking pretty much stopped me in my tracks for the following simple reason: any one of the four explanations was rather mind-boggling and exciting. Yet one of them, it seemed to me, *had* to be essentially correct. There weren't any other fundamentally different possibilities to be found. A feeling grew in the pit of my stomach that the Universe really is a pretty mysterious place.

It also struck me that this was not so much a puzzle about the Universe itself, but one that only arises with force when I—or you—ask the question. The mystery is not about why the Universe has some particular properties rather than others, but about the connection between those properties and our very existence as living, conscious, beings contemplating those properties.

The aim of *Cosmological Koans* is to explore this strange hinterland that arises between the deep structure of the physical world—from the infinitesimal to the largest cosmic scales—and our personal, subjective experience as inhabitants of that world. It is an invitation to explore deep questions in physics through personal experience, and, I hope, to gain some of the sense of mystery, excitement, and wonder that this exploration has brought me. I've devoted much of my life to physics because it represents a path by which some of humanity's finest minds have approached fundamental questions about how the world works. We are part of that world, and sometimes my own studies bring me experiences, such as that walking in the snow, in which I directly experience the mystery that underlies our world and our lives as part of it. Yet, many people—even some professional physicists—have a different experience of physics: as a rather difficult, abstract, and dry subject having little to do with actual experience, and very little to do with beauty and mystery. Even those fascinated with physics, and its exotica of black holes, time travel, quantum paradoxes, and

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cosmic questions, often consider these to be strange and interesting issues about the world "out there," studied and understood only by other faraway people who are, if you will, part of the high priesthood. But the beautiful unity of the world—and the physics that describes it—means that we are more intimately connected with such things than most imagine.

This book puts forward a rather radical proposal: that not only are you intimately connected with the Universe on the largest scales, but you are central. This is not to deny that you are in some sense an infinitesimal arrangement of dust on one small planet out of billions of trillions in our observable universe, which may well be one of many universes. In this physical sense you are, indeed, ridiculously insignificant. But I will try to convince you that you are also a giant: that you—a thinking, conscious being—are part of the community of such beings responsible for giving meaning, and even existence, to the universe you inhabit.

Sometime after my experience thinking about multiple universes, I was recounting it—and my thoughts about that experience—to a good friend who happens to be a longtime practitioner of Zen Buddhism. He noted that my experience reminded him of what occurs during Zen koan practice. After we discussed this for a while, it seemed clear that koan practice, while somewhat different in subject matter, was very much along the lines of the process I was looking for. Zen koans as collected in books are vignettes of a sort, that embody teachings about reality as explored by Zen adepts; there are classic collections you can buy at the bookstore. But as *practiced*, koans were devised as a means by which a teacher can confront a student with a situation that, while initially baffling, can be resolved when the practitioner is able to break through habits of thought and answer the koan in a way that is based on new insight, rather than knowledge or previous experience. And engagement with a koan is always a fully *personal* and *participatory* experience.

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So, I decided to create a set of *cosmological* koans to explore the connections between us and the unimaginably immense, astoundingly complex, and ultimately mysterious Universe.

The intention of this book is not to compare, equate, or conflate physics and Eastern mysticism, as some books have done. There are real parallels that will emerge, but the adopting here is primarily of method and attitude rather than of content. In both physics and Zen, deep understanding is achieved by breaking through the previous patterns of thought and looking at an issue in a genuinely new way. These patterns can be incredibly tenacious and hidden. For example, Aristotle stated what pretty much everyone believed (and many still do): that objects tend to be at rest, move only when pushed or pulled, and return to rest when the pushing or pulling stops. It took fully 2,000 years for Galileo and others to discover (and convince the world) that the true tendency of objects is to *stay in motion*. Things come to rest not naturally, but by the action of a specific force, such as friction.

The history of physics is rife with such revolutions in insight: Newton's understanding that the physics of gravity on Earth and in the solar system is the same; Einstein's radical revolution in our understanding of space and time; Heisenberg's discovery of intrinsic uncertainty in fundamental physics, and so on. How were these leaps achieved? Much as in Zen practice, it was by being willing to sit through long hours of confusion and "not knowing," often wrestling with apparent paradoxes. And in the end, by finding the courage to perceive something in a new way. As the philosopher Arthur Schopenhauer put it: "The task is . . . not so much to see what no one has yet seen; but to think what nobody has yet thought, about that which everybody sees."[1]

By many accounts, Zen is largely about direct insight into the relation between the self—the inner, subjective world—and reality. This relation is also the subject of this book, though from a rather

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different standpoint of modern hard-won scientific understanding arrived at via intense intellectual effort.

Thus, my aim is to co-opt a tool and a method—the koan—to gain some real understanding of the structure of physics and what it tells us about the true nature of our physical world. This approach will also lead to questions on the frontiers of scientific and philosophical understanding that are some of the most exciting questions humanity has come to ask. But this, however worthwhile and important, is a means toward the core aim of the book: to confront your *subjective* experience of the world with the *objective* world that is described so well by physics—and revealed to be very different from what it seems. Most importantly, I hope that the book brings you, as it has brought me in writing it, experiences of the type described so well by Einstein: "The most beautiful and deepest experience a [person] can have is the sense of the mysterious. . . . To sense that behind anything that can be experienced there is something that our mind cannot grasp and whose beauty and sublimity reaches us only indirectly and as a feeble reflection."[2]

SOME CAVEATS and considerations to keep in mind:

While the format of the book is loosely based on a book of Zen koans, these are not actually Zen koans, and no experience with Zen practice or thought is necessary!

The koans make up a fictitious journey, which also has something of a story line that will come into more focus as the book progresses. They should be read as historical fiction, or parables: while real historical figures are involved at roughly the times and places they existed, most of the events depicted never took place, nor probably could have.

By contrast, I have made every effort to convey the core physics and cosmological ideas accurately, if perhaps unconventionally.

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This treatment is cumulative and interlocking, and assembles various arguments and lines of thought for which the destination will not be clear until several koans or even sections later. So you'll probably want to read the koans in order, rather than jumping around.

Note that while I have minimized mathematical content, I have not eschewed equations entirely; I've included some that, for someone with a decent understanding of high school mathematics, will hopefully simplify rather than complicate the treatment.* I've also included a smattering of technical details in endnotes, for those interested.

Finally, although many koans delve into their subject quite deeply, none of them constitute a fully fleshed-out treatment; indeed the question posed by nearly any koan could easily take a book, if not a lifetime, to address. So this is not a textbook, nor is it really a full explication of any particular set of ideas. Rather (and especially in the later koans), it is a set of open doors through which you are invited to walk. This is also a suboptimal choice of books if you are primarily looking for easy answers, or indeed definitive answers at all! My view has always been that the *questions* are the important things. Answers to deep and subtle questions can be satisfying, but only briefly and incompletely, and are best viewed as useful in posing deeper, subtler, and more interesting questions. If this book succeeds, you will understand much more yet also far less of what there *is* to understand, than you do now. So if you feel confused, I invite you to see that as an opportunity and even a joy, rather than a problem—and certainly not a deficiency. I virtually guarantee that whatever you are confused about, some of humanity's finest minds wrestled for years to achieve (or fail to achieve!) some understanding of it.

* If you don't believe that's possible, try looking at Newton's most famous work, the *Principia*, which uses largely words rather than equations!

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PART 1

The Path Laid Out before Us

What has been moved is not moving.
What has not been moved is not moving.
Apart from what has been moved and what has not
been moved,
Movement cannot be conceived.

—Nāgārjuna, *The Fundamental Wisdom of the Middle Way* [1]

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1

THE ARROW

(KYOTO, JAPAN, 1630)

With effortless focus, Munenori Sensei smoothly pulls the arrow to bend his bow. Released like a ripe fruit, the arrow glides.

It races toward your heart.

In the eternity of the arrow's flight, you wonder: What is this present moment?

Confronting its end, your mind becomes razor sharp, cleaving time into uncountable, quickly passing moments. At one such perfect instant you see the arrow as it floats, suspended between the finest ticks of the most precise clock. In this instant of no time, the arrow has no motion, and nothing pushes or pulls it toward your heart.

How, then, does it move?

While your beginner's mind embraces the mystery, the arrow flies.

> There is such a thing as an interval into which not even a hair can be put.
>
> —Takuan Sōhō, *The Unfettered Mind*

What is this single moment, at which the arrow hangs, in midair? We often imagine time as series of strung-together instants, like the ticks of a clock. Yet if we try to focus on just one single instant of now—a single tick of the most accurate clock—we

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find ourselves in the company of a long line of thinkers, and start to see something rather mysterious. As William James put it: "One of the most baffling experiences occurs. Where is it, this present? It has melted in our grasp, fled ere we could touch it, gone in the instant of becoming."[2]

Let's consider an "instant of time"—this one right now, or any other. Does this instant have any duration? Does it *last* a little bit? Suppose it does last, just for a while. If so, then like any interval of time it must have a beginning, a middle, and an end. Well then, let's divide it in the middle into two shorter instants. For each of these we can ask the same question again: Does it *last*? Because we can repeat this reasoning indefinitely, it seems that we must arrive at one of two possibilities. First, that there really is no limit to how short a duration of time we can imagine, suggesting that we approach an ideal, perfect instant of time, with exactly zero duration. Or second, that we might, during our endless divisions, come to some segment of time that has some duration, yet nonetheless cannot be further decomposed: an "atom" of time.

Yet both possibilities—instants of zero duration or of finite duration—are perplexing.

Suppose the instant has, strictly, zero duration: nothing at all has any chance to happen during the instant. Then, during that instant, the arrow is only in *one particular place*. It is fixed, hanging in midair. But if it is really only in one place during that instant, then the arrow cannot possibly move during that instant, any more than a photograph of an arrow can move on its page. Motion requires going from one place to another place, but there is only one place at that instant. But now the problem is clear: if time is just many instants strung together, and during any one instant the arrow is fixed in place, then how does the arrow ever get anywhere?

This line of reasoning might convince us of the alternative possibility: that what we call an instant of time does go on for a little while, yet is discrete and indivisible—rather like the still images that

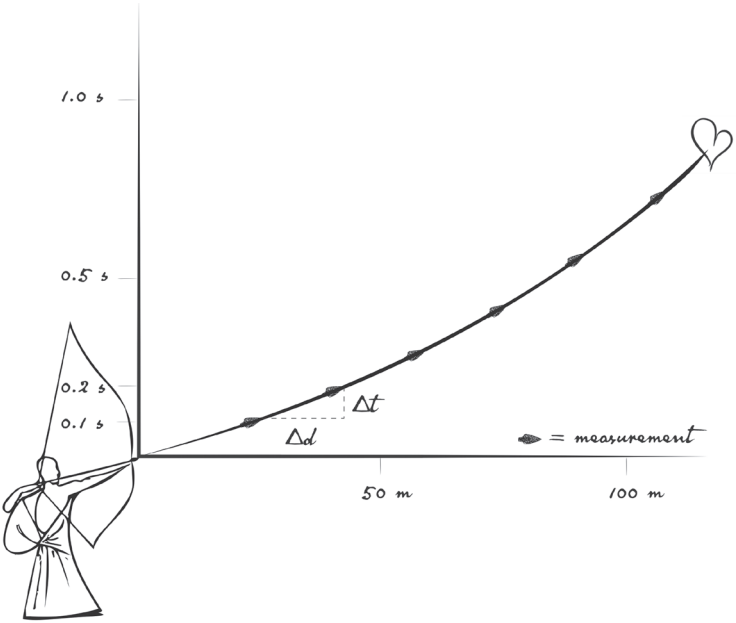
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are strung together to form a movie. In this view, as we imagine a movie of the arrow's flight, the position of the arrow changes from one frame to the next; only when the frames are strung together do they create motion. Yet when closely examined, this idea seems no less perplexing. Movie frames are separated by a fraction of a second, with our mind stitching them together into motion; what would stitch together atoms of time? A movie can be played at many speeds, or it can be left in its canister. If the world is like a movie being played, what is playing it, and at what speed? What prevents everything from happening at once? And what connects one frame to the next? A movie might contain an arrow in one image, and a sudden cinematic cut to the arrow's target in the next. Yet reality never does this: each inexorable moment appears to be born smoothly from the preceding one.

In short, how does motion occur, if time is composed of moments and each moment is devoid of motion? This paradox (along with several others) was put forth 2,500 years ago by Zeno of Elea, as recounted by Plato in his *Parmenides*, and by Aristotle in his *Physics*. This paradox might really bother you—if so, let it! Or, you might not quite see the problem—think some more! Or, you might feel an almost overwhelming desire to think about something else—resist it! Or, you might dismiss it as already solved, or "empty philosophy"—but such dismissal is just like walking past that small overgrown path into the woods; where might it lead? Indeed, described by Bertrand Russell as "immeasurably subtle," for two millennia Zeno's paradoxes have been tackled and explored by some exceedingly subtle thinkers, and solved—again and again and in different ways!

Yet nature solves this paradox. Things move, and the arrow flies. And in understanding motion, humanity has made vast strides from the time of Aristotle. We can predict the hour and minute of an eclipse 50 years in the future, and aim a spacecraft so precisely that it slingshots years later around Jupiter and encounters Neptune at close

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Elapsed time versus distance of Zeno's/Munenori's arrow.

range. We understand motion well enough to predict it in some situations with astonishing accuracy. How, then, does our amazingly effective physics of motion tackle Zeno's arrow?

Consider the arrow's speed. If the arrow crosses the 100 meters to your heart in a single second, we say that it moves at an average speed of 100 meters per second (m/s). Yet very careful observation would reveal that during the second half of its flight's duration, the arrow travels more slowly and covers less distance, because during its flight, friction from the air slows its motion. Perhaps it moves 55 meters in the first half second, 45 in the second half second. And we could imagine subdividing time yet further. Perhaps between 0.1 and 0.2 seconds into its flight, a duration of 0.1 second, the arrow travels 12 meters; hence, 12 meters / 0.1 second = 120 m/s during this interval.

In many ways, physics as we know it was born when Isaac Newton

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and Gottfried Leibniz developed the mathematics to take this idea to its logical conclusion. To illustrate their scheme for understanding motion, let's plot the arrow's *position* (in this case, its distance from Munenori) at a sequence of times, as shown in the figure at left. Very crudely, your eye measures these positions as you sense time passing in your mind, but we could imagine attaining much more precision with, for example, laser ranging and an atomic clock. In any case, through this discrete set of measurements we might draw a smooth curve that accurately describes the arrow's motion. Using this curve, we can assess how far the arrow moves over shorter and shorter durations.

This basic idea was understood even by Aristotle, but Newton and Leibniz, crucially, tackled the question of what happens when the time interval* Δt *approaches zero*—precisely the domain of Zeno's paradox. What they were able to show is that, as you would expect, during this infinitesimal time interval, the distance interval Δd vanishes just like Δt does. Yet in a well-defined and mathematically precise way, the ratio $\Delta d/\Delta t$—the speed—nonetheless takes on a particular finite and *nonzero* value. This mathematical method, which forms the roots of differential calculus, gives a response to Zeno's paradox. It says that you must not go all the way to the limit of zero duration without also going at the same time to the limit of zero distance interval—and if you do this correctly, the speed of the arrow never goes to zero. No matter how short the duration, the arrow is never at rest. There is no such thing as an instant of time during which the arrow does not move *at all*, so the premise of Zeno's paradox, as well as the necessity of thinking about "atoms of time," is neatly avoided.

Paradox solved? Perhaps. This way of looking at motion works very, very well, and we could, if we like, just leave the matter right there. But physics, like the world it describes, is a matter of great

* The Greek symbol Δ ("delta") often denotes the difference between two quantities. Thus, "Δt" is shorthand for "the change in the quantity t."

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depth and subtlety, with secret passages and hidden rooms if you push in the right places. So let's ask some questions about the seemingly straightforward account of an arrow following its curved path to its destination.

Why this particular curve and not some other curve? The same arrow, fired again and again in the same way, under the same conditions, will follow the same path. Why? And what exactly determines *this* path out of all of the possible paths the arrow might take? (Can you imagine that the arrow actually takes all possible paths, which average out to be one that is straight, but looks curved?)

How, at some instant of time, does the arrow "know" which way to go? At that instant, it has a position, but its velocity depends on where it was a moment ago. Does the arrow "remember" where it was? Or does it carry its velocity as some intrinsic property, like its color? Why does the arrow have *inertia* that keeps it going in the same direction as its velocity, yet changes in just the right way for the arrow to perfectly trace out a preordained path?

What would happen if we tried to precisely calculate the arrow's speed at a particular instant, by measuring the traversed distance Δd during an infinitesimally short time interval Δt? Measurements in the real world are imprecise, so we can never measure Δd perfectly, nor even Δt. Then as Δt approaches zero, the speed $\Delta d/\Delta t$ will be utterly uncertain. What do we make of this? Does it even make sense to think about durations of arbitrarily short length, if we cannot know anything about motion during them? What does it even mean to measure an object's velocity? (Would you believe that just as its velocity is made up of different positions, an object's position is made up of different velocities?)

On the nicely drawn curve of the arrow's flight (see the figure on page 6), which point is "now"? Go ahead and point to one—any you like; no theory of physics will make any objection, or comment. Indeed, physics has no place, *no role whatsoever*, for this idea. Yet

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you sense "now" instantly! Try, if you like, to experience the past or future instead. You can't, can you? (Can you?) How can it be that a fundamental aspect of our personal experience has no place at all in physics?

The arrow is made up of an inconceivable number of atoms arranged and evolving together in a way that we call "an arrow in flight." What are the atoms made of? "Quarks and electrons," you might answer, or "superstrings." But whatever the finest particles are, I'll argue that modern physics suggests that they, in turn, are made of *information*. But then isn't the arrow made of information? Yes! But information about what? Known by whom or what? And how can information be pulled back, let loose, fly through the air, and pierce your heart?

These questions can be asked so quickly, in just a few hundred heartbeats. But it will be no small feat to even fully understand them, let alone answer them. So let's be on our way; the arrow is getting closer.

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2

SETTING SAIL

(VENICE, 1610)

Six hundred million heartbeats earlier . . .

The fog is thick at the port, and the delay is interminable. It was not easy to leave behind so much in embarking on this insane voyage, but with the decision made, you are eager to depart. You peer around gloomily at the other boats appearing and vanishing in the fog.

As a neighboring ship slips into its berth, your heart skips a beat as you are momentarily taken by the illusion that you have set sail. You realize your mistake with amusement at your impatience. Will this journey ever begin?

Soon enough you are indeed on your way, toward the Islamic Empires and the fabled Eastern Kingdoms beyond. That night, you awaken from dreams of adventure, and feel that your quarters are all too still. Has the wind died? Are you dead in the water? Unable to sleep, you wander up to the deck and see to your surprise that the ship is quickly but smoothly slipping through the calm waters on a steady breeze.

How is it, you wonder, that you cannot tell the journey from stillness, or motion from rest?

Perhaps, you muse as you look out at the glittering stars, you and all the world are careening through space at an unimaginable speed. Would you ever know?

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> Shut yourself up . . . below decks on some large ship . . . have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change.
>
> —Galileo, *Dialogue concerning the Two Chief World Systems*[3]

At this moment we are rotating at a speed on the order of 1,000 kilometers per hour (km/h) around the center of the Earth as it spins on its axis. Earth moves about the Sun at about 100,000 km/h, or about *30 km/s*. In turn, the Sun orbits at 220 km/s around the center of our Milky Way galaxy, which glides through intergalactic space more than twice as quickly, relative to the cosmic sea of galaxies.[4] In a very real sense, we are speeding through the universe, right now, at about Mach 1,000—the sort of speed that could whisk someone to anywhere on Earth in less than a minute. Do you feel it?

You do not, any more than you feel the (relatively snail-paced) 1,000 km/h of smooth jet travel as you sip your drink on board, or know, at moments of confusion in a train or car, whether you are rolling forward or your neighbor is rolling backward. You might have noticed this peculiarity of our world, but you probably did not expend much careful thought on it. What happens if you do?

As Galileo did in his famous *Dialogue*, let's first delineate the experience precisely: if we are inside a closed vessel, then our experiences—*insofar as they are confined to the vessel and there is no peeking outside*—are the same whether the vessel is at rest or moves at any given *constant* speed and direction.* Confronting this experience, we face a choice.

* Speed and direction can be combined into a single "vector" quantity of *velocity*. As such, *constant velocity* is equivalent to "constant speed and direction." This differs from *constant speed*, which allows for changes in direction.

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First, maybe we're just not paying enough attention; perhaps there is *some way*, via a very precise experiment, that we could absolutely determine whether we are moving. For example, we might posit that human infants possess a special sense that allows them to fall asleep when a vehicle attains 100 km/h, and awaken when it again falls below this speed. But of course this is absurd; these are tiny changes relative to the 108,000 km/h at which we move relative to the Sun, so how could the infant sense one and not the other? (Presumably, it's instead the noise and vibrations that work their soporific magic.) Moreover, incredibly precise laboratory experiments spanning more than a century have all failed to find *any* effect enabling us to discern how fast we are going in an absolute way.

So, let's take the alternative route and boldly declare that there is *no possible way* to detect absolute uniform motion. If it is utterly undetectable, should we not simply abandon the idea of absolute motion altogether? But we can, of course, move, which you can prove by just doing so. So we must retain the idea of motion, but motion *relative to something else*. Put differently, two people might honestly disagree as to whether a given object is moving. Yet they would surely agree on whether two objects are moving relative to each other. A side effect of this relativity of motion is that you can always assume that *you are not moving*, even if this means that a whole lot of other stuff is moving relative to you. Every observer, in this sense, carries around a sort of "reference frame" *relative to which* they may view everything else as moving—or not moving—in various ways. This sounds a bit self-centered, but if there is no absolute reference frame, then everyone is just as entitled to privilege their own reference frame. Let's see, then, where this "relativity" leads.

As a first yet surprisingly profound question, let's ask: "If an object is in motion, is an external agent necessary to *sustain* this motion (lest the object revert to rest)?" Aristotle, as well as humanity's finest thinkers for thousands of years, believed that motion did

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require an external agent to be sustained. But given our bold and experientially grounded declaration that absolute motion is impossible, do *you*?

I hope not! And if not, then you have attained what was a profound insight of Galileo: if there is no such thing as absolute motion, then there is nothing particularly natural or easy or special about being at rest; it is *just as natural* to move at constant velocity! As he put it: "If placed in a state of rest, [a heavy body] will conserve that; and if placed in movement toward the west (for example) it will maintain itself in that movement."[5] Aristotle's belief that sustaining the motion of an object requires the action of an external agent was wrong.

To be fair, Aristotle had good reason to think the way he did, and the fact that humanity erroneously accepted his conclusion for so long is not surprising: it is how everyday objects act! When you shove your refrigerator, it does not effortlessly glide forever in a straight line. It stops, generally quite soon after you stop pushing it. And the harder you push, the faster it moves, so you might be forgiven for thinking that motion at constant speed requires the sustained action of a force. But it doesn't: what your push really does is to counteract the force of *friction* between the refrigerator and the floor. If the floor suddenly became perfectly slick, you can imagine the refrigerator moving far indeed, and if you can imagine a refrigerator with nothing whatsoever slowing it down, you can imagine that it might float along on its own forever, requiring nothing to sustain it. (The history of physics might have been very different, had Aristotle had more experience with large expanses of ice.)

But does the naturalness both of motion and of stillness in the refrigerator (relative to you), mean that it is easy to go between the states of motion and nonmotion? You will surely agree not! Pushing the refrigerator is hard work, and in fact, stopping a moving refrigerator would be exactly as much work as getting it going. Thus, the

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fridge effortlessly sustains a state of either rest or uniform motion, but resists *change* to that state. Let's name this resistance *inertia*.

It is rather astonishing that it took thousands of years for us to understand the world in this way, even though this understanding is based on analysis of the most everyday of experiences, such as the illusion that your ship is moving when it is not, or the illusion that it is stilled in the water when it isn't. What other truths are sitting there at our fingertips?

Indeed, this idea of inertia sits on the shores of a rather deep sea of thought. Let's set sail. When considering THE ARROW, we concluded that at each moment, an object has an intrinsic property called its velocity. And yet, our acceptance of the relativity of motion tells us that this intrinsic property is illusory. It corresponds to nothing: we cannot say in an absolute way whether an object has high speed or none. But while "high speed" and "no speed" are both empty of any fundamental meaning, *relative* speed is meaningful, and the *change* from one speed to another is as real as a speeding refrigerator is hard to stop! Behind this reality is inertia, which is what we call objects' ability to resist change in their velocity. Yet while familiar, inertia is strange: it measures the change in velocity, but absolute velocity is empty of meaning, and even relative velocity appears rather ephemeral, depending on which other object you happen to compare to. How do objects know how to resist change in something so ephemeral? Does an object somehow "sense" all the other objects around it, so as to know how it is moving relative to them, and resist change to this motion? How does this make sense? What *is* this thing called inertia?

Another perspective is through our *experience* of nonuniform motion. When our plane dives, our train turns, our car crashes, or our boat rocks, it is immediately obvious! When a car accelerates, one can *feel* how much, even with eyes closed, and nobody can claim that the feeling is imaginary. This is puzzling. Uniform motion is *only* relative, meaning that we can measure the velocity of one object

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relative to another, but cannot agree on a universal reference by which to measure everything's velocity. Yet nonuniform—that is, "accelerated"—motion can be easily and directly sensed, without apparent reference to any external object. *Relative to what, then, are we sensing it?*

What is inertia, and what is acceleration? As amazing as it sounds, nobody on Earth can authoritatively and fully answer those two questions, which inspired Einstein but are not wholly settled even by his deepest theories. And as I write this, I feel that most delightful sense of also not *really* knowing, and of adventure.

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3

BEING TIME

(ZUIŌ-JI TEMPLE, JAPAN, 1630)

Sitting in this meditation hall, you've seen hours pass like days, and days pass in the blink of an eye.

Your journey to get here took you over the seas, into a cave, and through royal courts full of splendor. It brought you across forgotten deserts, down mountain passes, and through mysterious gates. Years in the tallest mountains, and in the service of a khan. Then you crossed the small sea, to learn from sages and warriors that you had not really left that terrifying cave behind, and to forge a slowly unfolding plan.

And here you sit, in stillness, artfully drifting through the years. Or do the years drift through you?

Contemplating the flow of time and reminiscing about the past, you think back to your journey's very beginning in that foggy harbor. The questions, and an old curiosity, suddenly arise: "So I'm drifting through the years. Moving in time. Steadily. But how do I feel that motion, when I could not feel the ship? If motion is meaningless, is the flow of time also empty?"

With all of your concentration on this sense of motion through time, it suddenly stops, as time floats away like a spring breeze.

As eternity begets duration, the breeze becomes the swish of the stick just before it strikes your shoulder.

Your eyes fly open to confront those of Master Zenjo. "Your heart is racing toward an arrow," he whispers with a fierce intensity. "Can it be avoided?"

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> You will die! You will die! . . . Never forget about death.
>
> —Suzuki Shōsan, when asked by a few old women about the essentials of Buddhism

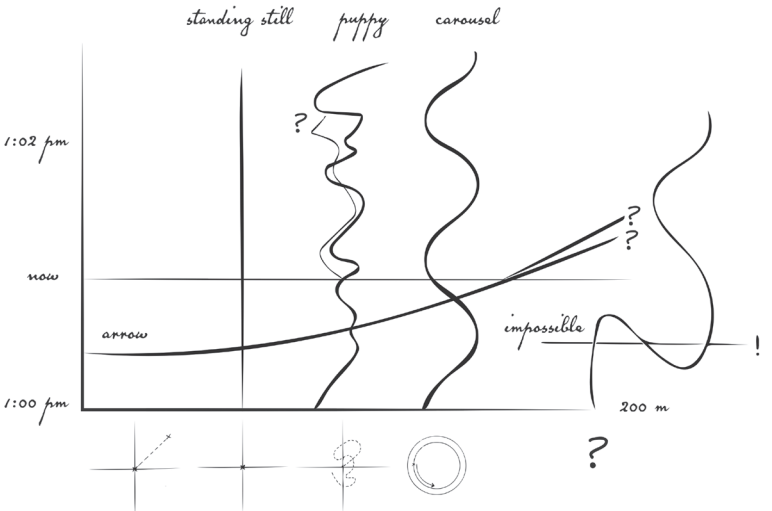
At some time your heart will make its last beat. A last breath will escape your lips, and you will be unable to take another. The patterns of thought coursing through your brain will fade and cease.

While you do not know *when* this time will come, and you probably dislike contemplating it, you know that you can no more avoid encountering the future than a skydiver with a failed parachute can avoid the onrushing Earth. This future is approaching you inexorably. (Or are you approaching it?) Does it, like the arrow, already exist and rush toward you fully formed, or can you dodge one fate and gain a reprieve before being taken by another?

Time is central to our human experience, yet ever so elusive to analysis. Let's think about moving through time. Do we do this? We often think this way, certainly: first, one is at some place at 1:00 pm; at the different "point in time" of 2:00 pm, one is also at some place in space, perhaps different from the first. So simple in words, yet immediately confusing: when contemplating THE ARROW, we characterized its motion as a change in position over a span of time, but then moving through time would be . . . a change in time during a span of time? What does that even mean?

Yet it seems that surely something moves: now it is 1:00 pm, and later, "now" is 2:00 pm. Does "now" move? What does *that* mean? "Now" always seems to be right here (as it were)—where would it go? Perhaps, rather, it is time that flows through now: the future approaches, becomes "now," and recedes into the past. That's often what it *feels* like. But isn't that view a bit egocentric? We don't generally think of ourselves as standing still while the street walks down us. Perhaps the ambiguity is just like the confusion of which ship is

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Worldline through space and time for various objects. Paths through space are indicated at the bottom.

moving: perhaps it's just as good to say that time is moving through us as it is to say that we are moving through time.

To try to create some clarity, let's return to the flight of THE ARROW. When we drew its path through space and time, it seemed pretty straightforward. At many different moments, we noted both the reading on a clock and also the position of the arrow. Each pair of readings gave us a point on our plot, and we then drew the path connecting these points. This path really represents a collection of labels: for each point on the line, there is a set of numbers—call them *coordinates*—that tell us the time and place of that point on the path. In general, we need four such numbers: three* to tell us exactly where the arrow is, and one to tell us the time. In this picture of the arrow's full trajectory, often called its *worldline*, time is very

* For example, longitude, latitude, and altitude on Earth. The fact that we need exactly three numbers to describe our location is precisely what we mean when we say the world is *three-dimensional*.

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much like space: just one more label for "where" in *space-time* the arrow is, some way along its path.

To get a feeling for worldlines, imagine drawing such diagrams for all sorts of different objects in motion, as illustrated in the figure at left. (Because of graphical limitations, the figure displays only one spatial coordinate—say, the east–west distance from some location—along with the time.) Uniform motion would be a straight line that is more steeply sloped with slower motion, since a slower object takes more time to cover a given distance; a worldline would be vertical for something standing still. The path of the arrow is nearly horizontal because the arrow is moving very fast, and slightly curved toward the vertical at later times because it slows down. The path of a circling object would look like a wavy curve, while the curve for a puppy would wiggle all over, as puppies do.

Where is time in this diagram? We can think of it in two ways. First, there is the time *label* that we have used to know how to draw the curve, which is presumably measured by a clock ticking away in the background. But second, there is an *experience* of time that one would feel while sitting still or on a carousel, probably as a puppy, and probably not as an arrow. The distinction between these is quite familiar: as we sit reading a book, we experience time passing, but then we might also check a clock to see how much time has "really" passed. As we well know, these two notions of time can go somewhat differently, depending on the state of our consciousness. As Einstein is said to have joked: "When you sit with a nice girl for two hours you think it's only a minute, but when you sit on a hot stove for a minute you think it's two hours."[6]

From this perspective, the phrase "moving through time" seems to make a bit more sense: time is laid out, like space, and as our *internal* sense of time ticks away, we experience both different places and different *clock* times. In this way, we move through space and time, both of which exist, all laid out, quite independent of us moving through them. And this is nicely in accord with the worldlines in

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the figure: they are all mapped out as paths through space-time, and we follow along them.

And yet, this sort of picture leaves out some pretty important aspects of how we think of time. For one, if you look at as many curves as you like for actual objects, there is something you will never see: you will never see a curve that doubles back on itself in the *time* direction, so as to encounter a given time (coordinate) twice! This means that although it is fairly easy to avoid walking into, say, a brick wall that exists at a particular position, if we choose a particular time in the future—say, the time at which an arrow strikes—our worldline *must* encounter that time. We move through time in just one direction: forward.

Another absent aspect is that if you were to draw your own worldline and label a point on it corresponding to "now," then the part of the diagram depicting the future of "now" has quite a different meaning from the part depicting the past of "now." In particular, you don't know how to draw the future part of the diagram! Even if we can't revisit a time that we've previously passed through, we certainly can know about it. In fact, we can imagine knowing everything we require to draw our diagram completely, everywhere in space, up until the present moment. Yet just as we get to "now," we become uncertain what to draw: Will you stay here or walk away? Will the puppy run this way or that? Will the arrow miss, slowed by a passing breeze, or pierce the heart and stop its beating? One would never say that events exist and are known "to the left" but are unknown and undetermined "to the right." But we think of events to the future as undetermined, while those to the past we consider fixed and immutable.

Similarly, space does not have any sort of preferred *direction*: can you think of any processes that happen "to the right" but not "to the left"? But there are lots of things that go one direction in time. For example, it's easy to tear a page of this book. But just try to *un*tear that page, which is precisely what it would mean to tear the page in

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the backward time direction. Nope, if you actually tore the page, then you are stuck with it torn! Time runs differently into the future and into the past. This directionality is, fittingly, often referred to as the *arrow of time* that points toward the future.

These aspects of time are intimately familiar parts of the fabric of our lives. We cannot undo the past, and we can visit it only in our memory. Nor do we know what will befall us tomorrow; we can only dream, plan, and scheme. And once something is carelessly destroyed, it generally cannot be restored. Yet these limitations accompany enormous gifts. We can create things that are genuinely new in the world: yesterday a piece of music did not exist; today it does. We can choose our destiny: what I decide today can alter the course of my life. This experience of time is deeply and profoundly focused on the *present*: it is "where" in time we can choose, act, and create. In fact, since what we know of the past is based on memory, and what we know of the future is based on prediction, what else is there but the present? As the great Zen master Eihei Dōgen put it: "Each moment is all being, is the entire world. Reflect now whether any being or world is left out of the present moment."[7]

YET THERE IS another, almost wholly opposed, view of how the world operates. Consider our flying arrow. When we come to the end of its half-drawn path that ends at "now," is there really any choice as to how the path continues? It would seem not: we know quite well which arc the arrow will take, and could quite accurately complete our diagram of its path. That is, we can *predict* which path it will take, given everything we know from the bottom half of the diagram, such as the arrow's path and speed and direction, the air's density, perhaps an oncoming gust of wind. The more we know, it would seem, the better we can predict.

If we were to perfect this ability—if we could predict the path with *perfect accuracy*—then we could go ahead and draw it with complete

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confidence: we could not *see* the future, but we would know what it will be. And it isn't just the arrow that is subject to these laws of physics. Dropped from an airplane without a parachute, our fate is just as determined. The laws apply to *us*, even if their application is quite complicated. We might even say that what right now we consider to be the future is already laid out before us. We'll have to wait a while to see exactly what it looks like, but it is *already there*. In this view, which we might call the *eternalist* view, time is almost precisely like space: it is all laid out at once. The future, just as much as the past, already exists. The present is a sort of illusion—just one arbitrarily chosen time out of many, with no particular significance. Nothing is created, because the future exists already. The hour of the last beating of your heart is already chosen, and you move through space-time inexorably, struggle as you might, to meet it.

Can this really be the case? We should not discard the idea just because it violates our everyday intuition about how we, and the world, work. Throughout this book we'll see many things that violate intuition and yet are true.

But in this eternalist view, when we go to decide something, when we struggle and agonize over which path we should take, what are we doing? Why does it feel that we can make the right or wrong decision? Why can we have guilt, regret, or blame? Are all these illusions? If so, what is real at all?

The challenge that Zenjo whispers is a difficult one: Is time everything, or is it nothing?

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4

THE TOWER

(PISA, 1608)

We might say that your whole path starts on a hot, dusty day in Pisa as you struggle up the tower stairs with a heavy iron ball. It does not surprise you by now that your mentor, Galileo, is carrying the much less burdensome wooden ball. But the ideas to which he has opened your eyes are so fascinating that a dripping brow and damp shirt are a small price to pay.

As you reach the top, Galileo announces that you will drop both balls at the same precise moment. He asks you: "Which ball do you think will hit the ground first? Aristotle says that an iron ball of 100 pounds falling from a height of 100 cubits reaches the ground before a 1-pound ball has fallen a single cubit. And indeed, as the sweat on your brow attests, the iron ball is pulled much more strongly to the Earth."

You can only nod, still out of breath. Galileo goes on: "But Aristotle's reasoning is flawed! Think carefully. You see, the iron ball is also much more difficult to move; even rolling it on level ground takes a great deal of force."

As you ponder this, he continues: "So tell me, does the greater difficulty in moving the iron ball overcome its greater attraction to the Earth, or the opposite? Which effect will win out? Which ball will actually fall faster? I'm quite sure that Aristotle never actually tried it!"

You confess that you are uncertain. Galileo nods, and signals that you should proceed with the experiment. Even when you see it, it is a bit difficult to believe: both balls land at exactly the same time, producing two simultaneous puffs of dust (though

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