Astronomers' Universe

Gavin Bascom

On the Inside of a Marble

From Quantum Mechanics to the Big Bang

Springer

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Gavin Bascom
Department of Chemistry
New York University
NY, USA

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Foreword

As a quick introduction to this text, most of the original ideas arose while working on my dissertation in 2014. I was trying to overcome some of the technical difficulties associated with extending dynamic simulations of nucleic acids a couple orders of magnitude in time, and I found that there was a strange anomaly in how we define an observation, especially when cross-corroborating that observation with various experimental setups that span different temporal scales. The resulting conundrums began to sound a lot like some of the oddities of quantum mechanics, despite the fact that I was working entirely in the classical regime, and I found that sure enough statistical mechanics oftentimes mirrors quantum mechanics both mathematically and physically, even if this relationship is seldom talked about. This is especially true when you start to think about measurements which are sensitive to the frame rate at which they are observed, and it was my time spent constructing and analyzing theoretical simulations that spelled this out for me. One of the main difficulties arises from deciding how often to “snap” pictures of atoms as they move throughout the simulation, attempting to represent positions that are meant to be continuous. In practice, however, they become discrete because that’s the only way to treat such large systems with precision and versatility. The more I struggled with this seemingly *technical* requirement, the more I realized it can in fact be described as a *physical* requirement of all things representative, which is very similar to the physical difficulty that lies at the heart of both quantum mechanics and cosmology. To be honest, however, I didn’t spend much time thinking about cosmology at all at that point—it is a very daunting subject.

In the years that followed this idea developed into an early draft of the fourth chapter of this book, which deals with frame rates and energy and measurement. The second and third chapters were then developed as spatial corollaries to the main idea, which also happens to mirror the ideas developed in the theory of relativity, much to my surprise and slight discomfort—I had never anticipated needing to broach this other daunting subject. Finally, almost to my protest, the work led me into cosmology, bringing the scope of the text infinitely wider than I had ever intended. As such the fifth, sixth, and seventh chapters were added to bring the whole thing back down to earth, so to speak, and anchor them to the basics of the theories as they are currently being taught. In the end I was quite pleased with how it turned out, although I never expected it to develop quite the way it did.

I should also mention that most of these ideas are not new, and while I think they're central to the topics on hand, they are not meant to make up a comprehensive treatment. I have only attempted to present the crux of what I find interesting in a novel context compared to how they often appear in the scientific canon, mostly because this is how they presented themselves to me. As it turns out, most of these ideas were developed originally either in mathematical or technically precise language and as such they can be very difficult to grasp, much less expressed in any language other than mathematics or technical writing. For this reason, my approach was to abandon any efforts at direct translation, and instead rework and redevelop the entire set of concepts from a more physically intuitive standpoint. The downside is that every point may not be immediately obvious the first time it is introduced, but I assure you every word has been purposefully included to build a coherent argument about how we should be thinking about our universe and our fundamental particles.

In short, this text is only meant to use an uncommon viewpoint to draw some new insights into a very difficult set of questions. If you enjoy the work that follows, I urge you to pursue the subjects further in a more formal setting, whichever suits you best.

Now that I've said that, let me say one more thing. Writing this book was *hard*. Every sentence was difficult to construct, and getting through this text stretched my faculties to the very thinnest they have ever stretched. As such, I imagine that it will also be a difficult text to read, although I've done my best to be as clear as possible while still covering the ideas I originally set out to cover. My point is this: don't be dismayed if every point isn't immediately clear the first time I point it out. Regardless, in my experience the key to making any sort of headway on these topics is patience and time. You just have to sit with the discomfort as best you can and trust your instinct while appealing everything to empirical observation whenever possible. Most importantly, though, stick with it. If you are at all interested in what we know about the universe and what makes up our reality, those are not questions that can be answered in easily digestible ways. You can trust, however, that building a deeper understanding of our universe (even if it's only slightly deeper and still riddled with questions) is immensely satisfying. Finally, despite whatever understanding you do manage to carve out, never close your mind to an even newer and possibly deeper understanding of the universe you live in.

New York Dr. Gavin Bascom
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The cover illustration was created specially by artist Pablo Carlos Budassi for Wikipedia.org, made available under the creative commons license. It is the "artist's logarithmic scale conception of the observable universe with the Solar System at the center, inner and outer planets, Kuiper belt, Oort cloud, Alpha Centauri, Perseus Arm, Milky Way galaxy, Andromeda galaxy, nearby galaxies, Cosmic Web, Cosmic microwave radiation and Big Bang's invisible plasma on the edge." Downloads are available at Wikipedia.

Finally I have to acknowledge the superb illustrations done by Andy Gaskill. They add a dimension to the ideas that I never would have seen on my own.

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Introduction

1.1 Putting Past at the Edge

This is not a book about the universe. This is a book about how we *think* about the universe, and how we *observe*, and subsequently *represent*, that universe with symbols whether they be equations, letters, words, sentences or even images.[1] To start, let's do a little exercise. Take a second, close your eyes, and imagine the universe. Try to picture everything that ever was, or ever will be.

That probably didn't work, so let's try it another way. This time, instead of trying to conjure the entire picture immediately, start with something easier, such as the room you are sitting in. After you've got that, expand that image out away from you, encompassing the nearest city block. After you've got that, move it out again, now including your city. Try for the state, the country, now the planet, solar system, galaxy, galactic cluster, supercluster, and finally…the cosmos.

I'm serious, do it. Don't just think about what would happen if you did it, try to conjure up images inside your mind in one smooth fluid movement from here to there. Try to pace yourself evenly and take about a minute to get there.

Now ask yourself a question. When you envisioned the room or immediate space around you, were you inside or outside of the room? Did you envision the walls of the room situated in such a way that you would have to turn your head to see one wall, and if you had that one in mind you wouldn't be able to see the other? How about the city block? The city? The planet? Did you find, by the end, that you were picturing something from a bird's eye view, as opposed to it being somewhere out above you? Interestingly, at some point during this exercise I always find that I go from envisioning the location from how it would look to me now, from where I'm sitting, to some idealized version of the thing, with more and more *representation*,

[1] And how it is impossible for those symbols to fully represent a universe which is cleanly linear in time, but that ends up being a good thing.

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and less and less *observation* involved. Notably, I also find that I'm now *outside* the thing I'm representing. By the time you were envisioning our planet, were you thinking of something like Carl Sagan's blue marble? Is it an image inspired by the picture taken by Apollo 17 astronauts who had traveled 30,000 miles *away* from the surface of our planet before they could take that picture?

Also note how the thing you're envisioning goes from being larger than you, or something you can't fit into your vision all at once, to being smaller than you in terms of observation. It's not that you truly think the universe is smaller than you, you're just using the only method we know of to fully understand something—representing it in a size where we can see all of it at once, which is, in our case, the same as getting some distance away from it.

It's the same, or maybe even a bit worse, when we envision our galaxy. Despite what you may have seen, humanity has not yet been able to take a photograph of our entire galaxy. Sure, we have pictures of *other* galaxies, which have led to artist's educated guesses and subsequent renderings of our own galaxy, and we have plenty of pictures of the milky way from inside our galaxy, but we don't have pictures of our own specific galaxy from outside of it. Think about that for a minute, despite the notion that the entire sky is readily available for observation, in reality anything farther than our own galaxy only has something like half of its map filled in. So when we envision our galaxy, we're bound to end up imagining an *idealized representation* of our galaxy, even if at least half of that image is made up entirely of educated guesses. If I were to supplement this image with the one that is derived from direct observation, it would look like the milky way on one side and some stars and dust out behind me, but it wouldn't look like a nice neat disc with a bright spot in the center, even if that image would be more correct if you could move outside of the galaxy. The problem we're running into here, namely that we cannot fully view, and as such need to supplement or replace observation with representative symbols, a system of which we are a part of, becomes even more apparent the larger the system. It became noticeably more apparent in moving from earth to galaxy, and it will become even more apparent from galaxy to galactic cluster, and by the time we've reached the cosmos we don't really have much of an image at all!

This phenomenon, namely the way in which we continually replace idealized versions of things with what the actual measurements tell us, forms the basis of this book. We will little by little break down what this means at both the large and small scales, and after we've done that we'll put it all back together again in order to more fully understand how our universe works.

So now, once you agree that this is an important phenomenon in space, consider that things get even more complicated when we realize that it is also an important phenomenon to study in *time*. In very much the same way that we cannot see the universe except from inside, we can only see our current *temporal* universe from inside our current timeline as well. Hence, if we were to repeat our theatre of the mind exercise from a moment ago, but now for the timeline, we would run into the same problem. First, we start with an instant in time, say right this second, then we expand outwards, our window opening up to encompass an hour from now and an hour in the past, then a week, then a year, and eventually all the way out to the beginning, and end, of the universe. Can you see the main problem? Not only is it difficult to imagine much of the past because so little of it has been written into our collective memory, it is also difficult to imagine the future because the farther away an event is on the timeline, the harder it is to predict!

Let me reiterate. What we will be interested in for the text that follows is not only the objective universe which we all might be able to agree on if we had an infinite number of observations and symbols to describe it, but *also* the way it looks, even if that changes with perspective. We're going to claim that to fully understand something, you need to view it from both inside *and* outside, and combine those two representations together, even if one isn't any more objectively true than the other.

Before we can do that, however, we have to note that the problem becomes even *more* exacerbated when we take a note from Einstein and realize that space and time aren't cleanly separable, and in reality the farther something away is in space, the farther away it is in *time* as well. So, in a sense, the two different versions of the thought experiment are one and the same! When we point our telescopes up at the sky and wait for light to accrue on the lens, the further away an image is, the *older* it is as well! This means that if you were truly able to envision the entire cosmos, you would *already be* envisioning all of the timeline. No matter what symbols you want to use, correctly referring to the *biggest* thing in the universe is also referring to the *oldest* thing in the universe, which, as we'll see throughout the course of the text, is also referring to the *hottest, loudest* thing we can observe.

In a sense, we are effectively trapped inside a great big ornate marble which, amazingly, becomes seemingly simpler and more symmetric as you go towards the outside. And not just simpler, but also older. And not just older, but also *hotter*.[2]

Combining Perspectives

Many of us carry an image of the universe that is something like a giant, mostly empty warehouse as illustrated in Fig. 1.1. We tend to think of it as a simple space stretching off as far as we can see, with six different directions to it; up, down, back, forth, and side to side, but all of it *concurrent*, as in happening right now, and additionally *invariant* or unchanging when we move around in it. We usually think of our universe as independent of any observations made of it, with physical reality constituted by the vast collection of *now* moments, where right angles lie at 90° and infinite parallel lines never cross. In other words, we tend to think that the past, and the corresponding physical construction of our universe, lies at some point far away from us not only in distance, but also in accessibility, where it only exists in an imaginary location we collectively call the past, not in any particular spatial direction.

[2] Well, more energetic anyway—we'll get back to that.

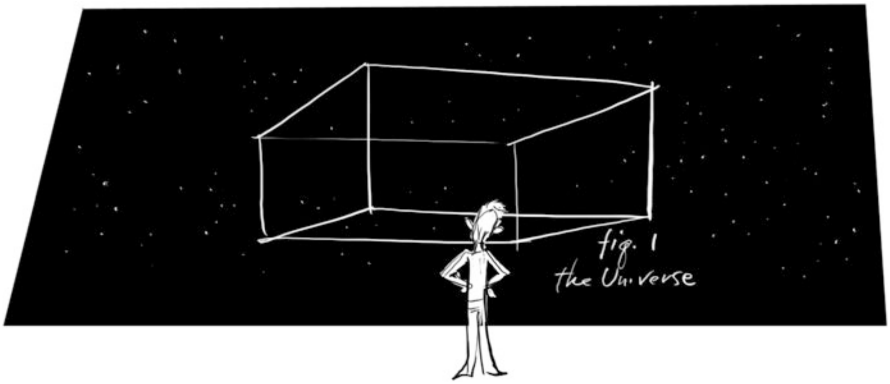

Fig. 1.1 The universe as a giant, empty warehouse

This vast collection of now moments, as impressive as it is, is not, however, a *complete* set of descriptors for our physical reality, just like neither of the inside/outside collection of viewpoints from our earlier thought experiments were complete by themselves. The hallmark of modern thinking, as it is coming to be understood in cosmology and quantum mechanics, is the ability to distinguish between the *singly observed* universe and the *multiply observed* universe, or what a universe might look like if we were able to move around with respect to it, and not only observe it from the center. We have to remember, however, that this applies to both space *and* time, so it's a little tricky to understand.

Take, for example, the case of a child visiting a giant empty warehouse and asking about the construction of that warehouse. The child's parent will answer, quite logically, that the construction is not in any place the child can look *now*, but instead some place that is only inferred and labeled as the past. This isn't, however, what cosmological scientists envision when they think of the universe—although it may be better to say this isn't how they *look* at the universe to study it. To *look* at the universe, scientists peer further and further away from our current point in space, with telescopes taking measurements in real time that record elements of the big bang.

Let's say that again. Scientists take measurements, *now*, which are recording *in real time*, things which *are still happening,* during the big bang. But the big bang, you might contest, is not happening anymore! It's only happening in the past, and the past is only just reaching us now 13.78 billion years later, so really it's just a trick, an illusion that light plays on us. This isn't *in*correct, but it misses a fundamental point that we will need to move forward—the past is *physically* located at a distance very far away from us, wherever we are at this moment, in every direction, and we cannot fully understand light, fundamental particles, and fundamental forces without shifting our thinking to include it situated as such. Returning to our analogy,

Fig. 1.2 Orthogonal versus perspective views

we could say that the cosmologist who's child asked where to look to see the big bang might answer, "well, if you look hard enough, it should be in every direction!"[3]

This counter-intuitive shift in thinking, namely placing the past in a physical location as opposed to an imaginary one, leads to some truly remarkable consequences at the largest and the smallest scales we can measure. Placing the past in a physical location in your mind is analogous to placing realistic perspective into an otherwise flat drawing[4]—it is anything but straightforward—but once achieved it is hard to do without (see Fig. 1.2). There are big puzzle pieces missing at both the *newest* (taking a measurement), and the *oldest* (the big bang) places we can look, and we've only just started looking in those places. In fact, as difficult as it may be to fully grasp, the physical superlatives, namely the oldest, newest, smallest, and largest things which can be observed, are not only part of the same extreme puzzle, but also intimately interconnected, in real time. Being able to see the connection, however, will require you to do something akin to placing perspective in an otherwise flat drawing, and it isn't going to necessarily be a simple task.

To place the big bang at the physical edge of our observed universe, you must first *unlearn* the invariant idealized version of reality (the one where parallel lines don't intersect, and right angles fall at 90°) and *relearn* to draw them how they appear with reference to your eye in a single instantaneous moment (where right angles do not necessarily fall at 90° and parallel lines indeed *do* intersect). It's not as simple, however, as copying the angles as they appear to the eye, but instead you have to learn the ideal version, and then abandon that version, or maybe better said distort that version, to correctly describe the desired perspective. In other words, one needs to combine both the ideal *and* the perceived versions of reality to get a complete picture, which is a distinctly modern thing to do, just like we needed to combine both the inside *and* outside observations, and we will need to combine the vast collection

[3]But you would have to hold still in order to see it, which is a fundamental distinction. You cannot reach it physically anymore, and cannot interact with it causally, so it will also recede away from you as you chase it down, much like the pot of gold at the end of a rainbow. Admittedly, however, saying all that to your child would probably only serve to confuse the issue.

[4]I borrowed this analogy from Daniel Dennet in *Consciousness Explained*, although he was using it to explain an entirely different concept.

of now moments with the collection of *not*-now moments to move forward and see everything correctly. To carry our analogy any further, however, we will first have to learn what we mean when we refer to an ideal universe,[5] and conversely what we see when we look up at the universe,[6] and combine these two views into a more complete grasp of what's going on.

In fact, the role of perspective in representation runs deeper than our analogy. There is an old[7] ontological question originally posed by William Molyneux and later responded to by John Locke in an essay that spells this out a bit more. Put simply, the question asks whether a blind person, who is intimately familiar with spheres and cubes, but only by touch, would be able to recognize such objects by sight alone if their vision were magically restored. The phenomenon they were pointing out is precisely what I mean about combining two distinct views to get at a more complete description, which we naturally do since birth in the case of recognizing shapes. When touched physically with hands, the invariance of a cube is easily noted; all of the edges fall at right angles. What Locke and Molyneux reasoned was that it would be difficult for the blind person to recognize them at a distance—because the angles will not appear to be at 90°!

Until very recently this reasoning remained speculative only—until the modern age when vision *can* be miraculously granted to previously blind individuals. The result is that these individuals do indeed have a very hard time discerning cubes and spheres by vision alone, at least at first. Perhaps even more interesting is that these individuals *also* have a hard time understanding why objects shrink to a point as they move far away in distance, or why the horizon shrinks to a line.[8] It is the perhaps lofty goal of this text to spell out what this looks like[9] at cosmic and quantum scales, which will help us build a counter-intuitive but physically accurate view of the grandiose universe, noting where the cosmic horizon appears to us from our humble perch down here in the center of it.

Horizons

Horizons, as you'll see in the text that follows, are a key feature that we will use to try do all this combining, but for both the big *and* the small, the old *and* the new. For now, though, let's consider the way an atom interacts with an apparatus attempting to measure it, and the immense complexity of making sense of the jumble of forces barreling down onto it at any given moment. In the spirit of our thought experiment from before, put yourself in the shoes of the atom and imagine you are

[5] Or the version described by the cosmological principle.

[6] Or the one that starts with a loud pop.

[7] Circa 1690 to be precise.

[8] This research was published in *Nature Neuroscience* in 2011 by Pawan Sinha and others.

[9] Or perhaps what it cannot look like.

spinning and tumbling at incredible rates. How difficult would it be to discern a sudden unexpected change in velocity, even if it originated from someplace inside the atomic horizon? How precise would such a force have to be for you to separate it from the other tangle and jumble of forces and give it a name and a label? Even more, what exactly do we mean by atomic horizon? Where would it lie in reference to you? Somewhere near the edge of a molecule, or a sea of other atoms? What are the rates at which things vanish with distance from your atomic eyes? What I'm getting at here, is that many of the things we measure, in terms of quantum mechanics, are things we measure not by direct observation, but by tracing out *problems* with how we trace out observation, and then label the thing we can't account for without widening our scope of view. If you're an atom, you may have to widen your scope of view a phenomenal amount before any of this picture starts to come into view. What's more, we also have to remember that not only is there a spatial horizon to look for, but also a *temporal* horizon to consider. How small and fast would something like a tornado have to be for you to notice it? How would it look to you if it were moving ten times slower than you are? Ten thousand times? Ten followed by 23 zeros times? Is it still fair to call it a tornado from your view?

When drawing a comparison between the atom and the universe, however, the question isn't necessarily how these two topics are connected directly, but rather how they are connected in form, or in relation to the laws which efficiently describe them. Again, consider how atoms behave *in reference* to a macroscopic apparatus attempting to measure it; there is an immense amount of smoothing and calming and quieting that has to happen or no measurement can be made. In the context of our measurements of the universe from inside of it, *we are the atoms*. In the same way that the temporal and spatial horizons will appear in strange compressed or dragged out ways to the atom (and parallel lines will appear to cross), our view of the universe is arrayed out in a smashed together echo of the biggest loudest things to have ever happened in it. It is important to realize that the written remnants of our universal past, the tail end of giant cosmic measurement, is not written in the normal linear language we've developed in our earthly timescales. It only gives up tiny pieces of energy, hardly distinguishable in a way well behaved in time. As difficult as it may be, however, this allows us to rupture our idealized notion of what the universe *is*, and start to work on what *it looks like*. Once we start to realize that things at infinity only present themselves in a jumble of pieces that may or may not be out of temporal order, we will realize that putting all the pieces back in order is the real difficulty that faces cosmology, and by extension, fundamental physics today.

This *same* difficulty extends in the other direction as well, in that atoms are as far away from us in time and space as we are from the universe. The act of taking a measurement, at its core, is not a simple feat, and communicating such a measurement is often even more complicated. Once we accept this as it applies to both the small and large scales, we can start to see why and how quantum mechanics and cosmology are not only deeply intertwined, but also fundamentally interconnected with everyday life. For example, I'm now going to ask you to ingest a difficult concept which I've only been dancing around up until now, despite the fact that it forms the crux of how we are going to achieve reformulating our new view of the universe.

A Concurrent Universe

The big bang did not happen a long time ago at a place far away from us. It is *currently* happening. It is happening at every point in the measurable universe in every direction. The *beginning*[10] of it, however, is now far away from us, smeared out in a complicated mess, much the same way a classical tornado might appear to an atom contained within it.

This is not, however, the end of the story. This initial image is only the first step towards building a modern view of the universe rooted in empirical observation. Our view will eventually incorporate some version of a cyclic universe where the cycles are very big and very large and very difficult to make out. It is not a universe that is cycling from some previous epoch to a future epoch, however, but instead it is a universe that contains *everything, ever*, meaning that the timeline is infinite even if the observable universe has possibly undergone some cycles.

In certain technical senses, this means that a precise description of the future may be fundamentally indistinguishable from the past, which has implications for gravity, entropy, and especially fundamental particles. This also posits that our final moments in this universe could be indistinguishable, at pretty much all scales, from the initial moments of our universe depending on the size of the window you are using to look at it, in both time *and* space. The unpredictability of quantum mechanics arises not in that there are separate parallel universes all crammed into small spaces somewhere, but that measurements taken of very small things *depend on things which haven't happened yet*. Let me reiterate—our ideal model of the universe, one in which there was nothing and then something and the universe followed linearly in time, is valid in an ideal sense[11] but unfortunately this universe is impossible to observe directly.[12] The universe we see when we look up is one that contains many fundamentally unknowable and unobservable details, all the way back to the beginning of measurement itself, inferred or otherwise.

In short, the uncertainty of quantum mechanics dictates that some part of our collective past cannot be observed—*because it hasn't happened yet*. When we crane our collective necks to look at what is coming towards us, we are simultaneously looking at the past, because both the future *and* the past is physically located at a distance far away from us, and it is almost impossible to tell the two apart. Trying to travel to infinity in one direction means you can't travel to infinity in another direction, which you would need to do to compare notes and establish a linear sequence of causal events that we take for granted in our neat and tidy theories of universes. To see the whole picture simultaneously, which would allow for exact measurements of quantum scale objects, you would need to do something akin to traveling to the end of a rainbow for the fabled pot of gold. Actually, it would

[10] Admittedly this is a very tricky word to use in this context.

[11] As in, say if we had a outside-in way of observing it as opposed to being stuck in one spot in time.

[12] Or computationally for that matter.

be more like going to the end of two different rainbows simultaneously, and then comparing and contrasting the gold in the two pots. There are very good reasons it cannot be done, and not just because the whole thing is technically an illusion.

Now, this may seem like verbal gymnastics as opposed to meaningful observation, but it is so much more than both of those; the consequences are far reaching and ubiquitously present in every physical movement you've made since your birth and every movement you will make since. This is not exaggeration, hyperbole or metaphor. It is concrete, observable, reproducible fact, it's just fairly difficult to wrap your head around.[13]

1.2 Putting Now at the Center

Now that we've covered some common ground, let's return to our thought experiment from the beginning lines of the book and ask a few more questions. First of all, when you got to the point of imagining the entire universe, did you find yourself exerting effort to do so? Was the universe you were imagining something you observed directly, or something that's being maintained by active processes? Is your universe, or better said the *description* of your universe, more of a constructed entity, or more of a passively observed entity?

To fully understand where the modern descriptions of the universe are coming from, we have to note that science has undergone a major shift in the last one hundred years, and this shift corresponds to how we derive knowledge as much as how we experience that knowledge. Namely, we have collectively realized that knowledge is constructed as opposed to passively observed, and that there are subtle differences in the way that constructed descriptions can be put together. Take, for example, the way that an author might put together a description, as opposed to the way that an engineer might put together a description. Both are constructed, but not necessarily via the same routes. The author's description is constructed from a tinkering with sequences, thinking about how and when things can influence each other and then stringing them together into a narrative. The engineer, however, builds their description by a kind of step by step plan for constructing the event being described, where each tool is implemented at certain intervals and produces a description of the observed event. More importantly, the engineer's description will not necessarily have a linear timeline, whereas the author's most likely will.

For example, what would happen if you were to witness a car crash and then decided to ask both the author and the engineer to explain what happened in a technically precise way? You may, despite asking them to describe the same event,

[13]Precisely because *it* (namely the universe) is wrapped around *your* head and has been from the beginning (and end) of time.

get entirely different responses. The author might tell you that the driver ran a red light and the two cars hit each other. The engineer, however, might tell you that the red light failed to alert the driver, the car brakes failed to stop the car, and they hit each other. Note both the differences and similarity in their responses; they are both correct, they are both describing the same event, the length of the description itself is almost identical, but the descriptions are different. The engineer lays out the facts non-linearly, not necessarily constrained by any temporal order; failure of the car to stop increases the probability of a collision, and a collision is evident, so the picture works. Also notice how it is not necessarily describing a specific event, but more of a generalized event which fits nicely with the current situation. The author, however, is describing something that happened in sequential real time, where if more and more details were to be given, it would limit our description in terms of the number of situations to which it correctly applies. The engineer's view, although not being exact and not necessarily sequential, can theoretically be applied to a whole host of situations, whereas in many ways the goal of the author is to constrain the correctness of the narrative, by adding more and more details, to the correct slice of time embedded somewhere in the long timeline made of such slices.

Which is more correct? Could it be that having *both* of them is necessary for a fully complete description? Which is easier to construct?

To understand what is going on with the big bang and fundamental particles, we are going to need both kinds of description before we can make full sense of what we're observing, in the same way that need both the inside *and* outside view of things in our thought experiment. Additionally, even if at first glance it may seem that narrative descriptions, i.e., those that the author would provide, are easier to construct than engineering descriptions, the modern era is now spelling that precise narrative descriptions are *much* more difficult to generate and work with than engineering descriptions, and this will end up playing a *very* big role in how we should be thinking about all of this. For technically precise situations, deterministic narrative descriptions often require an exhaustively large amount of resources to generate. What's more is that the returns of said descriptions not only diminish with added resources, they diminish exponentially as you move towards each extreme in measurement, whether it be the very small or the very large.[14]

In fact, largely for these reasons, quantum mechanics and cosmology both developed in the late twentieth century as an engineer's view of either the very small (quantum mechanics), or the very large (cosmology). Both, however, are largely lacking in a unified narrative description, mostly because they are so difficult to construct. Both topics were brought into the modern age by two of Einstein's revolutionary ideas, in cosmology by using the inability to distinguish acceleration from gravity, and in quantum mechanics the inability to distinguish waves from particles. Both these observations were used to drastically upend existing theories of narrative type descriptions of the very small, and the very large, even if he didn't

[14] And this indicates that the *sequence* of events you are describing is less and less reliable, even if the descriptions of individual events are usually reliable in a vacuum so to speak.

Fig. 1.3 We're ***sure*** about this right?...

use this exact language. In short, they both pointed out crucial aspects of why complete causal narratives cannot be built from functional descriptions alone, only probabilistic descriptions, even if this fact bothered him later in life.

Einstein, by the way, pioneered both subjects not only by influence but by direct concrete calculation and publication. In many ways the scope of his ideas, from the largest to the smallest, is what was truly revolutionary, and we will need them all to make significant headway on these topics. Of course I don't mean to downplay the role of other great minds in this era, of which there are many. In my opinion, however, the three big ideas to truly advance these anti-arguments are Einstein's relativity, Heisenberg's uncertainty principle, and Gödel's incompleteness theorem (see Fig 1.3). In short, one of the most important aspects to come out of this time in physics is the realization that as our descriptors get more precise, the less they can say about the specific narrative that they comment on, and the more information must be supplied at the start of the calculation to make meaningful descriptions stay valid. Hence we get the provocative titles of the theories: *relative, uncertain, incomplete.*

Let me spell that out a bit more, but for now let's focus on the cosmological part, and we'll come back to quantum mechanics next chapter. Consider how, in adopting the author's description while investigating the universe, we can ask if there is one single, objective history that we can write down and represent with symbols. If this is the case, that would denote that every particle that's ever existed has a specific beginning, correct? Not only a theoretical, generalized beginning, but an *actual, physical* point in time and space that could be attributed to the birth of that particle. Say we then write down all of these births, it would not only result in a very long list of births, but it could theoretically be strung together into sequential order, forming a single narrative $\sim$13.8 billion years long, correct? Except, now consider that some of the particles can spontaneously interconvert and most likely did so somewhere between when they were made and now, not to mention there are many atoms still moving around and interconverting, as we speak. What's more, what if it is very difficult to tell some particles apart from others based on when they were born? What if we're moving in an accelerating reference frame and now we can't agree on whether particle *a* was born before particle *b*, because it depends on which reference frame we're using?

If we move to the engineer's view, however, we don't need to worry as much about the narrative version of the universe, and instead look to build a theoretical model of all of the constituents residing within the universe, and then apply the correct rules to each situation. In this approach the resulting picture is non-linear, kind of like modern approaches to storytelling where individual pieces of the story are told out of order and it's up to the viewer to decide what happened. In this view we attempt to describe the individual elements, *independent of narrative*, that give rise to the big bang attributes, and then put them in a list and organize the list however it suits you best. You can see how, on the one hand, it's liberating because it doesn't require us to sequentially order every individual constituent, but on the other hand, we note that this approach is fundamentally limited in the way mathematics are fundamentally limited. They can only build a generalized theoretical framework that is somehow symmetrical and in which energy is conserved fundamentally, which may or may not describe any more than very idealized situations. Theoretically, however, given enough of these components and rules describing the components, we should be able to incorporate the physically reproducible parts of the giant hot soup we see at the edge of the cosmos and infer some sequence, but this sequence is limited to large events which have left very large signatures. Also note, however, that there is no direct observation we can appeal to for ultimate correctness, no guaranteed universal timeline. There is only the utility, accuracy, and adaptability of your individual descriptions and tools, the rest of the narrative has to be inferred secondarily from the mathematics.[15]

Even more wildly frustrating, this also hints at the idea that *there may not exist* a single narrative that is neatly behaved in linear time. If it helps, this refers to the *observable* timeline, or one which we can passively observe without interacting with it. It doesn't mean that a nice and neat linear history of the universe *cannot* exist, it just means that if it does it will likely end up looking a lot like our current picture of our galaxy, constructed of good guesses but not observed directly. More importantly, constructing those guesses will require that we interact with that timeline somehow, i.e measure it, and we don't yet know how those measurements behave near the extremes.

The main difficulty that arises, as we will see again and again, is that if you want to nucleate a narrative description of an *observed* phenomenon, you are going to have to assign "now" to a couple different places at once, and that is a notoriously

[15] Which have to be combined with initial conditions, which, as we'll see in the following chapters, means there will also be some unknowable or unobservable component to the picture.

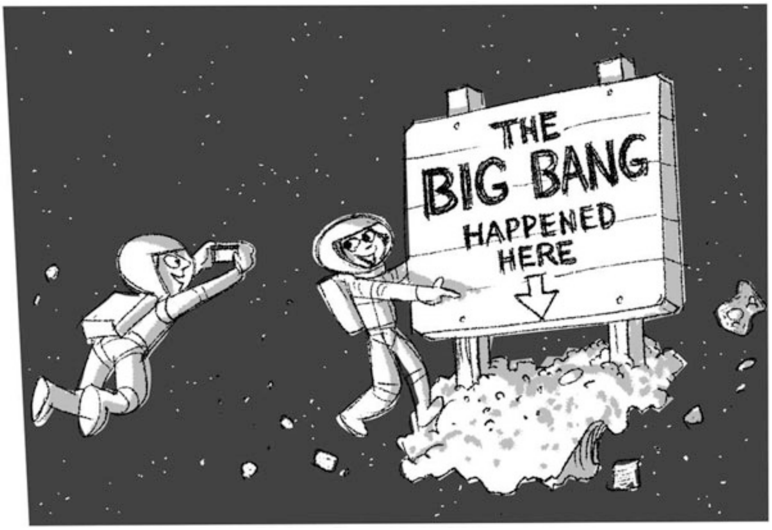

Fig. 1.4 Does the Big Bang have a particular spatial location? Can you visit?

difficult thing to do for the very small or the very large. In a sense, the two places, or at least the measurement of the two places, will always be fundamentally irreconcilable at the extremes, but we need a label on both to convince ourselves that there is an observable universe which is linear in space and time. Conversely, allowing that there might *not* be a linearly observable universe leads to a liberating, albeit wildly frustrating, new view of how things work.

In fact, one of the neatest consequences of the big bang theory is that all energy has a precise beginning, and that that energy can not only be traced all the way back to a single point in time $\sim$13.8 billion years ago, but that it also traces to a single point in space . . . sort of. Like seeing a rainbow, however, knowing it exists doesn't necessarily mean we can travel there for a visit (see Fig. 1.4). To put it another way, all measurable energy in all directions can be rewound back to a single point with infinite density, but that space corresponds to all points, now, and we don't really know what we mean when we say infinite density. This is hard to understand no matter who you are, but one of the main themes we'll build towards in the chapters to come is that the apparently infinitely dense point is a temporal and spatial *horizon* effect. It is a point when viewed in time, but will never *appear* to us as a point because we are stuck *inside* the measurement of it, which is now infinitely far away from us. Even if the point can exist in a theoretical sense, trying point at it with our fingers would be a lot like trying to point at the end of a rainbow.

This is easier to swallow if you remember that these descriptions are in engineering-speak, and have to account for observer effects. In other words, we aren't saying that the big bang exists at all points *ever*, it's more like saying; "it is theoretically possible for any given observer to construct descriptors which place all currently observable energy (observable to the observer) at a single point in space, but that point would correspond to all points now, as long as they are very far away from the observer."

To be honest, however, physicists aren't as interested so much in what happens at the singularity itself, but more what happens just immediately after it, or, if the differences turn out to be discernible, what happened just before it.[16] Let's repeat our statement again—the rules of mathematics are physically limited in their ability to assign meaningful descriptors to sequentially placed phenomena, and that limit lies somewhere near events just moments after the universe suddenly had a definite shape and size, which also happens to correspond to energies, lengths, and units of time comparable to the stuff that atoms break down into. And *that* lies, as hard as it may be to understand, in *any* point in current time, as long as that point also happens to be a very far distance *away* from you.[17] I should note, however, that while the mathematics are limited fundamentally in how they can be applied to the narrative picture, in places where they *are* applicable, they have been applied very precisely and with great success. This is why we spend money to build particle accelerators and giant computers, to get more and more precise measurements to refine our mathematics ever onward, and get closer and closer to a complete and correct view of the universe.

However, herein lies the difficulty. When building narratives, you often have to start by assigning *now* to some set of particular spatial locations, and that is infinitely regressive and subjective. There's always a bit more precision you can add that may or may not help in synchronizing the measurement, and there always might be a better reference frame to use for it. It follows the observer. It follows the measurement.

This does not mean, however, that there's something special about a conscious observer. In fact, all of the difficulty hinges on simple classical phenomena and the way numbers work. There's nothing quantum mechanical about it, and yet it still suffers from the so-called *observer effect*, which is really more of a *measurement effect*. Measurements, at the core of things, rely heavily on innate synchronization between two objects, which requires a precise rest frame, which is, at its heart, something which is not always easy to have. In short, if there ever were a 'center' to how things work, it would be nestled somewhere deep down in the heart of

[16] In fact, as dense as it is, much of the quantum gravity formalism is attempting to do just this, reformulate the mathematics in ways such that a giant cosmic bounce allows for a sort of skip over the infinite parts of the singularity, where the need arises because general relativity, without modification, states that asking about *before* the big bang is a malformed question, like asking what's more north than the north pole. Let's just note that it's very complicated and move on for now, but we'll come back to it by the end of the book.

[17] In both time *and* space. Indeed, one of the most fundamental consequences of relativity, as I discussed in the opening section, is in moving to a non-sequential view of the universe and noting that the past (namely an infinitely dense, infinitely hot universe) is physically (not metaphorically, but *physically*) located in every direction, stretching off away from the *now*. In short, the observable cosmos is not just a giant ornate marble in *space*, but also a giant ornate marble in *time*.

every measurement taken, but as a hard-won, constructed, virtual object[18]—not a simple observation. As we'll see, this makes all the difference when it comes to understanding the very big and the very small.

1.3 Putting Ourselves in Between

So far we have made the case that the past is located at the edges of observation, and the infinitely regressive present is at the center of each measurement. It follows naturally, then, to ask—what is in between? The answer is that we are! Perception and measurement encase the illusive center, in both time *and* space. The way we are going to go about defining the past and/or the future from here on out is in reference to the act of a measurement, which is what we're going to use to nucleate our modern picture of the universe. Admittedly, this necessitates a certain amount of anthropocentrism, which we'll address more directly in the last chapter. Note, however, that this is applicable to how things work with or without humans to puzzle over the results. It's just how things happen.

Let's return to our thought experiment again. When your perspective was expanding, going from city block to street, did you imagine a city block that was situated *inside* the city you then moved to? After all, this was why we set things up this way; we wanted to emphasize that it is easy to lose sight of the correct perspective while it is expanding. Now let's tweak the thought experiment just a bit, and say that we're imagining *all* rooms, as opposed to just the one you are in currently. Now move to the set of *all* city blocks, and then *all* planets, galaxies, superclusters, etc. Is there something interesting about the difference between the two exercises? Does it make you uncomfortable moving that way, maybe because there isn't necessarily a well defined set of city blocks as opposed to cities or states or whatever? Are there some sets of rooms that don't include city blocks and some sets of city blocks that don't include rooms? Even worse, are there some places where rooms are *also* city blocks, and therefore some city blocks that are *also* rooms? Does this mean that some of the sets will have repeat members? Is it possible to move smoothly between these kinds of sets, like we wanted to do with the original version of the experiment?

This same problem extends to the system of laws as well as the physical contiguity of perspective. As a scientist, it's common to overhear people using science as a way to tidy up their views of the hierarchy of laws. The attractive, yet subtly incorrect claim is that the various scientific fields should be placed in a compact hierarchy that mirrors the size of the things being studied. It usually goes like this; biology reduces to chemistry, which reduces to physics, which reduces to quantum mechanics, which reduces to mathematics, and so on.

[18]A good example of something like this is the center of mass of an object. The exact precise location of it is infinitely regressive, you can always envision moving a little closer to it. What's more you cannot assign it due to any intrinsic property of the spot itself, but instead by comparison with how the object interacts with its environment.

This approach has some problems, however. A simple one is to point out that this view would completely miss Darwin's insights entirely, because there's nothing in chemistry, much less physics or quantum mechanics or mathematics, that guarantee's natural selection. Historically, each field developed in response to careful systematic investigation of variables which become evident in context. Chemistry was developed in part because people wanted to see if they could make gold from other mundane items,[19] physics developed because people wanted to build bigger houses, make better boats, and ship things faster, biology because people and animals kept getting sick or hurt, and astronomy because we needed to use the positions of stars to keep track of where we are down here on the surface of our planet.

Now, the intent of such statements is not generally to dismiss or neglect the history of each discipline, so you might reasonably ask, what's the harm? In many ways, this pyramid representation of the hierarchy of physical laws, while useful, has acted as a sort of cognitive crutch for modern thinkers that goes all the way back to the Greeks. The hierarchy, while applicable for ideal problems that show up in high school text books, becomes much more involved, and in many cases *tangled*[20] when we move among the different regimes of inquiry in practice, particularly when trying to move from the smallest to the largest, and particularly if it turns out we ourselves (or whatever is doing the measuring) are *moving* while ascending or descending scales.

More importantly, however, is that in certain cases, it gives the wrong impression. There are very good reasons that biology is not produced *a priori* from chemistry. It is true that the two disciplines go hand in hand, but consider the conundrum we talked about before, namely how the narrative view, with any real precision, is very difficult to construct based on the rules that engineers would use. Chemistry, which really boils down to an engineer's view of how to make or use chemicals, does not contain a long laundry list of what happens inside humans or animals. On the contrary, it contains a set of descriptors which apply only generally to a set of specialized circumstances, some of which may or may not occur naturally within the cell. It is not the *enclosure* of biology within chemistry that makes the two subjects related, it is the *intersection* of narratives observed in each discipline. Some parts of the discipline within biology, which may have developed completely independently of chemistry, *happen* to mimic what happens when you put pure chemicals in a beaker and heat them up. As such, when people fully appreciate each other's disciplines, these intersections become evident. What's more, they are incredibly useful because they increase the precision of the rules that are derived from each in the absence of such intersections.

This is why we can easily envision our own galaxy, without having seen it. Not because our galaxy is encompassed within a nice and neatly defined set of all galaxies, but because our galaxy shares many features with *other* galaxies, and it

[19]Namely urine. See Bill Bryson's "A Short History of Nearly Everything."

[20]In the same way that Escher's hands drawing each other are tangled.

is the intersection of those features that allows us to make an educated guess about what our own galaxy looks like. Note, however, that the guess will be probability based, not determined precisely, until we have the technology to go out and observe it.

In other words, these intersections do not necessarily denote some deeper truth regarding the direction of biological or chemical research, much the same way our educated guess on the appearance of our galaxy should not be used as the teleological reference. The deepness of truthfulness of a set of rules in biology may have everything to do with how a given organism behaves and interacts with its environment, where the insights from chemistry provide little extra utility past a certain point, and empirical observation is what really counts in both cases.

As much as physicists don't want to admit it, their discipline suffers from this problem as well. Some fundamental puzzles, as chafing as it may be, depend very little on fundamental laws, and depend very much on some specific narrative that comes at some specifically opportune time, a time when the causal outcome of some set of initial conditions is very hard to predict. In certain senses, we could call these moments *cold*. Cold in the sense that Maxwell's demon, given the correct amount of information, could take energy out of a system one atom at a time and cool it down, however theoretically unlikely. Cold like that.

Which leads us into the last major class of descriptor we need to establish before moving on to the main treatment. Things which are "cold" in this sense have everything to do with why we say the universe is *hotter* when we get to the outside. It's hotter in the way some descriptors are less anchored in determinism, and more anchored in probability, even if they rely *more* on determined outcomes.[21]

Is it possible, however, that this may have more to do with the inability of symbols to fully capture meaning than for the actual physical outcomes to be observable somewhere? Consider, for example, the difference between a reference and a referent, where the referent is the thing being symbolized, and the reference is the symbol or word you use to do the symbolizing. In semiotics, it is generally understood that language is not useful in a vacuum, but only in the context that we all agree on the meaning of a given word or a given phrase. In other words, the referent and reference are not necessarily linked intrinsically (i.e., a picture of a river is used to refer to the river), but definitely linked in social contract (i.e., we all agree that the letters r,i,v,e, and r represent sounds, which when spoken aloud in sequence form a sound which refers to a general version of said river). It is also clear that linking a referent and a reference is not instantaneous, it is driven into being by repetition.[22] This is apparent when we consider how a specific written letter, although appearing the same on the page to two different individuals, will invoke different sounds when read aloud by different language speakers. This relationship, namely one between

[21] If none of this is registering, don't worry about it. We'll come back to it next chapter, but it might not start clicking until Chap. 6 or 7, to be honest.

[22] A good word here, to borrow from neurology, is *Hebbian*. It refers to how neurons "learn" the appropriate reaction to stimulus by repetition.

symbol and symbolized, is subject to drift throughout the decades, and transporting one forward or backwards in time may render this relationship no longer valid. In short, there may be some intrinsic reason the symbol and the symbolized are linked, but these reasons are only subject to the conditions under which the original relationship was assigned. If I decide I'm going to coin a new phrase—for example, *semiotic drift*, and assign to it the meaning implied by the previous paragraph, I can't expect that meaning to hold if I change the environment in which it was assigned too much. If I go forward two or three hundred years, for example, there is no guarantee people will know precisely what I mean.

How does this apply to the world of physics, however? We stated earlier that the topics discussed are truly independent of the conscious observer, so doesn't that mean that physics escapes the problem of semiotic drift? This is one of the big fallacies of mathematics and science, even though it's seldom talked about. What physics has done, through many years of very hard work, has been to make sure that all of the descriptors they use are (to borrow a word from biology) *semiotically promiscuous*. What I mean by that is that the rules and the descriptors that we have built to describe phenomena independent of humans will work indiscriminately across time and space for similar events. In reality all precise language works this way, there are a variety of different events, places, and objects that can be easily described by each term when combined with the correct qualifiers, and this greatly increases the variability and flexibility of the language.

Sometimes I think of it like a set of pots, and their lids. Let's imagine you bought a whole new set of such pots, all of which are slightly different, but all with the same size lid. Now you go to put them away but there's not enough room to store them all together, so you put all the pots in one cupboard and all the lids in another cupboard. The next time you go to use one of the pots, it's very difficult to know if the lid you grab out of the cupboard is necessarily the same lid that was constructed for the pot that you are using. We could say that these lids are functionally promiscuous. They don't care which pot they go on, and neither should you, as long as you are focused on the functional utility of the thing. This is precisely what I mean by stating that many of the most useful scientific descriptors are noticed precisely *because* they have some intrinsic promiscuity in their functional applicability.

Now note what happens when we take the simplistic view that nature's hierarchy is one that mirror's size, and replace it with one that mirror's functional promiscuity across several different plausible scenarios. This hierarchy also loosely mirrors size, as each subsequent intersection often takes a smaller more precise set of rules, but they are also less applicable to a wider user base. You would have to start with the widest set of rules in existence and intersect them with an infinite number of different sets of rules in order to carve down to the *most* causally determinate pieces of information possible to complete the hierarchy.

Note, however, that's there's no guarantee, *a priori*, that such a thing exists. If there is one, it is one which we construct through monstrous amounts of effort. This is what the cutting edge of physics is abuzz about currently, constructing higher and higher energy situations that are intersecting, by way of massive collisions, many working theories in order to cross corroborate the results to derive deeper and deeper laws. They are working to complete the hierarchical pyramid of functionally promiscuous laws.

The thing that I find interesting, however, is that all such unification theories are set in *high* temperatures, as opposed to low temperatures. Does this come as something of a surprise? Would it make more sense for the laws to unify at zero kelvin?

Without commenting too much on that quite yet—although we will come back to it—let me point out something else. Ironically, there's an unspoken rift between people that work on what could be referred to as *cold* physics and those that work on what could be referred to as *hot* physics. Some high energy physicists apparently think of the low energy physicists as simple engineers, because in their mind low energy physics is just the application of old theories, as opposed to deriving new ones. Not only are there serious problems with thinking about physics this way, but it also sweeps under the rug the fact that quantum mechanics is not causally determinate in any local sense, and what that means for our laws and the *act* of deriving them.[23]

This last point highlights the difficulties of both the size-of-thing-being-studied *and* the fundamentalness-of-rules-derived hierarchies. They're both oversimplifications that don't have direct consequences on what the rules discovered will end up being anyway. Having said that, however, the latter hierarchy is one reason why high-energy physicists believe they are working on the big bang simultaneously, because that's where the largest intersection with the deepest cuts can be envisioned. The other reason they are working on the big bang, however, is more direct in that the are recreating the conditions last seen there or deep in the hearts of stars, and both of those places are very hot, not cold.

The point I am making, however, is that in the same way our words are subject to semiotic drift through time, they are also subject to semiotic drift through space, and perhaps even stranger, through temperature. As we go towards the outside of the universe, what we observe may correspond to something different than what that observation corresponds to down here on earth, because, as you may have guessed by now, things get older the farther away they are, which also corresponds to things which are hotter! Imagine I were to take a book written now and move backwards through time having someone read it every 25 years or so. At first they would understand it, then they would *think* they were understanding it, but would be missing certain nuances, then suddenly they would only get certain ideas and after a while they recognize the individual words and letters but not the meaning, and go back far enough and they won't even recognize the words anymore.

But remember how physics isn't rooted in social contract the way words are? They are rooted in the collection of *semiotically promiscuous* rules. So if we take those rules that we've derived comfortably from our perch down here on earth and start to move backwards through time what happens? It's going to take some

[23]Nicholas Gisin's book talks a little about being on the fore-front of testing the non-local nature of reality, and how that puts him at odds with the collider folks. I recommend it.

pages and effort to fully spell out but in short something very interesting happens, something much more complicated than the case with natural language. The effect depends on both the rate at which things are observed, the probability that an event has already been observed, and the temperature of the thing we're observing, and the resulting phasing of applicability results in the puzzle that is quantum mechanics on one side and a non-linear narrative history of the cosmos on the other side. This is what we are seeing when we look out into the horizon and attempt to make sense of the giant jumble that surrounds us.

In order to fully appreciate the effect, however, we will need to pay very close attention to many different concepts at once, and when we keep track of how things move on the most fundamental levels long enough we will eventually start to see a giant carved out sphere as large as the cosmos itself, bubbling and hiccuping on its own schedule, while we jockey to place larger and larger footholds on it in order to leverage closer and closer glances at something that is happening smaller and smaller *down here in the instantaneous now*.[24]

[24]That is, we build larger and larger particle accelerators, colder and colder experimental setups, and larger and larger computers in order to hold more and more instantaneous information in order to get closer and closer to *now*. All this is presumably in order to help reformulate our understanding things like entropy, gravity, and light.

Chapter 2
Narrative Time

Now that we've sketched the basic outline of our story and built some common ground to stand on, it's time to start the main treatment and start looking at some concrete examples of how laws and descriptors are more complicated than they may appear at first glance. In the way of a small recap, so far we have stated that the instantaneous past, which we could also call the freeze-frame version of the past, is physically located at some distance far away from us. The increasingly precise, or the increasingly instantaneous, present is located at the center of each act of measurement, and *we*, or you could say everything else, lie somewhere in between.

Next, let's imagine that we are in a freeze frame picture of the universe, like we just took a giant snapshot and now we can make the most precise, perfect, instantaneous measurements imaginable. Within the context of this ultimately precise universe we are going to see that drawing the difference between two specific scenarios, namely one in which we have *witnessed* something insanely precise, as opposed to a scenario where we have *engineered* conditions such that we can guarantee this event will have happened, is sometimes hard to tell apart, especially when the thing you're observing is very far away. The distinction relies on the difference between exact *deterministic* calculations, and non-exact *probabilistic* calculations, where there is always a case[1] where the deterministic calculation must be abandoned for a probabilistic calculation when increasing the need for precision in your description.

Now remember that inside this giant snapshot, everything that is separated by some distance is *also separated in time*. Everything that is far away from you in this giant photograph happened a little before the frame was frozen, because you were moving in reference to the things when you took the picture. This means that if you travel a certain distance at the moment that the photo is taken, then everything in the photo is spread out across time as well, correct?

[1]Particularly in the extreme case of the infinitely instantaneous.

G. Bascom, *On the Inside of a Marble*, Astronomers' Universe,
DOI 10.1007/978-3-319-60690-3_2

If we're going to continue to maintain our narrative vision of how the universe works, namely one that started with a loud pop, we will need to note that there is a subtle difference between what things *are*, and what things *may have been previously*, which is particularly important in the context we're considering now. The following chapter is going to utilize this distinction, in the frozen universe thought experiment, to intentionally rupture the normal way we think about the present state of things, and make the case that there is a valid way of describing the *now*-ness[2] of fundamental particles entirely in terms of what *they probably were before*, much like distinguishing what a certain word means now by discussing the etymology of that word as opposed to the most recent incarnation of its meaning. In other words, we are going to build a case for instantaneous relative time being restructured as a narrative—particularly in the context of the universe and small particles.

2.1 Atoms at a Distance

So if the universe has a story, and that story includes everything in it, and stories have beginnings and endings, then that would mean that everything within it should also have a beginning, and an ending, correct? In other words, if there exists some narrative version of the history of the universe, the narrative we generally think of as starting at the big bang and culminating in now, doesn't this require that matter, in a very real sense, should have some place where we could assign as the "birthplace" of that particle? Conversely, if a particular particle could be found that *didn't* have a definite causal beginning, would this denote that some aspect of the universe *also* didn't have a definite beginning?

For example, let's consider the case where a particular piece of matter is currently in the process of interconverting from one form to another. Let's say for the sake of argument that our chosen piece of matter is inside the sun, and is currently being compressed such that it will soon be a different kind of matter—say a couple hydrogen atoms that will fuse to make a helium atom (Fig. 2.1). There are rules about how and when this can happen, one of which is that it will take some specific amount of time to achieve, some finite interval. In keeping with our first chapter, this means that, technically, if you want to see the hydrogen become helium, or in other words see it at both the beginning and end of its transformation, the distance it is away from you *will also change during that interval*. It gets complicated if we need to keep all this distance/age stuff straight, but suffice to say that if something happens in a finite amount of time, then there exists a corresponding *space* that it must also span, especially if we are looking at it while it is very far away from us. In other words the light from the beginning of the transformation will be a little farther away from us than the light at the end of the transformation.

[2]Even if it requires some version of spooky action at a distance.

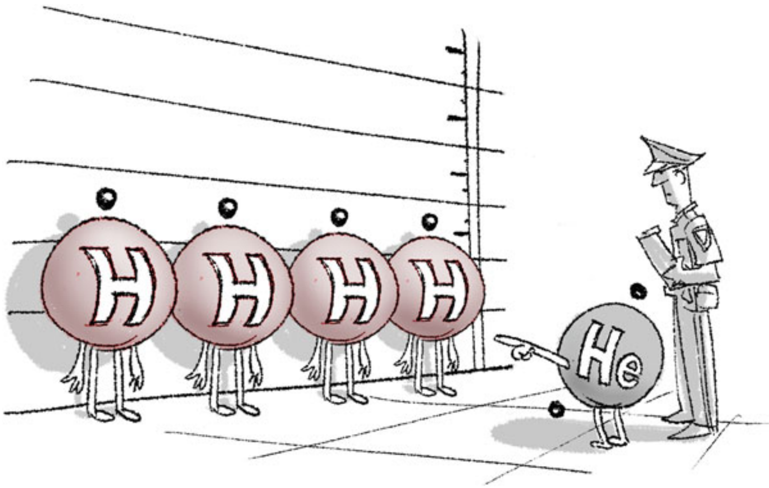

Fig. 2.1 The rogue hydrogen atom is finally identified

Generally, we can safely ignore these kinds of effects, especially if we're considering things down here near us where they are small. If however, we want to be exact and derive an exact, errorless description of our complete universe, paying especially close attention to all the *causal determinations*, complete with a narrative story with a beginning and end for each particle, we must also consider the way that matter converts from one thing to another, and even more annoyingly, the space in which this time interval exists. Additionally, this particle, while it interconverts, is probably moving relative to you. There are many ways that we can slice up how we might observe it, or imagine predicting an observation of it in the instant before or after our freeze frame which the interconversion might take, but you should see that we're not really looking for a single nice sphere frozen in space, we're looking for a kind of fuzzy smear, a pathway over which position isn't well defined. Notice, however, that the fact that there are multiple avenues it might take to get to the same outcome is not trivial. We could call this pathway degeneracy. If there are too many possible pathways this may start to get in the way of developing a precise description correct?

In fact, if we continue to think deeply about these and other relativity related phenomena, we start to note that the majority of the rules governing these interconversion events, namely the rules laid out in physics and chemistry, are generally taken as a given, where the stretching of normal space is only a consequence of moving too fast or being too light. Regarding precise calculations of events in a frozen universe, however, we must concede that relativity is ever-present. If we can find a way to re-introduce these principles as fundamental properties of observation as opposed to consequences of velocity we will be able to more deeply understand what the universe looks like in any given moment.

Let's look at it again. Given a perfectly frozen universe, the picture is actually a little more complicated than how I painted it before. In reality we would need to either *find* a situation where we know that a hydrogen atom is moving towards another hydrogen atom with the right velocity and angle of collision, and that the electrons on the surface of the hydrogen atoms must be in the correct orientation so that the correct chemical transition states appear, and the whole thing is quite complicated. Suffice to say, however, that we're going to have to know something about the velocity of each hydrogen, which is, unfortunately, *not* an instantaneous quantity. Given that we're in a freeze frame version of the universe, we're going to have a very difficult time deriving any such velocity,[3] unless we relax our requirement that the universe be frozen. So we let it move just a little, resulting in our previously mentioned smear of a trajectory which will then allow us to measure a velocity and decide if it's going to convert into a helium or not. This is all nice and good, but if it moves a little then it's also moved relative to you unless you're in the same reference frame, and then the other hydrogen atom should be in a different place than you—and if they're both moving the same speed as you then they can't possibly be moving towards each other! As such there *must* exist some amount of space that the atoms move relative to you in order to make a measurement, and this space corresponds to a finite amount of time, which also corresponds to some space that you also moved during the time the universe was unfrozen, and if it's very far away on the horizon that means what we're looking for doesn't have a definite position anymore!

Think about that for a second. What was before a well defined position becomes not just a line in 3D space over some time interval, but depending on how your reference frame is changing as well, it could be a small 3D *surface*. And what's even more complicated is that your reference frame may not be moving in a simple way compared to the way the atoms are moving. What if instead of a simple continuous motion between reference frames they are vibrating in a complicated way? Now suddenly the "positions" that we need our atoms to be in are not only smeared out in space, the paths they might have traveled will start to overlap in complicated ways, and if there are multiple ways that hydrogen atoms might squish together to convert, the required shapes can start to look like a big fuzzy mess (see Fig. 2.2).

Additionally, consider the fact that as we *un*relax our previous caveat, or in other words slow the universe back down to a single freeze frame again, the certainty we had that our chosen hydrogen combination will successfully interconvert to a helium drops off as our current moment becomes more instantaneous again! This is the heart of relativity, but we're not done yet, because the main point is that this is an example of when deterministic calculations start to break down once we accept that we are always constrained to observe the universe, and all the stuff that's in it, and all the stuff that's ever happened in it, from inside of it, and the effects of causal

[3] Either mathematically, or via simple observation and measurement.

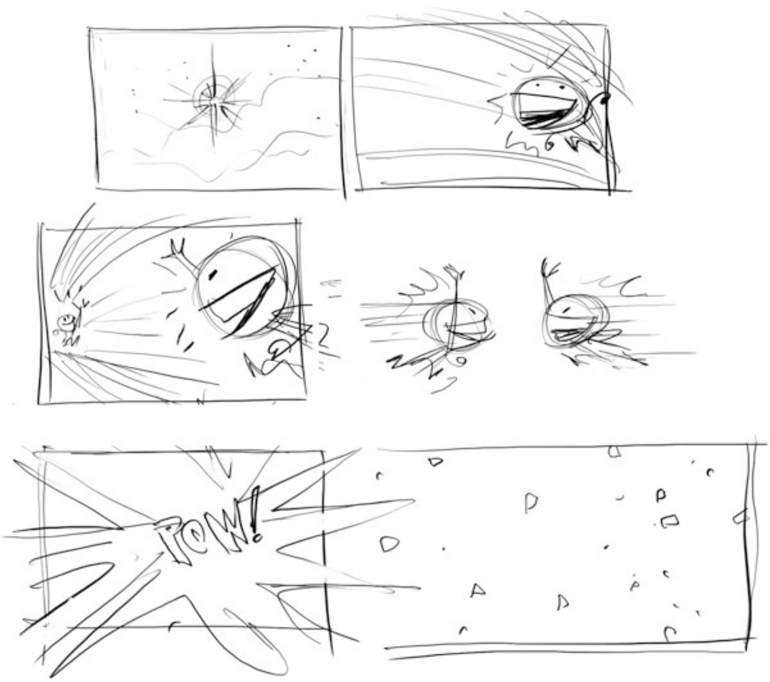

Fig. 2.2 Two atoms collide in a distant star

determination dropping off become more apparent the further out towards the edge we get.[4]

In other words there will always be issues with mapping an instantaneous measurement to another instantaneous event with reference to it, and this becomes more exacerbated the further things are away. To see this, let's add another layer of requirement. Now let's say we need to find *another* pair of hydrogen atoms which are also in the process of interconverting, and we want them to interconvert at *precisely the same moment*. It is impossible unless you are able to define a common reference frame, which is very difficult to say the least.

The take home message is this: even if it seems convenient to assume that the universe is all happening concurrently in a passive way, isolating and understanding how each event happens (which is necessary to engineer such events in the future) is very complicated and relies heavily on innate synchronization. The farther away from you such an event is, the less it is likely to be happening in a nice and neat

[4] Also, note that this starts to look *exactly* like quantum mechanics if you allow for lots of branches in your possible causally determinate moments between measurements, which is what the freezing and unfreezing parts correspond to. We're gonna come back to this and many other examples, but if you're seeing this, you're seeing the heart of how modern scientists are reforming their views of how things work.

deterministic way, or in other words, the harder it will be to say *after the fact* that you know precisely which hydrogen atoms were responsible for creating the new helium atom. In this sense quantum mechanics, coupled with relativity at distant scales, starts to look like more of an investigation into possible versions of the past that could have led to the present situation (see Fig. 2.1), than a more simplistic application of deterministic rules.

Quantum Galaxies

Let's take another example to drive this home. It can be seductively easy to dismiss the effects above, especially if deep down we just consider every chemical transition to be more or less instantaneous, even if that imbues them with a kind of magic we try to get away from in the sciences. Instead, let's consider something more classical, in fact something so decidedly non-quantum that it can't possibly be confused with a quantum object—say the formation of a galaxy. Not a general theoretical galaxy, but a specific galaxy, because we think it might soon give birth to a certain kind of star that hasn't formed yet, but there are really specific scenarios in which that kind of star forms, so I want to watch this specific galaxy and gather enough information about it to decide whether it is going to form this particular kind of star (see Fig. 2.3).

Let's slow down and make sure this comes across correctly. I don't want to know about some galaxy some other place that might be somewhat like this one, I want 100% certainty that *this* galaxy right here under my telescope will have this specific kind of star when I get there. A probabilistic framework will not work for me, I need to be 100% sure before I spend all the money and time to get ready to go there.

Fig. 2.3 The galaxy waiting to give birth

What if I can't wait until I directly observe the formation of the star via my telescope because if I do it will have burnt out by the time I get there? What can I do? I can gather precise real-time information about what's going on in the galaxy I have my telescope trained on, watching for the signs of the start formation and then run an exact deterministic calculation of the thing to be sure. How long do I need to observe it? What if I didn't start observing soon enough? Is there any way to calculate it out exactly?

No matter the distance that any galaxy is away from us, we can only observe it in real time. Even if we're looking further back in time to find a *different* galaxy that is similar, remember that I can't use that to guarantee that *this* galaxy, the one that I've been watching, will form the star in the same way, beyond a separate probability measurement. As such we cannot observe anything faster than real time, but we can simultaneously observe lots of events which are separated as different intervals in space and therefore in various stages of formation. This will never give us an exact deterministic calculation of the galaxy formation, however. In other words, things which are far away and wrapped in some deterministic set of criteria are therefore less and less local in terms of causal descriptions the further away they are. Isn't this is starting to sound a lot like quantum mechanics? Note, however, that the only thing we need for this effect to arise is the fuzzy descriptor for what is our causal constraint—we're not sure how much time we'll need to observe a specific event in order to ensure an exact result. This is the same thing for fundamental atoms which are just as far away from us in terms of time and the dynamics as the galaxies are away from us in space.

All of this cleans up nicely, however, if we abandon the idea that the universe is fundamentally deterministic, and instead realize that it is fundamentally *probabilistic*, where the deterministic version is more of a special case.

The Atom of Theseus

So what were the conditions we needed in order to make our fuzzy quantum-like observables pop up from a completely classical object? Distance, time, and fuzzy definitions of what things are. You might return to the earlier protest from Chap. 1, namely that definitions of atoms are not the same as definitions of galaxies, or stars, which are big complex systems. Atoms, you might say are very precise, so none of this actually applies right?

In order to move forward, we're going to have to rework our idea of what atoms are. Let's start by considering the ship of Theseus. In a nutshell Plutarch posed a question a long time ago about whether a boat with all of its fundamental components replaced remains the same boat or not. One might reasonably assume that the essential *boat-ness* remains intact, assuming all the new parts are identical to those they replaced, but it can hardly be said that the boat itself remains intact, or that it is the same boat. One of the difficulties in setting up a precise narrative history of the universe since the big bang and thinking that it should be precisely deterministic is that when it comes down to it, the atoms themselves are just as complex a system as the sun. They have life-spans, they are born and they die, and what's more is that they can swap parts when they interact with each other, sometimes jettisoning or absorbing other constituents.

In other words, if we had an infinite amount of time to wait and watch, we would realize that assigning intrinsic attributes to the atom is as difficult as assigning intrinsic attributes to something fuzzy and intersubjective, like a boat rebuilt with new parts, something that often happens to things like corporations or universities. Let's say, for instance, that I want to describe the amount of money that a specific university has, but I want to describe it as an intrinsic attribute, not a specific moment in time. I could say that it is *well off*, and you would understand what I mean. You wouldn't, however, then assume that they have an exact amount of money that isn't changing and corresponds precisely to the term *well off*. If, instead, we are interested in an instantaneous measure, the notion of the company being *well off* is no longer useful, especially if the university doesn't remain well defined with time. If the university has gone through many iterations through the years, say they had several names and invested their capital in different places, then a precise description of how much money they have becomes a constructed item as opposed to something we can passively observe. Pretty soon we're looking at a long spread sheet with footnotes, caveats, and fuzzy descriptors, where the length of the spreadsheet has to correspond in some symbolic way to the length of the lifetime of the institution itself, which also might not be a well defined item. It makes it even more difficult if later we find out that this particular university was the child of several smaller schools, or that it split into two different schools at some point.

As we saw before, fuzzy definitions like the intersubjective notions of a corporation or a university change on some timescale. So what happens if the lifetime of the attribute is on the same order as the timescale of the thing measuring it? This is what leads to quantum like indeterminacy, without any quantum mechanical axioms! So if we can argue that there's a version of describing an atom that is just as fuzzy as our definitions of corporations or planets, or galaxies, then we should also expect to see these strange indeterminacies. As it turns out, moving from an intrinsic definition of an atom to a fuzzy and hard to pin down definition of an atom is as simple as swapping its current existence with the narrative story of its lifetime, or imagining it as one of Theseus' ships.[5] A hydrogen could have always had the same three quarks, or it may have lost a quark for a while and then later gained a different quark again. Is it still the same hydrogen?

In fact, it becomes suspiciously important to note that even distinguishing between two fundamentally similar particles, say a hydrogen from another hydrogen, is prohibited when performing a calculation in quantum mechanics, and this is often used as a crucial aspect of how we perform such calculations. In a sense it is a fundamental requirement of quantum mechanics that *all* quantum mechanical

[5]Actually, there are several versions of this thought experiment. I could as easily have called it John Locke's sock, or George Washington's axe, or Jeannot's knife etc.

objects are no longer their original iterations. They have *all* been fundamentally obfuscated in terms of definition, and this obfuscation happened pretty early on in the universe.

In short, we cannot assign the simplistic picture where everything has a beginning and an end, and therefore a causal inference frame intertwined with it, to a universe that we are observing from the inside. As long as the universe is older than any observations of it, we cannot complete a precise causally deterministic description of it, because we cannot describe things which we haven't been observing since the beginning of time. We can only observe things in real time starting from the moment we start to know what to look for, and this ends up being a very real and important limit to how precise knowledge can be assigned to given scenarios, especially in quantum mechanics and cosmology. Oftentimes, the best we can do is assign probabilities based on inference calculations, noting that I can't say which electrons started out in which molecules.

Cracking a Marble

Let's take, for another example, the act of cracking a marble. To clarify, it's not that we want to describe general features of marble cracks, but instead to predict *precisely*, whether a given marble—not a generalized marble, but this marble sitting here in front of me—will crack when I do this or this specific action. This is what the precise engineered view of causal determinism requires. Can it be done? Can I decide that this marble will crack with 100% determinism?

Let's try it. One of the first things that comes to mind is that it depends largely on what the marble is made of. Maybe if we had a perfect mapping of where the atoms lie inside of it, with 100% accuracy, that would help us determine where the weakest point in the marble is. Conversely, there's a non-trivial and relatively complicated way that some set of applied forces would possibly converge into some geometric pattern, inside the marble, and this might be important in guessing where the marble will crack. So on one side, we can try to think of the point, or set of points where there is a preexisting crack or maybe some place where marble atoms didn't quite fill in a symmetrical way when the marble was made, and on the other side we have a set of laws describing how forces will propagate through the medium. If we had a perfect description of either of these things it would be useful, but in practice neither of the two are possible in all but a few special cases. The practical solution is to find some intersection of both approaches, which limit the probability that each will produce the correct result. These limited results can bring the resulting prediction to very high precision—if I know that both there is a weak point in the marble resulting from a defect while making it *and* I know that applying forces will focus them directly onto that spot, I can be pretty sure the marble will crack! This is the equivalent of folding a piece of paper and licking it before you go to tear it, ensure that a weak spot is preexisting, then apply the force along that preexisting weak spot in order to ensure a clean tear.

Note, however, that we failed to define a fundamentally causal description. The same approach won't necessarily work for some *other* marble, and it won't work for some other set of applied forces either, and we can always envision tuning our forces a little closer to the weak spot with more precision. No matter how confident we are, we're still not 100% sure it is going to work. The best we can do, and this image is going to come back to us later, is wait until *after* the thing cracked and then determine that it was our forces that did it.

Part of this is because the two simplistic images I provided above are not quite right. The idea that we could generate a map of the positions of all the atoms in order to start our prediction has some subtleties to consider. Say we were able to zoom in as far as possible on the marble with the best microscope available, to get to higher and higher resolution images of where the defects are. First, the atoms will not be sitting in one place, they'll be moving in complicated ways. Secondly, it's not a straightforward procedure to assign positions to the atoms themselves, and deciding how well each marble atom is holding on to its neighbor marble atom will require that we know the precise position (or wave function anyway) of the electrons, which is far from simple, and beyond the reach of the most powerful supercomputers in existence for anything more than a few dozen atoms at a time. There are simplifications we could make that would allow us to approximate the issue for a generalized set of marble-like atoms, but again doing it for *our specific* marble is largely impossible using existing technologies.

And that's just for determining the state of the marble before we've even tried to apply any forces to it! When we consider that it hasn't started cracking yet, the issue becomes even *more* complicated the moment we start applying forces and predicting how those forces will interact with the marble, and how some part of the marble will need to lose its cohesiveness and break up. In other words, during the cracking event, we're going to need some way to define what constitutes marble-like atoms in some way, and what is no longer considered marble-like (i.e., looks more crack-like) and identify those features, and how they interconvert, in real time.

Are you seeing the immense technical difficulties at play here? What's more, there really doesn't exist a good way to draw the line as to where there are atoms acting alone and where there is classical marble, and this is true whether you're a chemist, a particle physicist, or a mathematician, even if these three might disagree on what to call the lack of boundary.[6] So maybe what we're looking for, instead of a clean boundary, is a sort of gradual decrease in marble-ness and a gradual increase in not-marble-ness as we get closer and closer to being able to accurately describe the place that we expect the crack to first form.

[6]In case you think I'm exaggerating here, just be informed that there are very well respected physical chemists happily carrying the torch for arguing that the classical description of electric fields and their effects on atomic movements should hold all the way down to the nano-scales, especially in certain biological systems, and it is a matter of ongoing debate whether mathematics is capable of treating phenomena like this which reach across several space scales in small amounts of time.

But how would we do that? Is it possible to do without knowing that a crack is forming somewhere in the first place? Remember, we wanted to determine *exactly* not just where and when, but also *if* the crack would form. In other words, there are very good reasons that people studying macroscopic phenomenon such as cracks have a very difficult time theorizing about what those cracks should look like in terms of an axiomatic description involving atoms alone. All of them will concede that in order to tackle this problem, they take the initiation of the crack *at some point at some place* in the marble as a given, which is different from stating that *it definitely will crack*. A complicated process cannot be described entirely deterministically unless massively complicated initial conditions are supplied, like the fact that the crack already started somewhere in the marble, or we know all the positions of the atoms instantaneously.

It is true, however, that using a simplified model, i.e., one which assumes a clean causal event with a well defined cause of separation, can often be the most *useful* way to approach a problem, even if the model itself is akin to straight lines or perfect spheres. They are definitely useful as idealized shapes at large distances, but when we zoom in close enough we'll be hard pressed to find those individual attributes in any realistic system.

And that is the key. Engineer's can and do tackle these sorts of problems with great accuracy all the time, but they do so in probability space from very far away. They concede that they can't tell you exactly when or where the crack will start but that if you apply some amount of force for some amount of time, you'll see a broken marble, and that's pretty much all we need for everyday applications. The important point to take away is that by jumping in and out of probability space we can use idealized versions of our problems to make educated guesses at where and when things will happen. However, even if we can get those guesses up to very high accuracy, *we still don't have an exact precise understanding of what is happening*, even for something as common as cracking a marble. It's a lot like our thought experiment from the beginning of Chap. 1, where we noticed that there would be pieces missing from our view of the galaxy, even if we can make educated guesses as to what the whole thing should look like. Except now hopefully you see how the same issue applies to things which are very small, as well as very large.

2.2 Probability All the Way Down

Yet again you might reasonably ask what's the harm? What's point to all that marble-cracking stuff? Recall our nice and neat hierarchical pyramid from Chap. 1? The one where chemistry *reduces* to physics? What if, completely independent from the laws of chemistry and physics, some biological organism organized the atoms within in our marble in a way that allowed for it to crack in a specifically designed way? Where does that situation fall out of chemistry or physics? Sure the laws still apply, and there are certainly physical and chemical laws that can be used to describe the situation, but do the theories predict, based on fundamental axiom alone, that such a thing will exist in a specific place?

Basically, the issue we're running into here—namely that the mathematics have to be continually supplemented by initial conditions that are best treated in probability space, is one that has no bottom; it must be continually revisited no matter how far down (or up) the rabbit hole we decide to ascend. In practice, we can overcome these things because there's some degree of forgiveness in accuracy between each level. For example, in order to calculate the strength of an atomic bond, first we assume that for *an ideal version* of our two bonded atoms, there are a bunch of possible electronic configurations allowed to fit in between. There are an infinite number places the electron can be, even if the orbitals act as a sort of guide for the probability of the position of the electron at any given time, and the deterministic calculation becomes prohibitively expensive to carry out. You can simplify all that complication, however, by allowing the electron to move around with some predetermined probability (i.e. supply it with initial conditions), and then assign an *average* position to the electron which is what we'll use to calculate the strength of our bond. Note how it only works if we're interested in things which operate at long time intervals—like viewing it on temporal horizon as opposed to watching the electron jiggle from moment to moment.

So this is both the difficulty and the nice thing about how our universe works. Initial conditions are not guaranteed to be correct for your specific system unless you are directly observing the thing in question, always opening the possibility that you're a little wrong in your calculation. On the other hand, however, the chances of that happening are small if you know how to pick those initial conditions well—which allows us to move smoothly from level to level of inquiry. Note, however, that this requires that we be able to make independent measurements *at each scale*, which enables us to move between them, and there's no reason couched in the theory that any given observation may not have to be supplemented with more direct observation if you want more precision.

For example, what happens if we decide we don't need this process, that we're going to define something entirely in terms of things smaller or bigger than that thing? What results is a sort of categorical explosion of needed knowledge about each level of description, especially if you want to describe something even remotely complicated such as cracking our marble from earlier. If, instead, we assign reasonable initial conditions based on separate probability measurements, we can actually say something about the nature of those things at different scales, and note that this is akin to moving from the neat linear hierarchy of rules to a messier, albeit more accurate sets of rules that act independently at each scale and sometimes have intersections, as opposed to being contained within one another.

To be a bit more prickly however, it is interesting to note that all these things are common practice, often subconsciously, for our collective ontology. For instance, what kind of images are suggested by the values of commonly applied initial conditions? Even if we are tempted to use them as real physical objects, they don't represent actual physical objects—you would never be able to find an electronic configuration that corresponds directly to the average value we use for bond strength calculations, even if it is mathematically accurate! Much like using the existence of the rainbow to calculate the position of distant rain, we can say something about our surroundings without knowing precise position of the rainbow itself!

Let's put it another way. Isn't it true that many of the initial conditions we use in mathematical calculations end up being interchangeable with what we think things *are* in the popular conscience? A common example includes the perfectly useful view that everything is made up of atoms, each of which behaves quasi-independent of its existence in part of a larger macroscopic object. This is not the only useful mathematical view of how things are composed however, even if it may be the easiest for us to grasp today. Basically, we like to think of what things are made of because it allows us to easily imagine how to fix something were it to break—which usually requires taking the thing apart and then changing something and putting it back together again. This is an entirely modern view of how things work and it's really a baby in terms of its age. There are lots of perfectly legitimate ways of thinking about things which do not do this.

This is akin, returning to our example of the university from the previous section, to investigating the instantaneous amount of money a university has had over the course of its lifetime, averaging that amount, accounting for inflation, noting that that average amount is higher than the average amount that other universities have, and *then* referring to it as well off. Before we were pointing out that it isn't precisely true—now we're pointing out that even though it's not, it can be very useful and so we often do it subconsciously. This is okay as long as we don't go a step further and assume that it being generally true means you can assume an exact dollar amount and attach it to the school. You can use the precise description to assign an average, but you cannot recover the precise instantaneous measurement from the average.

Even if, however, we realize that some large portion of our ruptured hierarchy is necessarily missing big patches of information that we supplement subconsciously with idealized educated guesses, this shouldn't mean that there's anything fundamentally amiss with our tidy theory of a deterministic universe, right? We just need to make bigger and better and more precise observations and run up a very long laundry list of various initial conditions, and *then* our universe will be fundamentally deterministic right?

2.3 Tangling Our Hierarchies

In essence, this argument corresponds to a reductionist framework, which is often implied as the unilateral end-all theory of how stuff works. Basically it goes like this, if the measurements I'm using are not precise enough to describe the phenomena that I'm interested in (i.e., there are multiple solutions to the problem) what I need to do is drop down one level of inquiry and break up the current system into smaller units of observation. This is very much akin to realizing that knowing that a corporation is *well off* gives me very little in terms of whether I think they are going to buy some other company. I need to break up my average (whatever *well off* corresponds to) and go back and measure how much money precisely they have now and have had in the past in order to make my estimate about whether they're going to buy. Hence, we are *reducing* the measurement into smaller bits.

Here's what we need to keep in mind. Some things reduce in terms of composition—i.e. the instantaneous object breaks down into smaller and smaller bits, whereas some *also* reduce in time. In this framework we can say that things which reduce in composition but not in time are said to be, for lack of a better word, local, whereas things which reduce in both time *and* space we'll call field-like.[7] Things which are field-like are emergent in the way that the property only emerges if you watch things evolve in time as well as space.

For example, consider the tornado.

In one sense, you might think this is the poster child for reductive approaches. The tornado is clearly only made up of dirt, air, and water. What more is there to know about it? Imagine, however, that for whatever reason I have never actually seen a tornado, but I've heard about these crazy things and I am in awe of how much power they seem to have over those who have seen them. So I decide I'm going to dissect the next one that comes along, and come to understand it deeply, so that I can extract the essence of *tornado-ness*, and distill out these fundamental tornado-ness units, which I will then manipulate for my own use. I wait patiently until one shows up at my door, I get all my measurement tools, then I go out and start pulling the thing apart. At first I'm excited, there's so much stuff to measure! I discover dirt, water, air.....more dirt, more water, more air..... wait a minute, there has to be more to it than this. There's dirt and water and air all over the place when a tornado *isn't* here, this gives me no advantage, no good definition of *tornado-ness* that I can use to distill down into bit's of more concentrated tornado.

What's the deal? It's actually pretty simple—the essence of a tornado is not what it is made of, not in its fundamental constituents, not what it reduces to directly in space—but the actual value of the measurements, relative to each other, at different times. Its essence is found in reciprocal, hierarchical terms like *velocity, acceleration, and curl*. This is an example of when precise spatially reductionist definitions don't really work; taking an average, even a moving average of the air water and dirt positions will hardly give us back the *umph* of tornado-ness. The essence of the tornado is emergent, across time *and* space.

So, now, here's where things get weird, but hopefully it comes as a reward for making it all the way through this chapter. There are good ways to describe things like tornados or waves precisely in a mathematical context. Without going into details because the math is pretty intimidating, let's just say that in order to treat these precisely, we calculate what we call a wave, or something akin to a tornado,

[7]Just a note, however, even if this is how I'm using the term local in this book, the term non-local is reserved for some subtle things in physics and we have to be careful about when and where we use it. Generally, it's reserved for events which are proven to be neither correlated nor anti-correlated with events that should have caused those things, which has led to the popular notion that non-local things are "faster-than-light". I have some issues with this interpretation, mostly because the majority of us don't have a deep enough notion of light to evaluate a claim like that. For this reason I'm going to mostly stay away from the local vs non-local terminology in this text, but the way I'm defining field-like properties has to do with assigning labels to things which happen across time and space as opposed to just space.

but in probability space. It only works if you can measure all the air and dirt and water within the tornado simultaneously, and you measure all of it with reference to all of the rest of it across several time windows. We don't look at the total average, we drop down to a level somewhere in between where we're taking an average of a window small enough that it's still giving us useful information, then calculate the dynamics of those averages as if the averages themselves were a deterministic set of objects! We say, well look, if the average here is moving and it interacts with this other moving average, we can calculate how those velocities interact with each other, and the end result is a very complicated equation that describes how waves move around, without ever being able to say anything precise about the positions of individual pieces of air, dirt, or water! In my field we use this trick to derive fancy equations that basically tell you how to watch waves propagate through big groups of atoms, in order to pull out all sorts of neat measurements about that particular group of atoms.

Notice what happened though—we took our probability framework, and plugged it back into our deterministic framework and got something useful back out! But we said that's not allowed! We can't go backwards like that! In reality, however, we aren't going backwards at all, we're going out a step further in terms of abandoning exactly causal deterministic descriptions of each atom, but we've built a descriptor that is causal and precise and deterministic *in probability space*—i.e., we're no longer describing anything causal at all, except in the sense that probabilities can interact causally with each other! It's a neat trick right?

But all of this isn't really surprising per se, because we know that things like waves and tornados exist, even if it's hard to pin down a precise location to them, in the same way it was hard to pin down a precise decision for when to take off to visit a galaxy, or deciding that two hydrogen atoms will successfully convert into a helium atom while observing them from super far distances. These things are field-like, but mostly because the template we use to identify them is imprecise.

So what about something like a fundamental particle?

This is where things start to get *really* weird. If you apply the same methodology to atoms—namely not how they move in large systems, but instead look at predicting precisely when and where we will observe one, the *atom is the tornado*. Mathematically, or in other words in engineering kinds of approaches, if I put together a bunch of fuzzy imprecise definitions for when and where the atom will be, I can describe it very well based on the approach mentioned above, watching probability waves knock about and interact with themselves.

But aren't electrons both waves *and* particles? Yes. But I find that it's generally not explained correctly. It works like this. If you measure a particle, it was a particle. If you even detect it at all, then it was a particle in the normal sense of how particles work, like a tiny grain of sand that hit a screen and left a dent. A particle like that.

If you try to guess where the particle *is*, however, you will measure waves. In other words, if you measure the particle over and over and start adding up the probability of finding it in a certain place, you will uncover a wave! The particle itself is never both, it's just that we cannot predict things about it at any given time or space interval until *after* you successfully measured it.

Is this starting to sound like the discussion of our marble crack? How we couldn't really set up the math in a way that could predict the exact position of the marble, but we could definitely trace it out after the fact? Additionally, just because if we repeated the marble cracking experiments and eventually found that we could uncover something neat about the intrinsic properties of the marble, something that might even tell us about the narrative history of making that marble, we'll never be able to predict the exact location of a future crack beyond probability, and if you add up all the competing probabilities and map them out in the marble, you're bound to get something that looks like a wave!

What does this mean? First of all, it means that the existence of an electron, or a proton, or whatever, is not *only* determined in terms of things smaller than it, in the way we're used to thinking about things. It is *also* determined by things larger than it!

This is kind of like having your favorite camera and asking two very distinct question about it. One question, the classical reductionist question, would be to ask if it can take a certain picture *now*. The answer is related to which parts are inside the camera currently and whether they can handle the situation you are asking about. The solution can be achieved by reducing the camera into its fundamental constituents which are then combined in an engineering kind of description to decide—yes, the parts will function normally in these conditions, or no, they won't. Moving to a field-like description would be like asking if the camera *could ever* take that picture. The solution doesn't reduce only in space, namely the fundamental parts it contains currently, but also to a funny sort of time-dependence, where you could ask, "is it possible to track down the necessary parts, and if so, could I integrate them into this camera without the camera turning into a fundamentally different camera?" Notice how I can't say anything about when precisely it will take place, only that it could, and the probability of it happening goes up the closer the necessary parts are to the camera. Or, conversely, what if I said that the picture had *already* been taken, and now I'm asking if it could have been taken with *this* camera? We get the same result! The answer is a field-like response, i.e., it is smeared out in a quantum kind of way depending on lots of intersecting causal pathways that are necessarily obfuscated.

When we measure wave-particle duality, this is what we're measuring. There was a particle, could it have been here? Or here? Or maybe over here? The answer is yes for multiple positions, and no for multiple positions, and if you add up where all those positions are or aren't they fill the space in exactly the same way that waves propagate through mediums. But you can only say that *after* you've found a particle a bunch of times, and this tells you nothing exact or deterministic about where it's going to be the next time you find it. It's not a wave of particles, it's a wave of probability, and the probability tells you about where the particle *could have been measured, were the attempt made*.

In order to drive this all the way home and spell out the consequences, however, we are going to need to tackle a bunch of other concepts first. We're going to want to come back to it however, so let's give it a name and call it the *head swivel*. Instead of continuing to lean on a nice reductionist framework, where we usually drop down to a smaller set of fundamental subunits in order to get more precision, we now realize we have to adopt a slightly different view of how reality is set up. We instead try to understand the behavior of atoms by treating them as indistinguishable from the forces that sink down into them, combining mysteriously and doing an unexpected dance, where the shapes of that dance correspond to how electrons and protons move around and interact with each other.

In other words, if you really want to understand quantum mechanics, you're going to have to change the way you think about how causality operates at small, fast scales. Instead of looking for the causal nature of atoms by breaking them down into their constituents, you're *also* going to have to look over your shoulder, finding the source of certain unknowns up behind you somewhere. Only by doing that will you be able to pin down the place where the event was actually caused, and even then it's not going to feel like the same kind of calculation you are used to. Imagine you have an object in your hands, and when you pull or push on it, part of the ceiling up above your head *also* moves. And it continues to do so every time you push or pull, even if the relationship between the kind of move happening in the ceiling and the kind of move you impart on the object is not at all obvious.[8]

Again, we'll come back to all this. As we continue down the path, however, note that by the end of the discussion we'll have developed ways to talk about atoms as both capable of clumping together into classical stuff, and also be classical stuff that breaks down into atoms, and we'll be looking for ways to talk about that process as it accounts for *all* the properties we see in atoms. Only when we can carefully articulate clear descriptors at these scales and how they are related can we talk confidently about what atoms *are* in a meaningful way, and we have to remember that what we're describing will be field-like, in the same way that the tornado is field-like.

[8] And later you realize that even though you aren't *causing* the correlation to happen, it will always happen anyway because it turns out that no matter how clever you are, you will not be able to devise a way of pulling or pushing on the object that *doesn't* correlate with the ceiling also moving. That is what the universe requires in order to push or pull this particular object, but the reasons are only apparent in the end limits of observations, like a horizon or a rainbow.

Chapter 3
Narrative Space

So now that we understand something about probability and the distinguishing between things which have been *determined* and things which have been *predicted*, we're now going to do a funny kind of about-face. In the second chapter we showed how things can be determined, in the classical sense, entirely in probability space. Now we're going to turn around and ask which, of all possible probabilities, are the probabilities which are allowed to be determined?

Imagine you are a water molecule out in the ocean. You stay in one place more or less, even if you are continually smacked around and jostled in no particular direction. This is similar to what happens in the middle of a crowd of people, all of which are busy going about their own business. You are jostled around continuously but there's no real rhyme or reason to it.

Now imagine that, out of nowhere, a wave comes by. What does it look like to you, who are trapped *inside* of it? You won't necessarily know where it started or where it will end, but it is definitely something you can pick out—whereas the motion around you before the wave was random, your motion during the wave will momentarily *not* be random, you'll do a kind of rise and fall, even a little back and forward motion, all in a smooth way. What's more, you note that after it passes by you are still more or less in the same place! How do you recognize that it was a wave and not more random motions? Not because of any of the individual motions taken alone, especially considering that any of those motions were equally likely—remember that water molecules were already smacking you around in a random way—it's more that *taken together* all the motions are rather unlikely to witness. It's in the *sequence* of motions that allows you to note that something happened, even if it didn't happen *locally*. In other words you can deduce that something was determined entirely based on probabilities!

That's another neat trick right? This trick is particularly useful in terms of deciding when and where things like waves have happened, even if they can't say *what* happened and only say *that* something happened. The point is this—we know

G. Bascom, *On the Inside of a Marble*, Astronomers' Universe,
DOI 10.1007/978-3-319-60690-3_3

that something, somewhere, moved in a way that caused the water box it lived in to reverberate with its motion—and that motion traveled a long way to reach you. What can we know about the source of the wave? What can we *not* know about the source of the wave? What's more, will the hypothetical sources that are *not* possible contain a list of constructed objects? In short, in the chapters that follow we'll see that if we allow ourselves to move into probability space for the solutions to problems, most notably attempting to try and decipher classically determined stuff *in terms of probabilities alone*, we have to move into a constructed, imaginary space.[1] We have to ask ourselves, *is it possible*, fundamentally, to construct motions that would be indistinguishable in terms of what I measure locally, back at its source?

The answer is yes, such a thing is possible, and it has everything to do with our discussion on hand. So what can we do with them? What we can do is we add up all the motions, all the possible *obfuscations*, if you will, and then ask which was the most probable! You can see why this stuff is sort of dizzying right? We started with something observed entirely in probabilities, used that to determine something *causal* that had happened, and realized there are multiple versions of the causal narrative that could have led to our observation, and then employed our tools from probability analysis to resolve which event was the causal culprit, which landed us back in probability space! In short, the interplay between probability and determinism keeps getting deeper, but that's a good thing because we're going to use it to redefine some of our more basic concepts, like space itself.

3.1 Discontinuous Space

You may not have a hard time understanding that time can be subjective, but what about space? As weird as it may feel, there is a way to look at *space* that is similar to what we just did in the introduction. In the same sense that normal physical objects like waves are causally determined and integral to the classical way of thinking about things, there is an analogous, constructed version of all the classical properties, space included, that can be fiendishly difficult to wrap your head around and yet still imperative if you realize that you are trying to determine a thing in a field-like kind of way. Just like there is both an author and an engineering view of narratives, and there is an inside and outside view of spatial objects, there is another set as well, namely there is both a causally determined way of describing classical objects *and* some number of probability based field-like descriptions. To be honest, you likely need all six to fully understand the thing you're looking at, especially if

[1]Yes I mean imaginary in the complex sense, but also in the sense that goes with common vernacular.

you're trying to understand it in the context of a universal system of laws.[2] In other words, space itself can be re-envisioned as a constructed set of *possible* reasons things could have failed to interact with any objects that move through it, and that's just as important a way of thinking about it as simply thinking of it as a passive lack of matter. What's more, these constructed objects can be either real or *imaginary*, imaginary in the sense that they are constructed and to a degree intersubjective.

Let's set that aside for now, however, and move back to our more comfortable, classical, way of thinking about things.

Consider a completely deterministic object that is a closed system. There are some important effects to consider when we treat things this way as opposed to a bunch of fundamental constituents that are only deterministic locally. We've already begun to work with this idea several times in the second chapter, especially the marble cracking thought experiment. To fully understand the act of cracking the marble, we should think of it at least partially as a closed system during the initiation of the crack, where vibrations are barreling down through the thing and reflecting off the boundaries.

To spell this out a bit more, imagine that we tried to crack a giant marble with a tiny hammer. Will the initiation of the crack be in the same place that the hammer struck? It could be, or one can easily envision a wave moving out from the place where the hammer struck, running down along and the marble and reflecting off its edges. What if we sent several of these taps, in rapid succession? And we continued to do so for hours, days, months?

Now contrast this with a different scenario—imagine a tiny marble and a giant hammer that we strike very hard and shatter the thing all at once. Isn't it even harder to know where the crack will form initially?

What we're uncovering in this situation is a kind of harmonious interaction of different properties intrinsic to the *system* of the marble, arising from the geometric symmetry of the object and the way it depends, in a funny sort of way, on the timescales of the forces interacting with it. There are very well defined patterns, patterns where waves would propagate with different probabilities, much the same way our tornado rides on the back of the valley it originally forms in. These patterns only arise as emergent phenomena, they are not local to the individual constituents that make up the thing, but instead demonstrate potential properties of interactions of waves moving through it. The same thing would happen if we had any sort of symmetry, say a glass cube or a pyramid, or any closed shape at all, but the intrinsic patterns of how waves propagate through each shape will be drastically different.[3]

[2]Remember we introduced the term "field-like" as a proxy for non-local late in Chap. 2. We're sticking with it because it's still not clear whether space is fully quantized, but the important thing to note here is that we're going to build a description of space that is imprecise and field-like, allowing for it to be referenced as a semiotic as much as an actual physical measurable thing, and that's imperative for our discussion to move forward.

[3]Just a little extra to explain where we're going with this—say we set up a computer simulation that chose at random, some closed 3D shape and then sent waves propagating through that closed shape, and then simulated some marbles moving around in that shape, interacting with said waves.

Furthermore, note how something nice and continuous, namely a normal classical object, can produce features that are discrete and discontinuous if we move into probability space, and there's still nothing quantum mechanical going on at all.[4] In fact, the resulting frequencies of waves that will be sustainable and waves that will not be sustainable correspond to the intrinsic harmonics of the object—and they are discontinuous. You can hear them for most objects if you vibrate them in a way that amplifies these waves, which is what tuning forks do. They utilize the intrinsic properties of the shape of the object such that waves that can exist inside the object correspond to a desired frequency. Note that you can't necessarily change the frequency that the object vibrates at by hitting at different frequencies, the only way to change the pitches observed in these cases is to change the shape or density of the object itself—aka the system as a whole.

More importantly though, let's note again that the frequencies allowed by such closed systems are *not* continuous. They jump discretely from one frequency to the next, and often those frequencies repeat in the sense that they fit nicely inside one another, which is what we call harmonics. This is a normal thing for periodic functions, and any musician is likely comfortable with the idea, but how does it fit into our discussion of the big bang or quantum mechanics?

Is the big bang a closed system? Does it have some shape that leads to a set of naturally resonant frequencies? Do fundamental particles also have such natural frequencies? The answer is yes to both, but we have to be careful, because each lives in a different space, where one is observable in the natural way, and the other only exists in a constructed sense.[5] In the case of the big bang the harmonic frequencies arise in the narrative version of what happened, and they can be measured by looking out into the farthest reaches of the universe. Fundamental frequencies of fundamental particles, however, live in the future, in the sense that we can only see them if we hit them with other forces and then measure how they ring out. It's kind of like saying the big bang is in the *act* of ringing and fundamental particles *will* ring when we smack them with tiny little hammers.[6]

Then say we had the computer change the shape of the box as often as it updated the positions of the atoms. You would get marbles moving around the way quantum objects move around.

[4]We could argue that in fact these things arise from the discontinuous reflections of the waves off of the boundary, which only really arises due to friction, which could be considered in part a QM issue, but suffice to say that waves and interference are widely considered classical phenomena.

[5]Much the same way that our wave, in the beginning of this chapter, was observed directly and the possible sources were constructed and weighed against possible obfuscations and eventually chosen based on probability—but constructed, not observed.

[6]Check out the book by Amadeo Balbi *The Music Of The Big Bang* for a good outside popular science source on the fundamental frequencies of the big bang. After looking at the actual frequencies it really does start to look like someone rung a giant bell—but a really deep crunchy kind of bell. The big mystery, however, lies in how each fizzle and pop within the crunch led to the fundamental particles and eventually galaxies that are here today, which we'll talk more about in Chap. 6.

This denotes that, in some way, we should be able to think of the big bang as a closed system, something that was once rung like a bell. One of the key features of the modern view of our big bang, and more specifically the linear narrative view of the cosmos, is that it cannot be the same density, size or shape in every direction, particularly at every age, which is the same thing as stating that it has features which are distinguishable in some way through time. We haven't yet discussed where and how we observe those differences and how they play into the history of cosmology as a discipline, but suffice to say that at every point, everywhere, there is a quiet ringing, and if you map that ringing in every direction with ultra high precision you will find that it is not *exactly* the same in every direction. There are very small differences depending on which direction you point your sensor and these differences correspond to the fundamental frequencies of the big bang, along with the oldest, loudest sounds that has ever been recorded.

And it lives, as hard as it may be to grasp, in empty space itself. So maybe we should go back and talk about empty space for bit.

What is your concept of space? Is it something that is smooth, homogeneous, and passive? Like a big giant tank of water that is perfectly still? Often times we think of space as the opposite of "stuff" i.e. the inverse of the item, or the thing that the item is moving through. In reality, however, space is very difficult to define, and often it is easier to refer to it semiotically, namely in reference to changes in what we expect it to do, as opposed to any intrinsic nature. This is precisely what we're doing when we talk about space-time in special relativity. We realize that the way we define space in a system where everything is moving cannot be untangled from the way we define time, and as such there are certain dilations, or stretches, that occur when we reformulate the semiotic system to take them into account.

Is this a difficult thing to grasp? It should be. Time and space are some of the only things that are *not* supposed to be a semiotic, they are background items that are always there and always steady. Unfortunately, as it turns out, this isn't true. One of the hallmarks of modern physics is that time and space must be thought of as something defined by convention as opposed to independent of our interactions with it.

Which is kind of like saying that, at the root of things, space and time are like money, and they can become tangled solely based on how you define them. Imagine that we belonged to some closed group of people who had worked out our concept of money with our own defined units and values. Then one day we discover that some *other* group of people have their own money system, with their own value and currency. Pretty soon some politicians are arguing that we should be trading with that group, but that in order to do so we're going to have to start accepting their money as well as our own. Now, suddenly, something has changed intrinsically with how we are valuing our currency—it no longer depends on our own stock of items alone, but also on how much this other group values our currency as well. Everyone over there is suddenly watching the value of our currency as much as they watch their own, and *their* proverbial gaze has an effect the value of *our* money as well! Predicting the value of *either* currency from moment to moment just got a lot harder, and we could now say that our currency has become *hierarchically tangled* with their currency, which has its own agenda, semi-independent, tangled with our own.

As hard as it is to wrap our collective heads around, this is what happens with time and space in relativity. Space, at any sort of appreciable distances, which by definition includes very small scales, is really more akin to something like a money system, used to keep track of how things should appear to be moving based on who is doing the observing. It is assigned to be all the hypothetical stuff that doesn't, or didn't, or won't, interact with objects, but still needs to be kept track of in order to affix the correct vantage point in our minds eye.

Remember our analogy from Chap. 1, where we asked what would happen if we had a book written in our normal language but we moved backwards in time, having someone read it at regular intervals? If space is actually something that is defined in reference to other items, it should also suffer from this phenomenon, but not only because the reference and the referent aren't perfectly designed to span the ages, but also because sometimes you can have perfectly balanced forces which lead to zero, and no interaction that will occur, even though multiple waves were present.

Let's return to our topic involving waves out in the ocean from the beginning of this chapter. What if, instead of one wave moving towards you, there are two waves, converging from opposite directions, hitting each other right on top of you? Is there a point, somewhere in the middle of the two waves, where you would never see the wave colliding on top of you, and never even be aware that it had happened, even as the waves collide and pass through the point? Does that mean that the waves are indistinguishable from space at that point? Could it be that our universe is similarly poised between two whips cracking on the same point, like in Fig. 3.1? If that were the case would we be able to tell?

This is particularly important when we consider that there is a whole world of things to measure when we employ our trick from last chapter to re-envision how our universe is laid out around us, namely moving into a constructed probabilistic framework. We can measure things that are happening in the direct, normal way, and then we can measure things that are happening deterministically in probability space, and we find that waves are everywhere! In fact literally everything can be re-envisioned as some sort of wave with momentum springing spontaneously out of the big bang. Every particle is, in certain senses, just like a tornado that got started a really long time ago. Additionally, if we note what happens with horizons and how they tend to distort things, which we'll talk about next, we realize that all the sources are jammed together into one loud complicated clap we call the big bang, and the whole thing starts to seem indecipherable. Then we start adding up all the waves we can find and try to book keep when and where they all started, and we realize that for many waves, including those that live in probability space and describe the places where we might find a fundamental particle, go all the way back to the big bang, where the precise location of the original starting point can't even be inferred, because multiple waves may have been started at the same time and place!

What about empty space? Even if it's empty for us up here in a classical world, is it impossible that it is imbued with energy leftover from the big-bang, and is itself not at all definable as the smooth continual homogeneous lack-of-stuff we like to think of it as? The modern view now developing is that it is a seething, boiling cauldron of perfectly balanced forces and waves that add up to about three degrees kelvin. And all those roiling, boiling waves are essentially the quiet roil of the aftermath of the big bang, the internal crunchy frequencies that keep ringing as the big bang recedes.[7]

Note however, returning to our example from the middle of the ocean, that if we were careful enough, there *may* be ways to detect that unseen waves are moving through us. For example, if we were to push ourselves out of the center of the two crests just before they meet, we should be able to detect the deviation, however small. This is what we are doing when we smash particles together in giant accelerators, observing very tiny and very fast deviations from the classical behaviors where atoms are stable and don't fall apart, in order to further develop our modern theories that we've been discussing.

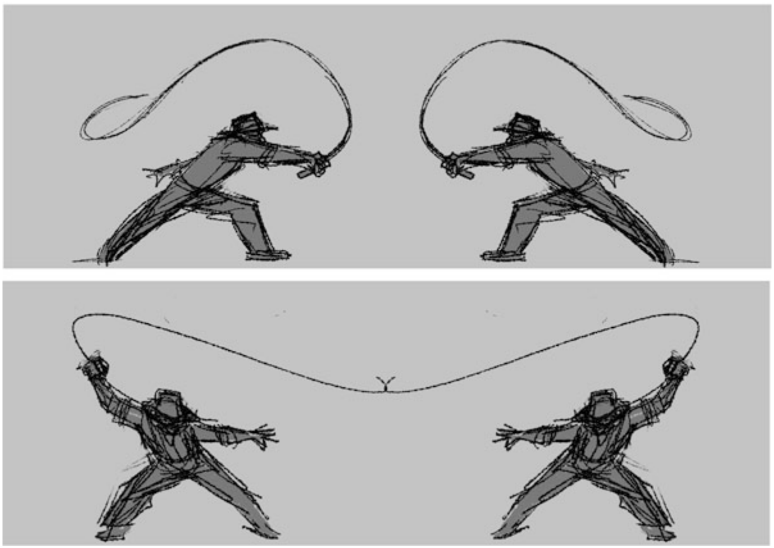

Fig. 3.1 If the universe were stuck in the exact center of two colliding whip cracks, would we know about it?

[7]Anything that's *not* empty space now, on the other hand, is the stuff that kept on howling down in probability spaces closer to us, with much louder probability waves.

So, oddly enough, when we talk about space, in the context of a semiotically defined set of descriptors that include the effects of the aftermath of the big bang, is when we get to talk about atoms and how to crack them open. In order to see this we'll note that the modern view of empty space is anything but a smooth continuous function, even if it is that at classical scales. As we go from macroscales to mesoscales to microscales, space becomes continually more disjointed in terms of how we describe it.

3.2 The Temporal Horizon

Now let's set aside the discussion of space as a local phenomenon, and discuss what it looks like *across* scales. We've seen how things which are well defined locally can be difficult to define when viewed from far away. Not only is this a real and important effect for spatial measurements, it is also true for temporal measurement, especially for atoms. Many of the measurements we make on atoms are only real in the sense that they can be viewed from very far away.

This doesn't mean that they don't exist, however, nor does it mean that we get to dismiss them. It's better to say that the existence of atoms, or the attributes we get to assign to atoms, is something a bit more complicated than what we're used to. In fact, subtlety in the way we define what does and doesn't exist is fairly common in modern analytical sciences, and cosmology, as well as quantum mechanics, is no exception.

Take for example, the cosmological principle. It is one of the fundamental axioms of modern cosmology. It is a given. You take it on faith as a fundamental requirement for everything else to work out. What it states is that the universe is the same, everywhere, no matter where you look, even though we've spent the whole book convincing ourselves that the past is what is physically out in the distance, that the instantaneous picture of the universe is anything but homogeneous. The trick is that what we've been discussing so far only applies to what we would directly observe *from our perch down here on earth*, not what we would find if we actually went out there to measure it from up close.

In other words, if we got on a spaceship and started flying around the universe and mapping out the structures, what would we find? More universe! It would just keep going, more and more of the same, more planets, galaxies, etc. If you went out far enough and took large enough measurements, it should all come to a smooth measurement that isn't changing; you will measure a constant density, with uniform stuff distributed uniformly. Remember in our first chapter, the analogy of noting the invariance of cubes and spheres by touch alone? This is essentially what the cosmological principle states, that where we to have giant hands that could interact with the entire universe simultaneously, we would note the invariance, like a cup of water than has been left out to settle. This is in contrast to only interacting with something sequentially as you do with your eyes, and the shape of it is therefore subject to the angle at which you are viewing it, which you note by watching it shrink down to a point on the horizon as it recedes away from you.

Which brings us back to horizons. Have you ever realized that straight lines are actually pretty hard to find in nature? In the same way that rainbows cannot be viewed from up close, neither can the straight lines of horizons. If you are tempted to simply dismiss the effect as an illusion, be careful because they are definitely real and measurable, it's just that they are only real in the sense that they emerge from the entire system interacting with itself, much the same way our tornado is real, even if it is hard to pin it down deterministically to a single moment in time.

Now let's extend this to time; there are not only spatial horizons we should consider, but *temporal* horizons as well. The temporal horizon is what happens to time scales as we measure objects from very far away in time scale. It can be difficult to envision, but in the same way that a rough ragged mountain can appear as a clean triangle at great distances, the causal narrative, or amount of time something takes to occur, can also change in subtle ways when expressed in measurements very much larger than it.

The temporal horizon doesn't act quite the same way as the spatial horizon, however. With a spatial horizon, individual objects seem to shrink into a point, or a set of points, as one recedes away from them. While you recede away from a temporal horizon however, i.e., start moving faster and faster, things seem to freeze in time, slowing down until they don't move anymore.[8]

So, when we actually *look* out at the big bang, as opposed to going out there and palpating it so to speak, what do we see? We see that all the spatial stuff has collapsed to tiny points, whereas all the temporal stuff has slowed down to a difficult to decipher long-drawn out kind of crunch that is still crunching 14 billion years later. One of the main points we have to remember, however, is that while it is tempting to assume that the narrative that lays itself out to us as we look backwards through the universe will be something simple and linear in time, it is actually a little more complicated than that.

In fact, one of the fundamental requirements of our narrative view of the cosmos is that it must maintain a certain level of indeterminacy, or none of the math can work out. Basically the story goes that some quantum fluctuations led to some soft spots and some hot spots in the primordial soup, which correspond to what eventually became matter and galaxies and what have you. Do you notice, however, that this is a decidedly deterministic thing to try to wrap your head around? Our deterministic heritage, so to speak, that runs backwards all the way to the beginning of time must *also* must retain quantum indeterminacy to make all the engineering types of math work out. Can you see how this is sort of like wanting to have your cake and eat it

[8]This is a difficult point to make but it is going to set the tone for why everything gets inverted from large to small, why light can reflect off surfaces, why friction exists, why all sorts of stuff happens the way it happens, so take a moment to really try to understand it.

too? We want the universe to be fundamentally deterministic, because things which are classical are fundamentally deterministic, but that requires, *a priori* that there is one single observable universe that is discernible and well behaved in time, but we *also* must oblige that at least *some* part of that determined narrative has to be *un*determined or we can't fit all the mathematical puzzle pieces together.[9]

So what do scientists do? They attempt to pull it all apart, to deconstruct it so to speak, much the same way we deconstruct our regular classical problems into nice deterministic puzzle pieces that actually ride on the backs of probabilistic stuff. They look at the data and build theoretical, generalized versions of what the universe could have looked like and then say okay, what we *can* know must correspond to palpable stuff that's around now, aka matter, and what we *can not* know but can see must correspond to quantum-like, undetermined stuff. Note, however, that there has to be quantum like stuff as big as the universe itself in the early universe, to make even the most deterministic parts work out.[10] What's more, the deterministic stuff is mapped *directly* onto the indeterministic stuff, in a rather uncomfortable way. For some reason we are allowed to determine things in terms of undetermined things, but not in our previous probability collapsing into measurement situation, this is more of a narrative kind of phenomenon. We watch, directly, deterministic things (stars) evolve out of a soup of indeterminate things (subatomic nuclei)!

Why do we get to do this? In part it is because of the temporal horizon effect. In this view, we abandon the idea that there is a clear and clean beginning where things were indeterminate before and suddenly are entirely determinable after, and we instead imagine that there are giant, loud, *incomplete* motions still determining things happening in the primordial hot spots, even if from our perspective they appear to be moving infinitesimally slowly.

Does this mean that there are ways to trace down that uncertainty all the way across the causal stream and imagine that there are things we should be able to tap into now, that should also have some internal indeterminacy?

Yes and no. In fact, it's really not clear how these two things interact and how the schema for tracing these things will spell out. What we *do* have, however, is a very clear place within our methodology that corresponds to mapping indeterminable stuff directly onto causally determined chains, even if they are going to take a few more chapters to explain.

We can start, however, by talking about imaginary numbers.

[9]For more on this, it was Stephen Hawking who showed that quantum indeterminacies could save the standard model.

[10]Without going into the details, this is where Alan Guth's theory of inflation comes in.

3.3 Imaginary Obfuscation

When we look out into the past and try to map what we can and cannot see it all makes sense in the normal classical way, as long as we allow for some indeterminacy, as we discussed before. This may be because we just haven't looked hard enough, right?

Wrong.

There are things we can't see, and never could have seen, and never will be able to see, because they haven't finished happening yet. The loud crunch is still ringing and some parts of that crunch are deterministically intertwined with what we see when we look down into the very small. Let me clarify though—it's not that we're looking through microscopes and notice that it is difficult to make out certain things, it's that we are iteratively combining the most fundamental rules—the axioms with the most promiscuous natures we can find—with the most fundamental situations that exist and then asking, very meticulously, what happens when we trace out what basic operations look like in causal space? What does it mean to rotate, translate, or dilate (aka stretch) the *act* of determining some part of the story of these fundamental scales? What we find, amazingly, is not only that these operations cannot be fully understood at very small scales without specifying very large amounts of initial conditions,[11] but also that these operations depend on stuff happening concurrently that we must specify *always*, which started from the beginning of time. Not only is there stuff that happened so long ago that it is hard to grasp, but there is stuff that has been *in the act of happening* since the beginning of time and there always will be, and these things are, as we'll see in a bit, what we typically think of as sub-atomic particles or fundamental forces.

But before we go too deep into that—let's explain again what we're doing. We are asking which of all possible operations, like bend, stretch, translate or rotate, that *can not* be distinguished from one another in a local narrative no matter how we construct clever operations that should untangle the mess we observe when we hit atoms with tiny little hammers and they break apart. The trick is embracing the unknowable tangles and giving them names and then moving forward, even if rather brazenly.

In fact, this is exactly what imaginary numbers are. If you take a number and square it, you get something positive. For all the numbers we can think of. So what happens when you try to go backwards? You can't! There are no numbers, *in existence currently*, that can square to a negative. So let's imagine that we could make one. And give it a name. And move forward. There you go, we've imagined that we've made a number with a special property. When we describe physical

[11] For more on this see Chap. 2.

phenomena with it, we are no longer describing a space that is in existence *currently*, we are describing a space which *could* exist, given our criteria were fulfilled. This is what I mean by brazenly accepting and labeling the tangled causality and giving it a name and moving on.

In a way, it's a lot like realizing that given only an average measurement of some system, you cannot know the individual measurements that result in that average. What we can do is just assign a symbol to mean "whatever individual measurements average together to this number" and move on. If this makes you uncomfortable because that information is technically not recoverable, just remember it's only not allowed if we are constrained to stay in casual space, and there's no reason we can't *construct* one of many solutions, even if it's just a proxy data set. There's no way I can determine exactly what the precise numbers were, but if I relax my requirements to be probability based then I can easily build a whole set of candidates that fulfill my requirement.

In case that explanation isn't very satisfying, though, let's draw another analogy, this time with negative numbers. These were very difficult for mathematicians to accept initially, mostly because they live so far out in abstract space. You can't have *negative* three apples. You can construct a hypothetical number and then impose the conditions we define, aka if three apples ever show up you take them away, but there's no actual physical thing that *negative* three apples corresponds to. The negativeness of the numbers is not physical in nature, but it is *intersubjective*, meaning that we can universally decide how to treat it and then move on. With imaginary numbers we're doing the same thing, but we're imagining a number which we construct which allows us to multiply two negative numbers and get a negative number back out. If you are still protesting that you cannot think of a situation where this happens, don't worry. We are going to build some, but they are going to take some elbow grease before we can get there.

Accepting that they can exist however, even if we're not totally comfortable with what they look like physically yet, allows us to fulfill the requirement set up at the end of the last section. Such a thing—namely a way to map undetermined things directly onto causally determined chains—is achievable by brazenly labeling this spot as untangle-able by currently known mathematics and moving on. In fact, let's name them *hierarchical knots*, because they are tangled in the way that Escher's hand's drawing one another are tangled. Even though they make your brain hurt and are only apparent when mapping multiple scales onto each other, they can and do exist when considering temporal, and spatial, horizon effects, even if they are not palpable in the sense that rainbows or horizons are not palpable.

This, to introduce one of the more technical terms, is the group of operations that spinors correspond to. Spinors are what we call it when we imagine a seemingly impossible rotation, one that is tangled hierarchically with a translation. They have been called the "fundamental unit of geometry," or even the "square root" of geometry,[12] and it is exactly akin to an imaginary number. It is an imagined operation, a seemingly impossible chain of causal manipulations that engineers a simultaneous translation and rotation.

Let's call this our third trick. It doesn't have anything to do with probability yet necessarily, but I can tell you now that when we combine it with our probability tricks from earlier and a few more we're going to develop in the next chapter, we can actually build, amazingly, a working model of particle physics that is integrally interconnected with the big bang in real time. All the fundamental particles, as it turns out, seem to live in a world where translations are fundamentally tangled (in *causal* space, remember) with rotations.[13]

Finally, graciously, here's where we get to have something systematic we can use to order or cognitive broom closets, which we've largely been lacking until now. A fundamental particle who's existence is tangled hierarchically in causal space between a translation and *no* rotations is a Higg's boson, with a *half* rotation is an electron, with one rotation is a photon, and with two rotations is, hypothetically, a graviton.[14]

Okay, maybe that didn't actually help as much as we would have liked, but you can take it on faith that the folks at particle accelerators are dutifully putting together these kinds of trends in order to build a consistent, albeit furiously complicated, set of rules which will allow us to characterize all these fundamental tangles and map them to seemingly fundamental quantities like charge and mass.[15]

So let's ask again, what does any of this *physically* correspond to? Mostly it doesn't! Instead, it's saying that *were* we to engineer a fundamental particle, just like in engineering a tornado, we could not do it entirely in a local space. In other words, doing it for a tornado on the first try without knowing anything about the valley you are doing it in would be impossible. What we can tell you, however, is that in trying to cause one of these things, or in other words trying to *make* a fundamental particle, sometimes you'll find that when you attempt to translate stuff, you'll instead get a rotation, or that it will have been fundamentally indistinguishable from one. That's what spinors are. They exist in engineering space to use our terminology from the first chapter, they exist in a way that negative numbers of items exist—they are an

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[12]Most notably by the accomplished mathematician Sir Micheal Atiyah who specializes in geometry.

[13]Don't worry, we're not going to actually build all the properties of fundamental particles, because that would require a much more formal setting and a lot more detail, but we're going to get you to where you can sit at the table to see how the professionals are working on it so to speak.

[14]Of course I'm oversimplifying here, there are more particles.

[15]In case you're tempted to simply replace charge and mass with spin in terms what is the most fundamental, we'll see later that this is *not* what this actually means. Spin is not a local quantity, and as such it can be very misleading to think of it as a fundamental quality of a sub-atomic particle, even if it seems to follow a particle around and be intrinsic to it.

intersubjective property, mostly used as a labeling scheme that tells us why and where we cannot cross the bridge from the narrative history of our cosmos to the fundamental constituents of its reducible components.

It's kind of like trying to map out a door by throwing stones at it and noting how and when they bounce back. Except in this case, the stones are fundamental particles, and the door is the big bang, as it is bouncing around in space itself.

And this is what we are doing when we do quantum mechanics—we are describing the unknowables in terms of their fundamental constituents and mapping them to the fundamental subatomic particles. Of course, they're not actually particles. They're a fancy set of engineered book keepers, telling us what is impossible to trace directly backwards in narrative determinism. What we'll see as we move forward, however, is that the particles' features themselves are not actually impossible, they just aren't palpable in the sense that horizons aren't palpable. They are observable, and important to observe, but not real in the way that local classical items are real.

What's more, this shift in thinking is nothing less than seismic. It corresponds to one of the most drastic shifts in modern thinking that we've ever witnessed. It represents a massive upending of the traditional model of the universe where everything is caused in backwards-in-time to forwards-in-time tidiness, but instead noting that there are unobservables affecting things simultaneously across multiple time scales, and this should be upending the previous reductive models of how things work.

Keep in mind, however, that we aren't really talking about observing single independent entities when we get back to the big bang scales, it's more that we are mapping forces on one side of a deterministic landscape to forces on another side of the deterministic landscape, and labeling the resulting tangles, which when viewed from the perspective of classical physics will look a lot like the previously discussed marble cracks! There's a giant chasm of unknowableness, where all we can do is label things that happen, or have happened, or will have happened, so fast and in such a way that it is impossible to trace them all the way back to the causal source (see Fig. 3.2). It's like trying to pin down the precise moment a tornado started, or the precise moment cracks initiate inside a marble. There are multiple ways it could have happened and we cannot be sure which is more correct beyond some probability measurement. These items are only guaranteed to exist when we smack the atoms they live in very hard, and they aren't guaranteed to repeat in the same way for the following crack.

Fig. 3.2 The giant chasm of unknowableness resists all interpretation, let's make one up!

Chapter 4
Narrative Energy

Let's summarize what we've covered so far. For a very long time, we've operated under two basic assumptions. One is that all *space* is fundamentally *invariant*, i.e., its characteristics persist independent from anything we might do to it. The other assumption is that the universe is fundamentally *deterministic* meaning that if we had enough information and initial conditions and enough of the rules worked out we could predict everything, everywhere. The hallmark of modern physics, however, in both cosmology and quantum mechanics, is that neither of these two assumptions hold at the very large or the very small scales. When we follow the consequences of these broken axioms, we soon realize that there must be some rift, some barrier of unknowable-ness where we cross from a deterministic universe to an indeterminate universe. Then we claim that this barrier, although a new and complicated challenge, can be tackled in a new and challenging way. Namely, we concede that instead of trying to untangle the mess of determinism that arises at the formation of atoms in the narrative history of the universe, we must label each tangle as delicately as possible and move forward into an abstract space we're not entirely comfortable with yet. We called the objects we labeled *hierarchical knots*, although we note that they have several names, and in mathematics they have to do with imaginary numbers. We further admit, however, that we do not have a very good physical basis for them quite yet, and as such they are currently only a purely theoretical construction for us.

It's now time to remedy that last omission. There are physical situations where the patterns which arise from imaginary numbers can be seen in everyday examples, not just in hyper-dimensional surfaces.[1] After we look at those we'll go back and apply them to physical problems like subatomic particles.

[1]A good example is in AC circuits, where the resistance of a certain element changes with sensitivity to changes in the frequency of the circuit in such a way so as to not be predictable without imaginary numbers. I like this example, because it's not too far off from what we're going to do next.

G. Bascom, *On the Inside of a Marble*, Astronomers' Universe,
DOI 10.1007/978-3-319-60690-3_4

Finally, we'll see that the world that these effects live in is better thought of as energy, as opposed to time or space alone. This will allow us to complete our modern view of the universe, one where narrative energy is the new currency of measurement, even if it takes us to the end of our book to get there.

4.1 Battle of the Frames

Have you ever had any experience in animation? Maybe you made flip books as a kid, or have messed around with animation software? One of the best things about animation is that there's always this magical moment when the individual frames seem to come alive, projecting fluid motion. The basic idea is fairly simple, we construct each frame of interest via drawing or computer rendering, and then we flash these images at a rate somewhere near the rate at which your eyes perceive them. As simple as the concepts may seem, there are a couple of interesting things to consider.

First, is that your eyes are fundamentally discontinuous in terms of observation. This is why animation works—if your eyes were able to observe infinitely smooth transitions from one moment to the next, all animations would appear jerky, like a series of photographs as opposed to smooth movement.[2] The second thing about animation is that there's this magic number you have to keep in mind, namely the rate at which the frames are flashed. Note that the rate itself, let's call it the *frame rate* of the animation, isn't necessarily intrinsic to the nature of animation itself, but instead depends on the *comparison* of two frame rates, the frame rate of the animation and the frame rate of the observer.

Now, you might reason that the frame rate of our eyes is relatively constant, so the two rates can be simplified into one, and you wouldn't be far off for most applications. Just to play devil's advocate, however, let's consider a certain special case.

Let's take our regular flip book and ask what happens when we add or subtract pages at regular intervals. If we subtract pages the entire animation gets shorter and more jerky, more discontinuous. If instead we *add* pages, say by taking the average of some page and the previous page to create an 'in between' page,[3] the animation slows down and becomes even more continuous. In other words we can add in a slow-motion effect. Finally, if we add pages in a more random way, say in some places we add pages and in some places we take them away, the animation will

[2]In fact, we can extend this to more than just vision, this is also how *measurements* work, which is akin to saying this is how observation works, which, if you recall all the way back to our first chapter, is what is physically located at the center of our time—distorted marble. So just like that we can envision a clear argument that our universe, or at the very least any interaction with it, is fundamentally discontinuous.

[3]By the way, this is a new feature of many high-definition televisions, often referred to as frame interpolation. It generally makes the resulting image smoother, like a day time soap opera.

either slow down or speed up depending on how aggressive we are with our page manipulations. Anywhere that the frame rate slows down things will look more continuous (or we could say more *classical*) whereas anywhere it speeds up things will look less continuous (or we could say more *quantum mechanical*).

So far so good, right?

Now let's see what happens if we substitute our eyes for a video camera with a variable frame capture rate. We now have another knob by which we can engineer the same effects correct? Instead of adding frames into the flip book we could simply take snapshots faster than the frame rate that the flip book is displaying pictures. Note, however, that things are starting to get a bit complicated. Where before we had one knob that could turn two directions and result in two predictable effects, we now have two knobs that, taken together, can be turned in four combinations of directions with only two effects, even if the knob controlling the number of pages in the flip book is a rather cumbersome knob to turn. In this spirit, let's replace it with another camera, this one recording a real-time image of whatever it is we want to look at, which is then being filtered in real time by images from a second camera also pointed at our object, each with a variable frame rate attached to some knob somewhere.

Did you follow all that? We no longer have an animation, we've substituted that for a real-life scene we are recording, and we have two cameras, each with a variable frame rate knob somewhere, and whatever frame is being taken from either camera gets deposited onto a screen that we are watching. Whenever one camera takes an image, regardless of what the other camera is doing, the image is thrown up on the screen, and if the two cameras take an image at the same time, both images are shown at the same time, so you'll just see one image.

Now, and I'm not doing this to be cruel or cumbersome, let's add one more layer of difficulty, and imagine that the real life image we are recording isn't a linear narrative event, but instead is a real-time broadcast of an infinite loop of a periodic motion. Let's say it's of a child spinning a toy above her head.

Now something interesting happens.

Now we have three rates to consider. The first is the rate at which the first camera is capturing frames, the second is the rate at which the second camera is capturing frames, and the third is the rate at which the toy spins. Assuming that the broadcast depicts lots of frames in one rotation of the toy, we can safely guess that setting the frame rate to be much faster than that of the toy will give us a nice, clean movie, even if it is slightly delayed from what the toy is doing in real time. Additionally, if we keep turning up the frame capture rates, we can slow down the rate at which the toy appears to be swinging, and if we push it hard enough we can effectively stop the swinging. If, however, we turn down the rates, something different happens. Not only does the video become more quantized, like before, but now the toy might start to swing backwards! This is the same effect as when you are driving on the freeway and you look out at a neighboring car's hubcaps only to notice that it looks a lot like they are rotating backwards, even though the car itself is moving forwards!

Now what happens if we turn down both camera rates, but fiddle with one of them? First of all the toy will start swinging forwards again, and backwards again, several times depending on how fast we turn each knob, and relative amounts they are turned relative to each other. Next note that the final animation becomes less and less continual, or more quantum mechanical as we said before, but we can almost start to engineer certain kinds of jitters, making the toy seem to dance around however we want.

Let's also note, however, that there is another situation where we match both the frame rates to the period of the toy's motion. The toy will stand still in mid-air!

Now, and this is the last thing I'm adding to this thought experiment I promise, but let's imagine that the child is also walking in a circle. Keeping all the settings we have in place, it will look like there is only one period to observe, namely how often the child completes the circle as she walks. Now what happens when we twiddle the two knobs? We can make all kinds of funny squiggles! Even more, we can get the child to walk backwards, and the toy to swing forwards or backwards and perhaps even more compelling, we can imagine twiddling the knobs in just the right way so that we can make the toy walk a straight line! And if we pushed even harder, we could theoretically build a movie that shows the toy moving *continuously* in a straight line!

But why do we care? Well, remember how in the last chapter we ran up against this strange situation where we were mapping fundamentally indeterminate things onto determinate narratives? This is precisely what we're doing here if we only consider the very last scenario, where the toy is moving in a nice, continuous, and even deterministic way, even though we know that it is *actually* moving in many crazy, twisty-turny ways in the spots between frames! We've *engineered*, to use the language from earlier chapters, a continuous motion that is composed of non-continuous motions!

Now if you're tempted to dismiss these effects and assume they are trivial, remember how we were tempted to do the same thing with our horizons. Even if these things will theoretically vanish were we able to interact with them in specific ways, this is how things look when we interact with them across many spatial and temporal scales. The truth is that every force, and not just video cameras or spinning toys, are possibly subject to this phenomenon, and things don't have to be moving in nice neat ways for the effects considered above to be important. Basically, anytime something is interacting with something else in real time, especially if those two things are smashing into each other with lots of force, phasing effects of frame rates will happen objectively and independent of observers, very much the way trees probably make noise in the woods when they fall, and the way to treat it mathematically is to introduce an extra dimension, namely an imaginary one, where we can separate the effects and treat things deterministically, even if in truth they are not really behaving as such. In fact, this is at the heart of how quantum mechanics treats the fundamental forces, which we'll come back to in later chapters.

Remember how we said that spinors are the fundamental obfuscation of translations and rotations? This is what we set up, even if it's not a fundamental obfuscation, it's still the tangling of rotations with translations, which is what defines spinors. Making it more fundamental would be returning to our example of a crack formation, where the same effect could be envisioned as happening in a fraction of a second, where the window that we are using to interact with it and measure it is on the same time and space scales as the crack itself. As in you would have to be stuck *inside* the crack while measuring, and the thing causing the crack is so large that you cannot make it out.

4.2 Ancient Forces

The effects above are even more evident, and important, if we also consider that they can reach across multiple time and space scales without interacting with anything in between. In other words, if we were to write down a history of the forces emanating from the big bang, they don't have to come locally through traceable lineages, and neither do they have to come forward linearly in time. Remember how the toy may be moving forward continuously in our final animation, but it might be *composed* of motions which are not in order in terms of the original source material?

Let's go back to the thought experiment for just a bit. I want to emphasize this specific case, one where the toy and child are moving in the opposite direction of how they were moving in the source material. In some sense they are not only moving backwards in time, but the images we are seeing are physically older than those in the source material as well. There's a delay between when the source material completes and when the images reach you.[4]

We're now finally ready to start talking about what our analogy corresponds to physically, but be forewarned that this is a particularly difficult thing to think about, mostly because everything is related in inverses, flipped on its head from how we normally want to think of it. Faster frames means slower animations, slower frames means faster, jerkier animations, etc.

When a molecule slams against another molecule, and I mean molecules specifically, not an atom or a sub-atom, it is a very complicated process. Part of the reason it is complicated, however, is because molecules are not rigid items. Even if we are tempted to think of them like baseballs, smashing two molecules together, no matter how small each might be, is more like smashing two complicated, oblong shapes together. For example, let's say a squash is smashing into an eggplant. As the two items begin to make contact, no matter how you orient them, they will not exert perfectly symmetrical forces on one another, and as such you will have vibrations which begin in one place in the eggplant, then emanate through the eggplant on more or less the same timescale that the eggplant continues smashing through the squash. These vibrations will overlap inside the eggplant, and, as complicated as it makes this situation, interact with themselves, sometimes canceling out and sometimes making bigger and bigger waves which will account for some damage to the two vegetables even before the collision is finished.

[4]This delay is precisely what we will use later to rebuild our modern image of the universe and laws which are defined intrinsically.

What's more, these forces overlap and phase together much the same way that our animation phased out and slowed down certain motions, introducing the delay mentioned above.

Now imagine that you are inside the eggplant, and you have no idea that it is about to collide, mid-air, with a squash. If you happen to be on the side opposite of where the collision begins, and you are just a split second too late in beginning your measurement, it is feasible that you will believe that the waves are emanating from *your* side of the aubergine! The reason is that there might be one single wave coming from the direction of the collision, and then there will be waves coming from both sides, and if they overlap at slightly different frequencies, it will appear that there is only *one* wave, coming from the wrong direction!

Needless to say, the same situations can be constructed for almost *all* physical interactions, especially if they live in a closed system that is interacting with itself.

Now remember how in Chap. 3 we discussed that the big bang is a closed system? Does this mean that we could construct a big bang delay, where the phasing effects allow us to slow down the causal nature of the animation of the big bang? How would we go about doing that? It would require that the big bang is still ringing correct? Lucky for us, it still is.

Let's use our thought experiment from before to spell out what it looks like—but this time let's have our first camera take a short movie, with as fast a frame rate as possible, and immediately project it onto a monitor, which another camera then takes an even shorter video of and throw's that up onto a monitor, which another camera then took an even shorter movie, and so on and so on. We could effectively "stop" the image, slowing it down infinitely, while it converged onto one single image from the moment the cascade of cameras began to take images.[5]

This is essentially what we're doing when we interact with atoms, but the necessary precision involved is mind-boggling. Getting a good picture of an atom requires tuning forces that mimic on average something like 10^{23} cameras, all lined up and snapping off a progressively shorter movie.[6]

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[5]Remember how I warned you that the temporal horizon is tricky because it's inverted? The faster the frames, the more cameras we use, the slower the resulting image. Interacting with the past requires that you very quickly slow things down—smoothing out local fast motions exponentially fast. Think of a tunnel getting tighter and tighter while slowing down an object falling into it without damaging it's surface. That's what we're actually doing when we look at the very small (or very old), but it's hard to tell apart from the camera set up we grappled with before, which is essentially the inverse process.

[6]I have to be careful here because there are actually lot's of ways of looking at atoms, and some of them involve cooling things down in laser traps, while some don't "see" the atom at all, only detect them, but all of them have to collapse time and space scales in an enormously difficult way. None of them (that I know of) have single-atom detectors, they instead all involve ramping up a signal iteratively until it's large enough for us to detect, much like the 10^{23} cameras. What's more, even if they didn't, we could still make the argument that the forces barreling up out of the atom are phantom forces that sink into, or retreat from, the atom as fractals without definite position, but we'll get back to that.

Another thing to note is that we're only slowing down real-time correct? Any image we get must be at most what the toy was doing when we started looking at it, right?

Now comes the hard part. What if we tried to do all the analysis above, but there was no guarantee that any child was actually visible anywhere? All we have are lots of cameras and images, cascading on down into the horizon? The answer is that the more precise we get with our camera setup, the closer to the big bang we are getting, and we said earlier that stuff near the big bang is fundamentally obfuscated. In short, the more cameras we use, the less what you are seeing is 'real' and more of a book keeping representation that lives in probability space. That's why the big bang, as hard as it is to understand, actually lives in small spaces, the way that rainbows live in across multiple space scales. The big bang, and making atoms break apart, lives somewhere deep down in the temporal horizon, close to the beginning of everything which makes it less and less deterministic.

I warned you it was hard to wrap your head around. The universe is fundamentally inverted in terms of measuring it. In a sense, everything in the small regimes is moving backwards, on a giant infinite phasing loop, whereas the narrative history (or any deterministic type of image) is one that we construct, not observe passively.

In this situation we don't get to decide, deterministically, what forces are describing beyond probability space. When we look at atoms we are describing fundamental unknowables pasted along the horizon—spins which are inter tangled with rotations or vice versa, and as such we *know* that we are not actually seeing the correct positions of atoms, or any other observable for that matter, until we interact with it directly. Even if we can impose probabilistic descriptions with great precision, what we are seeing is not necessarily moving forwards in time, and it is not necessarily reflecting forces on it *currently*, but might be reflecting forces composed of ancient pieces of energy from a *very* long time ago. Just like the waves in the eggplant were moving the wrong direction, and the straight line from the end of the last section was actually composed of pieces of arcs, the interactions we have with anything smaller than atoms are not *necessarily* composed of the forces that come bouncing back at us. They may be, and probably are, composed of random jumbles of forces that formed in the primordial soup of the big bang, but they *look* like atoms and sub-atomic particles so that's what we call them and that's the very best we can do.

4.3 Reality as a Field

So far in this text we've avoided axioms pretty fervently, but now that we have the basic outline of our story we get to do yet another about face and replace them—not with new axioms, because our ruptured hierarchy needs to stay ruptured—but instead posit some guidelines, just so we can find some footing in our newly fractured epistemology.

First, both the rules of the small and the rules of the large can be rewritten not as eternal truths waiting for us to unearth them—but instead as consequences of the *entire narrative history* of whatever was happening in the early universe, which is a terribly complicated matter. In other words, the fundamental forces are not hierarchically embedded within each atom or sub-atom intrinsically, but instead arise from the ecology, or set of interacting circumstances, going on near each atom now, all the way back to the early universe as they relate to our current universal observations. It's more a matter of book keeping (i.e., this thing can't be this other thing in the future because it became *that* thing over there in the past) than a matter of assigning universally applicable labels to every constituent. The hard part is that when we try to put together axiomatic descriptions of the universe, it is difficult because the laws we have aren't derived from actual physical atoms we are observing currently, only generalized versions of atoms, and their behavior, as hard as it may be to wrap your head around, relies more on the book keeping of aggregate behaviors, or emergent behaviors of the system as a whole, than they necessarily do any inherent attributes.

In other words, atoms are not only independent little balls of matter, but also phantom skips in space which correspond to textures in the big bang—because the big bang, and our current observable universe—is, in certain ways, a closed system, and *that* is the weird part.

Let's try this from another viewpoint. Effectively there *may* exist, from an engineer's perspective, a method by which we could theoretically reproduce the early events of the universe which would help us study the seemingly fundamental values such as charge, mass, the weak force, the strong force, electromagnetic radiation, and possibly even gravity, not as fundamentals, but as *emergent* phenomena arising from how the system interacts with itself as a whole, as opposed to fundamental properties. What's even stranger, is that these attributes probably aren't emerging from things which are more fundamental than the objects that carry them, but they seem to be emerging *in the act of a complicated head swivel* . When we think about why they have the values that they have, it is likely because there is an ongoing concurrent shakiness embedded in the very fabric of our universe that is not apparent to us in any sort of static way, but you can get a glimpse of the form of it if you watch things shrink down into the horizons, both temporal and spatial, both forwards and backwards.

Remember our situation from Chap. 3 where we were sitting in a spot where two waves perfectly happened to cancel each other as they moved through us? It would now seem that our *entire reality* is similarly poised precariously between two colliding waves, which are in the act of canceling when you look locally, but become apparent when you look out into the horizon. It's not unlike looking out at the ocean from a lighthouse and realizing that the curvature of the earth actually starts to become apparent, whereas it wasn't before. The horizon shows us something we would have a very hard time deducing while looking around only in our immediate vicinity.

In fact, let's state this as our second guideline: a unified picture of the universe, where everything has a nice cause and effect, is not couched in the engineer's rules *directly*, but only how those rules constrain the narrative history of the universe, which will always contain some level of indeterminacy. This is similar to how thermodynamics is a perfectly valid theory of atoms yet cannot say anything precise about the specific positions of the individual atoms beyond a set of probabilities, which are only apparent in the end limit of the system when the number of constituents becomes enormously large compared to the size of each individual constituent alone.

Instead of relying on a comfortable set of hierarchical rules to study the very big or the very small, we instead try to say something precisely deterministic about *the system of interacting rules*, which may or may not depend on local stuff. In fact, this system of interacting rules probably does and probably does not depend on local items, much like Schrodinger's cat. Can you define a tornado in terms of one or two air molecules? Can you define a tornado in terms of one or two seconds? Even if you can't, you can't define a tornado *without* the concepts of molecules and seconds.

We could argue that the head swivel unearths a horizon effect, but where the horizon is actually *adding* information, as opposed to taking it away. In fact, we're finally ready to add something important to that idea. While before it was mostly implied that quantum mechanics requires a head swivel in space, or the actual physical act of looking over your shoulder in order to reduce the problem further, it is now evident that we also need a head swivel in *time*. This entails looking over your shoulder more figuratively, this time into the past. Now we note that as you look further and further backwards in *time scale* you start to notice more information than anything you would get locally. We could call it a *retrospective* head swivel, where we need to look into the past to get the whole picture, not just over your shoulder in space. Not only do things in quantum mechanics reduce to things *larger* than their most fundamental constituents, they also reduce to things *older* than their most fundamental constituents. Remember, atoms are old. To understand all the properties they are capable of carrying, we must look *very* far back in time, not just into smaller and smaller spaces.

Finally, here's our third guideline. The *observable* universe is finite in space and time, which allows us to construct some rules about it, even if the unobservable universe is not and does not obey those rules necessarily.[7] Keep in mind that they are not fundamental, eternal rules, just the consequence of book keeping made easy by symmetry, and hinging on the fact that amazingly there seems to be a finite end to measurement we call the big bang. The important thing to keep in mind is that if anything happens now with similar energy as things that happened in the early universe, they will become indeterminate and no longer calculable, or we could say they will become a *hierarchical knot*, as we discussed in Chap. 3. We'll develop this idea in the following chapter, but suffice to say that even though the universe may be more of a non-equilibrium process than a steady-state or equilibrium process, that does not mean that we cannot assign rules to how it works, we just have to

[7]Where the observable universe is everything that *can* be measured, so falls within a vast measurement which begins with the big bang and ends with a slow sigh.

keep in mind that those rules, fundamentally, must be field-like, i.e., depend on stuff that happened both in the past *and* the future in both small, *and* large ways, and if we're trying to use these rules to describe things which have similar energy as the energy that established the boundary of our early universe, they are going to tangle hierarchically and have strange properties.[8]

[8]Again, the word *non-local* might replace the word field-like in this statement depending on who you talk to. There is plenty of evidence demonstrating that QM is non-local, and Bell's theorem is generally considered proof. There are, however, people still holding out for slightly different interpretations, but all experimental evidence points towards reality being fundamentally non-local, and QM effects being reproducible at all scales. Check out Bohmian mechanics and pilot-wave theory for an alternative interpretation. I personally wonder if there are ways to combine both without breaking faster than light rules, but it will require reformulating what our understanding of light is. I'll talk more about it in Chap. 6.

Chapter 5
A Universe Far from Equilibrium

Talking precisely about the universe in terms that come from rules solely deriving from *inside* said universe is difficult, to say the least. This funny conundrum, namely one of not being able to separate the observer from the observed, is a central tenet for almost all the concepts in this book. When we look at time and try to deconstruct it, it is difficult because it has become tangled with space, when we try to deconstruct space it has somehow acquired a messy tangled relationship with time, and when you try to untangle them as a unit, we find that they depend on reference frames which are tangled as well!

As frustrating as it can all add up, there is a simple answer that does not involve appealing to the divine, or the supernatural, or the surreal, or even the untestable—as far as we can tell. The answer is to accept the tangled nature of our reality, even if we need to be wary of tautologies and false relationships. As such we can redefine everything we thought we ever knew about how things work, while staying firmly grounded in observation accessible to us. Additionally, when we realize that it is *observation itself* that is so fiendishly difficult to understand in all this, the linchpin for our ontological framework remains empirical observation, while simultaneously allowing us to appreciate approaches which highlight the interconnectedness of all those measurements.

Once we've achieved this zen-like acceptance of interconnectedness of rules and observation, we are finally ready to return to a more comfortable position than where we started the text, in which things are ordered in a logical manner; from big to small and fast to slow; but now we'll add a new one, local versus field-like, or instantaneous versus not instantaneous. The place to start is to re-imagine the universe not as a giant unmoving warehouse with lots and lots of empty space that exists in one single moment, but instead one giant, huge, inconceivably large process that began $\sim$13.78 billion years ago and is still happening right now as you're reading. This means, in short, that the universe is *not* at equilibrium, that it is more like a giant whip-crack burning off energy than a stable, constructed entity.

G. Bascom, *On the Inside of a Marble*, Astronomers' Universe,
DOI 10.1007/978-3-319-60690-3_5

What makes it so hard to understand, however, is that it is not the thing doing the whipping nor is it the thing being whipped—it is both. It is the whole thing, the whip, the crack, the beginning and the end, and we are riding along it from the past into the future.

5.1 Infinite Sinks

At the end of the last chapter we said that the modern view of the universe is one that no longer depends on intrinsic rules that are eternal, but instead a universe where the rules are consequences of book keeping made easy by symmetry. What does it actually mean, though, to go from a deterministic universe to a well book-kept universe? What is it exactly that we are keeping track of, and how will this change our understanding of it? In order to start discussing this we'll need to borrow from the field of thermodynamics, which does a good job of defining and keeping track of large numbers of constituents, and treating the *aggregate* behavior deterministically, even if it treats the actual positions of the individual constituents probabilistically.[1]

As a short summary of the field, there are two fundamentally distinct sorts of physical processes. One is an equilibrium process, whereas the other is a non-equilibrium process. An equilibrium process involves dealing with an entirely closed system, and so the book keeping is all symmetrical and you can balance the forces in one direction with forces in another direction and ascribe sets of rules to the behavior. We have to be careful, though, a system which is *far* from equilibrium, but is still a closed system, is still considered an equilibrium system, even if it equilibrates slowly. A *non*-equilibrium system is not closed, and leaks some form of energy irretrievably into the surrounding environment. To be honest, I prefer the term *dissipative* as opposed to non-equilibrium, because there is a tendency to use the term non-equilibrium to refer to all things far from equilibrium.

Dissipative systems are notoriously difficult to treat deterministically, so you might reasonably ask, isn't every system technically an equilibrium system, if we consider enough of the surrounding environment? In other words, can't we just redefine our system so that it includes everything around it as well as whatever we originally were interested in, and therefore consider all systems equilibrium systems? The main problem with this approach is that sometimes what we end up with are tautological statements, like saying that heat which left the place of interest ended up going …somewhere. Defining the system to include all places that heat can run off to is often saying that it can go anyplace in the whole universe, which oftentimes isn't all that useful for our local calculations.

Wait, but we're interested in discussing the whole universe, so it should still be useful right?

[1] Which should sound a lot like quantum mechanics to us by now.

Another way of thinking about this is that some kinds of objects act as *sinks*, infinitely deep wells into which we can pour tons of energy and it will just kind of disappear from our system without interacting with it anymore. A good example is friction. Without friction, which is dissipative, our physical reality would be much more symmetrical. In fact there are practical applications regarding what happens when friction goes close to zero, like trying to design controls for hovercraft or rocket engines. What's important to note however, is that the reason friction allows us move around easily in our normal classical world, is that it takes some energy we are exerting and siphons it off into a seemingly infinitely deep well.

Then, what this allows us to do, is safely divide the classical forces from the atomic forces because they are so far away in both time, space, and influence, even though those forces are very hard to tell apart if we were to zoom in close to them. As long as the forces leaving from the classical domain and entering the atomic domain are just a trickle, we can keep the divide between these two domains safe and secure and keep the hierarchies separated, even if they are both drawing from the same fundamentals.

So what about atomic friction? Can we define the classical domain as having infinitely deep sinks in the atomic domain, and the atomic domain as having infinitely deep sinks in the sub-atomic domain and so on *ad infinitum*? Unfortunately, we can't. Even though the trick allows us to tidy up our universal views,[2] it turns out that despite giving the appearance of infinite depth, it doesn't seem like the universe acts that way. In fact, one of the main points of last chapter was to note that this *exact kind of thinking* got us in trouble and made us ignore the field-like nature of our reality for the last two thousand years or so. What's more, the bottom of the well, if you assume it goes all the way down, ends up coming out somewhere near the *top* of another domain, like some kind of Escher drawing. Such things aren't physically possible in our classical universe, so we probably did something wrong, or at the very least need to amend our internal semiotic landscape to get a better understanding.

The clean separation simplification of dissipative like forces leads us to end up assigning exceptions to our laws, which appear as inlets and outlets to our systems without a final location. In other words—friction is an infinite *sink* that takes energy out of our classical objects and makes it disappear into nothingness, so you can safely ignore its details in calculations of how classical objects behave. If we're going to define our system to include *the entire universe*, however, we can no longer do this, and if we do we have to deal with tautological and/or contradictory statements.

But friction is really indistinguishable from heat transfer correct? If I were to rub a coarse cloth on the surface of one of our marbles from Chap. 2 it would heat up. In fact, in the same way we cracked our marble with all sorts of different hammers, we could envision doing it with heat, which would be indistinguishable from doing it with friction. Imagine putting the marble in an oven, and shooting the temperature

[2] By jumping back into our old hierarchically well-composed universe.

through the roof, or better yet aiming the flame of a blowtorch on a marble which just came out of the freezer, and watching it crack. This is equivalent to dumping a bunch of energy, in the infinite sink kind of way, into our marble and seeing what happens. Note that as we watch it crack, the exact same mechanisms are in play as when we cracked it with a hammer, whether it was a large or small one. Why? Because in a poorly-made marble with defects, the heat doesn't enter the marble symmetrically and therefore follow the idealized rules that thermodynamics predicts, and it ends up sort of punching some part of that marble, just like a hammer. Sure a *perfectly* formed marble may not crack, and instead will melt into a liquid and eventually a gas, but note that is *also* what you get if you keep hitting the marble over and over again with any of the hammers for long enough. It's true that you've accessed different *intermediate* states, so the route the marble takes to get to that final state may differ, but the mechanisms are all indistinguishable on the microscopic scale.

In other words, our seemingly infinite sink, i.e., friction, was not so infinite! The energy didn't sink cleanly into the marble and siphon off into things we can ignore, but instead something about the rate at which we poured the energy down into it affected the way it was delivered, converting into mechanical energy in the process and then sending it back out of the marble. Real infinity, in this case, is what happens when we *apply* the energy for an infinitely long time, in a way that's both infinite in space *and* infinite in time. In the more interesting case, the one where we sloshed our timing around by taking a ton of tiny little hammers (aka atoms in the blowtorch) and slammed them into the marble *very quickly*, allows us to see how the thermal energy can be converted back into mechanical energy, and do so in a rather spontaneous way! Note that the energy didn't act this way because of the failure of any fundamental rules to apply, just that the system became unstable as parts of it heated up more quickly, and therefore increased local pressures, creating a conduit for all that thermal energy to become mechanical energy again.

The important thing to note here is that the idealized theory, i.e. the one that describes an equilibrium system without dissipation, is actually *less* correct than the one that uses the infinite sink trick, i.e. friction, even though we can argue that friction is mostly just a placeholder to say anything we have a hard time keeping track of in our ideal system. Even if friction, as defined as a dissipative sink, is not an *entirely* correct view of the phenomenon, it is a very useful approach for keeping track of hard to keep track of things.

The reason this is important, however, is that when we talk about atoms we are doing something very similar. Oftentimes, we have a difficult time realizing that time, in the sense that we measure energy and forces on those atoms, is actually sloshing around depending on how and when an object is exerting influence across multiple time scales, especially under circumstances where energies are converting quickly back and forth from one form to another. Again recall back to our last chapter, where we noted how simply changing the engineer's frame rates can quickly distort our narrative view of interactions. In that situation we were okay noting that it was just a trick, an illusion, but now we have to consider that it is not just a technical problem, but also a real-live physical issue. The difficulty arises in that things which are out of order are often out of order because the timescales at which an event is happening is constrained to a very quick window, and sometimes when the system as a whole is doing something complicated this can result in funny unpredictable behaviors at the small, local scale.

In other words, when forces reach across multiple time and space scales, in hard to keep track of ways for the system, things start to skip around discontinuously down in the local regime. Spontaneous changes in the determinism of the *rules governing the macro-behavior of the object* results, even if none of the individual constituents need to move around discontinuously. Suddenly a system, which when distilled down to its most fundamental rules, will actually be *less* correct than the system which includes these infinite sinks, such as the case with friction. You can see why all this is so difficult right? What it suggests almost surreptitiously, is that reality is secretly sloshing around discontinuously *all the time*, and *we* are the ones smoothing in the gaps by only paying attention to things which happen on near-neighbor time and space scales, but that if you step back a little and start looking at the system as a whole, there should be friction like processes that allow for the universe to be doing something complicated like our marble did when we heated it up and it cracked.

So now we get to stop and ask the big question, probably the most important one we can ask in modern cosmology—as we step away from our more comfortable quotidian time and space scales—is the *universe* a dissipative process? Does it have infinite sinks? If we are referring to only our instant[3] view of the universe, aka the universe *now*, many experts agree that a dissipative universe makes a certain kind of sense, although exactly what that means has undergone major changes in the last century or so. The hallmark of the modern universe, however, is that we don't get to assign the simplistic source/sink trick to the creation or destruction of our universe.[4]

In fact, the prevailing theory of how the universe works for most of the mid-twentieth century was one with both matter-creating sources and matter-destroying sinks, often referred to as a steady state universe. The big bang was not a popular notion, when first proposed by Lemaître.[5] The prevailing theory at the time was something where some parts of the universe were continually created and some were continually destroyed. In other words, the infinite sink and infinite source

[3]If we expand the definition of our universe to include all of *time* however, things get a little more tricky. Now we're in danger of stating tautological truths in complicated ways, much like how string theory seems to allow for an infinite number of realities, or that some *other* set of universes could explain some of the basic fundamental attributes of *our* universe we see here. We'll discuss these theories in more detail in the final chapter.

[4]As we'll see in later sections, however, we do get to use the source/sink trick in a slightly more complicated way, resulting in a pretty wildly new understanding of the fundamental forces.

[5]In fact, Einstein told him that his math was great but that his physics was terrible, because the notion of a single, dense, hot point that all time traced back to was so at odds with his own personal view of the universe, even though it was his own theory that led to Lemaître's work and subsequent interpretation. By the way, Einstein made another similar mistake regarding the cosmological constant, which ended up being wrong and then right again (except it got a negative sign about 20 years ago), which is where dark energy enters the picture. We'll get back to that in Chap. 6.

type of thinking has been around for a long time, often helping to tidy up our internal schematics regarding complicated systems. This is especially true if we assume that the system is at some sort of equilibrium, much like our old notion of space. The hallmark, however, of modern thinking that was ushered in with the big bang model involves moving from this older, simpler notion where a static universe is maintained by perfectly balanced sinks/sources to a version with *unbalanced* sinks/sources. Note however, that the old sinks and sources pertain to what was then referred to as 'creation' of the universe, where the newer sinks/sources refer to a more modernized version of 'creation' which looks a lot more like 'being made observable for the first time in our narrative' rather than pure creation or destruction.

All *that*, as strange as it may seem, denotes that the universe not only had a beginning but also has (or has had) an end, and must be evolving in time everywhere in between. In other words the universe is *doing something*, expending energy. It almost looks like it is converting and/or deriving energy from the inside, like a giant kernel of popcorn popping. In fact, we might even say that it resembles a giant marble expanding outward as it heats up, taking on and pouring out friction-like energy.

But is it cracking?[6]

5.2 Deduction Production

Whether the universe is more accurately described as a marble being heated unevenly by an external source, or as a marble that is in the *act* of exploding and therefore mostly expending internal energy[7] will take a few more chapters to fully flesh out. In fact I'll give you a spoiler that you probably won't leave with a satisfying resolution to that question, but hopefully you will be able to appreciate the problem a bit more fully.

Before we do that, however, let's back up. What does it actually mean that we live in a universe where the sinks and sources are changing with time? How can we treat this system? Suppose we could just measure the rates at which the sinks and sources are changing and fit them to some mathematical model, would the whole problem be solved? We *might* be able to suggest such a thing if we were certain the rate of one did not depend on the rate of another, but even then there are some major technical difficulties standing in the way.

Instead of that approach let's return to our animation examples from Chap. 4, specifically the examples regarding a series of cameras all snapping off shorter and

[6]Do you see what the cracks might refer to yet? Remember how it is very difficult to talk about cracks until *after* you know the crack is somewhere in the marble? We're going to exploit this difficulty to build up our modern laws, one by one, finally giving us a new definition of all things fundamental.

[7]Or maybe even a marble which *was* heated rapidly but then left to cool.

shorter videos of each other's recorded content until we have an infinitely slowly moving picture of an atom or a sub-atom. Did something bother you about that experiment? Maybe the fact that we would need to synchronize all those cameras, which we said in the end of Chap. 1, is a *very* difficult thing to do, especially for things which are far away? Or even worse, maybe that the whole point of this book is that there *isn't* necessarily a bottom where the snaps can all start firing off?

Here's where things get tricky, because if we're going to talk about the entire universe, we have to include relativity. One of the things relativity does that is so frustratingly difficult, as we discussed in Chaps. 1 and 2, is to note that we cannot order things sequentially in an absolute way, especially if they might be in an accelerating reference frame. In such a case, it is *very* difficult to imagine setting up a series of cameras which can snap off all the videos in any sort of sequential order, when we can imagine cases where no sequential order is even definable! What's more, this probably applies to both the very small, and the very far away, two key components of our modern picture of the universe.

So what can we do? Well, first we note that there *are* situations where certain rules can be applied, but here's the trick. They all have to be assigned relatively. Remember when I talked about things which can't be defined in the future because they haven't happened in the past yet? This is precisely the situation we're going to exploit to nucleate our modern laws, because we want laws that will apply to *all* situations, not just those that apply in different special cases.

In this image, the first thing to note is that absolute rates can't always be defined in a clean way, so instead we have to be thinking about either the most efficient, or most inefficient, way in which we might be able to observe or represent some event. In other words while we fiddle the knobs attached to our camera setup from before, we might ask which settings have the *truest* representation of the thing being observed.

The most important thing to take away is that there are *many* frame rates where a delay is introduced and the period of the toy is slightly misrepresented in terms of its absolute position, whereas there is one case where there is no delay and we are representing the position of the toy with absolute correctness. No matter what settings we choose, if the cameras are taking pictures slower than the rate at which the child swings the toy then the rotation of the toy on our screen will be slower than reality. Similarly if the cameras are taking pictures *faster* than the period of the toy, we see bits and pieces of the toy's motion which are out of order, but will *appear* to be moving with a period that is *not* the correct period.

There is no way in which you can fiddle the knobs to make a truer representation of reality than *matching* the rate of change of the original toy—if you turn the rates up too high, if you turn the rates down too low, the period appears to slow down and you introduce delay. What's more, there are lots of harmonic positions, where we might be seeing the correct period, but it will be a little behind the actual position of the toy—even if the periodicity is spot on the *absolute* position is off by a factor. This third case is one in which the periods are matched—but the two images are *out of phase*. Only by matching the phase *and* the period of the toy can we have a perfectly efficient and correct representation of the toy.

Now what if it's not moving in a nice neat circle? You will have to adjust your knobs with perfect efficiency, or in *real time*. This is probably the most important point to be made in this book. The truest representation of a thing that exists, after it has been filtered through the mess of time and space tangles we have a hard time of keeping track of, *is real time*, and some things we are trying to measure are interacting with other things, *in real time* as the laws which we use to describe them are changing.

This is the key, this is how we should all be thinking about what it means to be small—or more importantly—what it means to interact with things which are small. When describing small particles, there is no way to tell what real period of its motion is if you are trying to pin it down exactly into one position by matching those positions with the tool you are using to interact with it.

All in all, it's kind of like being in a movie crew, and trying to shoot a movie without knowing what it's about yet! Or even better, realizing that *we* are in the movie! How much tape do we need? It's impossible to know exactly! What we *can* know, is that we will need to have at least as much as the real time it takes to record the movie, and the most perfectly efficient movie we could make is the one where we do no editing, we match our frames exactly to what's happening to us now, and this will be the fastest thing we are allowed to make a movie about. If you want to make the movie about something that takes longer (either in the past or in the future) *or* shorter than what's happening to you in real time, then you are going to have to add or subtract frames from real life, and every frame that comes out introduces more delay and hence is less realistic than the reality from which it was derived.

So what do we do? We film a bunch of different scenes, cut them all into small pieces, and paste them back together again in a probabilistically probably way, i.e., we *engineer* a new narrative from non-narrative chunks! In much the same way that we conceded we can't see all the universe from inside of it, we cannot see all the time line for this very same reason, because the semiotics we use to represent narrative events are limited by this universal speed limit, which is, the fastest thing we can observe[8] inside our observable universe.

The trick is that the big bang is still deciding on how certain parts of the movie will play out, and predicting exactly where a particle will be in the future requires that we know something that hasn't finished happening yet—aka something still happening in the movie of the big bang.

Finally, just as a little preview of the next chapter, if a representation of something *is* correct for a little while, and we assign a name to it, but then it spontaneously becomes wrong again, what does that mean? If we have to adjust our semiotics to account for some amount of fundamental unknowableness, what's the fastest we can correct our ruptured definition? Think about the frames and the knobs, you

[8]Locally.

were either filtering frames too slowly or too quickly, so there's always going to be a speed limit to how quickly you can correct the knobs, and the fastest you could adjust your frames to become correct would be *real time* of the change.[9]

For example, the inability to know where a photon is at any given time before measuring it corresponds to a representation of an act of obfuscation, where specifically what is causing the obfuscation has something to do with the spin/translation of charge in the early universe being difficult to tell apart from the way that *current* charged particles should be spinning or translating, were we to try to point out exactly when they might hiccup in said rotations/translations and why. It is something like a *causal culprit* more than a specific physical act you point to with your finger. In other words, if you were tracking a pair of particles and predicting their future positions in a deterministic way and then the two particles exchange some energy and your prediction is suddenly incorrect, in that one emitted the photon and another received the photon so they are no longer holding the amount of energy you would have assigned to them the moment *before* the photon was emitted, you could then say Ha!, the universe just cracked a little! Some energy just spontaneously redistributed itself in a field-dependent way! What's difficult is that the field seems to exist currently as a fundamental attribute of the two atoms, whereas in reality it involves a very complicated head swivel in time and space, where there's stuff moving around in the early universe exerting effects (in probability space) on where and when these two particles exist and how much energy they have.

The main question in quantum mechanics is not so much pointing out that these things happen, it's more of a 'who-done-it?' type of inquiry, where the very best we can do is say that the culprit had something to do with rotations and translations of the early universe being reflected in particles and making them difficult to track deterministically now. The harder pill to swallow is that it's not that the prediction *became* incorrect in the moment the photon was emitted, *it was always going to be incorrect*, and that's how much of our reality is still missing from our direct observation. The fact is that all field-like phenomena, aka effects that spread out over space *and* time, are *required*[10] to proceed in a finite amount of time, and any amount of time corresponds to a physical amount of space no matter where or when you observe it. Even if the obfuscation, or the 'skip' in energy happens instantly for the universe, it doesn't *reach* the two objects instantly, or we could say we won't be able to observe the change instantly. From the view of the photon, or the universe for that matter—and this is key—the whole thing is instantaneous, it takes no time for the skip to occur, it has always occurred and it always *was* going to occur. It's just from our vantage point down here in the delayed reality that we won't be able

[9] And this correction, if it couples to some other correction nearby, could be a real particle like a photon or an electron, but if it doesn't couple to anything nearby, i.e. it's a trick due to problems with how things move around, then it's a virtual particle and (probably) corresponds to one of the four fundamental forces. We're going to spell it out even further in the next chapter.

[10] By relativity.

to see the change until a finite amount of time has passed, and the fact that it didn't happen or seem to happen until we engineered some conditions in which to observe it gives us the illusion that we *caused* it to happen. This is difficult to tell apart from that fastest thing that *can* be caused, but correlation does not imply causation. In short, since everything is moving, and the construction of the universe is maintained instantaneously, the propagation of changes made on the most global scales do not propagate to the individual constituents simultaneously, and there is a delay between two particles instantaneously exchanging momentum, which corresponds to some finite time.

So if we measure this amount of time, i.e., the time it takes for incorrect-ness in our predictions to be corrected, you will find that it is directly proportional to the amount of space between the two electrons that need correcting, and that if you divide that space by that time the resulting velocity should be close to *real time* for how the fastest things changing in our observable universe proceed in changing. That is what we are measuring here, the perfectly efficient representation of something changing fundamentally in real time out at the edges of our semiotic landscape.

And *that* is the speed of light.

5.3 Fundamental Friction

But what is it that we are correcting in these cases? It has to be something physical, as opposed to just a lack of information correct? Well, here's the thing. In complicated systems, and the universe is by definition the most complicated system we know about, sometimes there are things which are entirely physical but we can't directly point at with our fingers, even though they exist. Money, to return to a previous example, acts in a similar regard. Money represents the *power* to make a transaction happen, it doesn't necessarily represent the physical transaction itself. The distinction can be quite subtle at times, but note that money is very much a real thing, even if the realness of it is not well defined, the same way a university or corporation is not necessarily well defined, the same way that the total field a particle emits on its environment is not well defined at any one time alone. These things are real because they represent real things we can measure, and in some senses they can even cause things to happen that we care about in everyday life. Even though we can point to the physical currency we carry around and imbue it with the power we're talking about, that's not what directly imparts power to money. What gives money its power is the correctness of the outcome attributed to predictions surrounding that object. It's the efficiency and promiscuity of the representation of that object and how it interacts within the system that maintains its field like properties.

Take, for example, the relatively common practice of earmarking funds for a specific purpose. Now imagine that someone who didn't quite understand how money works took this a little too literally, and decided that the money set aside must *physically* correspond to the desired project as well as the amount. When we say we're earmarking funds for a specific purpose, we don't actually mean *these specific bills* I'm holding in my hands, we mean any number of bills that correspond to the same amount of money that I set aside. The thing that needs representing is not money or power of transaction, it's the *amount* of power of transaction, which is a very different thing.

There's a similar distinction in QM that can be hard to wrap your head around but pivotal for understanding how we assign attributes to fundamental particles, and it involves imaginary numbers. Basically anytime there's an imaginary number, i, in our position equation, we are saying that even though we can't technically tell it apart fundamentally from some other particle who also has this quantity, we're going to imagine we can, and after trying every possible combination of when and where that quantity *can* be, which is very hard to tell apart from where it *will* be, we add up all the possibilities and choose the most probable. What the imaginary number is allowing us to do is operate in a space that hasn't happened yet, or has yet to have happened, or has already yet to have happened, or all of the above. In quantum field theory, we say that there is a universal "field" that pervades the universe for various quantities, and that atoms "interact" with this field to produce the observables, but what we mean is that we can't tell, from the perspective of the universe, whether that observable belongs to this particle or that particle, just that there's some amount of it that the universe has been saving up to spend in propagating its own evolution. Saying that one particle "has" a certain momentum isn't quite correct, instead we should say that it has a certain *amount* of momentum. In this case, momentum is now considered a general quantity that the universe may or may not at any given moment have a certain amount of, and the universe imparts that momentum to each particle the same way that we earmark non-specific funding for specific purposes. The universe cannot distinguish between each individual unit of momentum, only a general sum of them all, and we force that momentum to attach itself to a specific fundamental particle by hitting it with a tiny little hammer. Asking where the momentum *specifically* comes from would be a little like calling your bank and asking them to clarify *which* funds were allocated to you when you requested an electronic withdrawal. It's a malformed question, because what you are asking about is a quantity that is fundamentally obfuscated when it comes to clarifying its representation, especially if the money sent to you was electronic, and doesn't necessarily exist in any physical form.

Do you see how this applies to our discussion, especially when we're trying to assign descriptors to atoms by interacting with them across several space and time scales? In the same way we couldn't tell whether the toy in our thought experiment from Chap. 4 was moving in a straight line or was simply *composed* of movements which were phasing together to make the toy appear to be moving in a straight line, sometimes atoms get hit with certain kinds of forces that cannot be distinguished in terms of their ancestry from other kinds of forces, and it becomes more important to start lumping the whole thing into a single observable where distinguishing one unit from another is no longer possible. As such we cannot determine what exactly those forces are going to do to the atom beyond a certain probability. The way we get out of it is to imagine that we *can* earmark specific designations, and then ask what is the most probable candidate for which bills will be given. There's nothing wrong with doing that, if that's what you really want to do, but you have to live with a probability measurement, not a deterministic one.

Everything that doesn't behave well in this picture because it doesn't seem to have *any* ancestry at all, corresponds to what we call the fundamental forces, although we haven't spelled out exactly why quite yet.

In part, though, we can say that the intersubjectivity, or fundamental unknowableness of our picture is between atoms and the universe, not between humans predicting other humans.[11] As we've started to spell out, the narrative story that makes up an atom is, or what it might have been, or what it will be, is not a single narrative that we can point to with our fingers. It is instead an amalgam of different possible narratives we are forcing to look like a single existing thing by throwing lots of frames at it, and all the information that we cannot recover is what we would need to distinguish between two particles that came from a similar place in the early universe. When we add up all the amounts and check it against our narrative story of how the universe is propagating, there are discrepancies, and those discrepancies are what we've simply assumed must exist from the beginning of time.

In an effort to make this a little more concrete though, let's talk about energy. Just like money, energy is not an actual physical thing, it's whatever purchasing power we have to move atoms around in space, time, or species. Let's say, for example, that we're interested in our model system from Chap. 2, i.e. two hydrogen atoms frozen in space. There are two distinct kinds of questions I can ask about that system, and those questions differ as the time scales to which they correctly apply differ. In one case, we might ask if a given system is *right now* going to produce some helium, whereas the other question would ask whether we can *engineer* a system to produce some helium at some later date. Note how in the second case we have to "spend" some energy, i.e. move things around such that we manipulate circumstances to ensure our outcome. In contrast to the first question, the energy spent engineering the conversion is indistinguishable from the energy we observe passively to ask if something *will* do something versus whether something *can* do something.

Can you see how manipulating circumstances, i.e., earmarking some amount of energy to engineer the desired outcome, is indistinguishable from saying we need certain initial conditions to be fulfilled if we want to use our nice deterministic equations to make a prediction? If we want to ask whether a certain thing was caused, without a doubt, then the precisely described narrative of the past becomes the initial condition we're interested in engineering for the other case! Each case relies on some amount of earmarking of the general pool of energy that is hanging out, where in the prediction case we simply assign energy to preexisting entities whereas in the engineer's case that energy is a bit more hypothetical.

[11] I suspect this distinction is why people often think QM relies on some sort of magical observer. We're going to talk about this later, but as it turns out information relies on the inability of the universe to talk to itself instantly just as much as light and fundamental forces, and as such the speed of information transfer is also the speed of light, which is the speed of gravity, and, of course, the upper limit to momentum.

In other words, if we move from simple questions about what is *going* to happen, to a list of what could *possibly* happen, our concept of energy encompasses all the parts of the prediction we have trouble keeping track of during the operation or tallying up before the operation, but those unknowables can arise because they are either fundamentally unknowable *or* equally because you aren't sure what it is you want to produce quite yet!

Note, however, that this is a problem that arises in expanding our timescale, just like we ran into problems expanding our space scale in the thought experiments in Chap. 1. When we expand the timescale of our system, what happens when it encompasses the beginning and end of our universe? If we include all the ways we could hope to engineer an outcome as well as seek to observe an outcome, there will *always, no matter what*, be situations where things could move a little differently than we would expect, or better said our equations won't be able to predict outcomes in a precisely deterministic way. Even if we run the biggest calculation with the biggest computers in existence, and even if we use the most fundamentally promiscuous operations we can define, there will still be times when we can't make it all add up nicely, and we're going to have to resort to things like energy to complete our calculation. Time and space operations, even though they theoretically describe everything in the universe in the most fundamental way possible, do not represent the most fundamental operations we can use to characterize our universal system.

So now if you're shaking your head and asking, "Gavin, who cares? So there's always a little leeway in our calculations, so what?" Here's the thing: if we want a nice and tidy theory of a universe, or any sort of theory of everything,[12] we need to set up a system of laws that are both coherent *and* complete, i.e., encompass all things that ever were and contain no contradictions. This would mean that the universe, and all predictions regarding the universe, should reduce to some deterministic equations if we were able to observe it with enough accuracy and time. Several key thinkers have pointed out this century[13] that this sort of question is actually malformed. It's not that it's wrong or incomplete, it's more that it doesn't make sense given the system we're using to make senses. There is no such thing as a set of all sets, and therefore there isn't a universe in the normal connotative way we like to think of it, i.e., a collection of everything ever that doesn't contain contradictions.

Now, this may seem like a bit of a jump, but if a complete universe must contain contradictions (or a universe without contradictions isn't complete), doesn't that mean that instead of ignoring deviations from the ideal, we should be looking for them? Instead of labeling all cases where the ideal is less accurate than reality as anomaly, shouldn't we be seeking out inexplicable behaviors of our system? Even more exciting, once we find them they should be indicative of our ruptured hierarchy, and if we can observe them and understand them, that should help us move forward stitching together a shiny new epistemology!

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[12]This would be the same thing as asking for a set of all sets, by the way.

[13]Involving Gödel, Einstein, and Heisenberg to name a few.

In other words, if we follow through the above logic closely, we arrive at the conclusion that there *does not exist* any ideal universe or any universally applicable ideal set of laws that are consistent that we can observe directly, so we should be able to find stuff that we can't define or understand without looking at the problem obliquely, through the lens of all possible obfuscations, which will include the entire system as a whole.

So where are the inconsistencies? Shouldn't we have found them by now? The trick is, largely unwitting, we've known about them, we've just assigned them as intrinsic attributes as opposed to systemic attributes. Certain things just *are*, they seem to have no place in an ecology of systems or narratives beyond that they reliably act certain ways–some atoms have a positive charge and some a neutral charge, and some a negative charge and that's the whole story!

This is, at least in part, because all the unassigned stuff, the parts we cannot account for, ends up looking a lot like friction. In many ways, the whole question starts to become *more* complicated, as opposed to simplifying, when you start exploring the relationships between charge and mass and spin and position and all that, instead of just assigning the characteristics and moving on. In the same way that our classical formulations actually become more complicated when we break down and spell out the individual forces that give rise to friction, as opposed to just looking at the aggregate behavior, our understanding of charge and spin is much easier to understand if we just imbue the particle with those magical attributes and not worry about any deeper relationships.

The trick is that the friction in question, if we're going to stretch our analogy uncomfortably thin, seems to be between something like 'atoms and empty space in the early universe.' More precisely, we could say that the system which maintains our normal semiotic we use to *refer* to space is actually an active process and it becomes slightly incorrect when some of the umph begins to bleed off due to the incorrectness of our calculations that *would* rely on the early universe if we had good enough calculations to do so. In other words, the *whole composition* of the universe and therefore the correctness of time/space operations are what is dissipative and therefore giving rise to the field-like interactions we observe when two charges come near each other. As hard as it might be to understand, the theories suggest that changing the momentum of a particle *now* requires that you line up and direct so many forces across so many scales that this corresponds to some amount of drag through the primordial ylem (a fancy word used by pioneering cosmologists to refer to the soup of plasma that formed just after the big bang), dissipating into things which haven't finished happening yet in the early universe (or better said will have finished happening by the time the calculation is finished), circumventing the need to go 'through' space, but still requiring a finite amount of time, and space, to reach us. What's more, these behaviors can be described in nice and neat predictable ways in our classical regime, so we label the behavior as a universal law and if someone asks why we have that law the answer is inevitably because we just do! This may be why the term fundamental feels like it fits these things, because they've been true for as long as we've been observing things and seemingly even a lot longer than that. When we widen our view just a bit, so to speak, we realize they are fundamental not because they are *eternal and unavoidable* but because they rely on the entire *system of rules* being true in a fundamental way.

The trick is to point out inconsistencies or incompleteness in our otherwise perfectly deterministic set of laws, and label whichever behaviors are deviating from them, and *that* is what we're really talking about when we talk about anything described by quantum mechanics. This is why things can happen at a spooky distance, because they aren't happening here in our local classical system, they are happening way back in the early universe and just reaching us now, and the effects have something to do with the fundamental forces.[14] In other words, it's not in the direct observation of atoms, which can't really be observed in the classical sense, that we derive the fundamental forces and properties that give rise to charge and mass, it's in the *tangles* of space/time operations that we now want to look in order to complete our ecology and therefore start working on the book-keeping. It is the hierarchical knotting that we should start considering the most fundamental, not the classical, reductive picture that we are so fond of where reality breaks down into little well behaved spheres with intrinsic charge, spin, and mass.

[14]Kind of like Wile E. Coyote running over the edge of a cliff and 'forgetting' to fall. The time it takes light to propagate is the time that the universe has 'forgotten' to tell us that the particles are no longer in the correct place, or containing the correct momentum.

Chapter 6
A Statistical Mechanical View of the Universe

So finally, after all that priming, we have almost all the pieces we need to put together our picture of what the Big Bang really looks like and how our universe is situated with regards to us right now. The last few pieces we'll need to cover are dark matter and dark energy, both of which arise from direct observation, and we'll cover the theoretical basis for dark energy, namely the cosmological constant.

Keep in mind, however, that what we're building, in consistency with what we've stated so far in the text, isn't so much a direct, literal picture or set of instructions on how to see the universe or imagine it (which would look like a nice clean narrative that is linear in time), but instead a non-linear set of engineering instructions on how to *build* such a universe, aka what attributes might we be able to *engineer* in order to understand the early universe more deeply, and the subtleties involved in specifying the differences end up telling us something just as interesting about the very small as they do the very big or very old, which requires that you put away the linear narrative, and start with a list of attributes that we then attempt to piece back together, admitting that it is a difficult and arduous process at best.

6.1 The Engineer's View of the Universe

Dark Energy and Dark Matter

The next thing we should clear up, however, is the difference between dark energy and dark matter. Despite the parallelism, the two things are really fundamentally different. Dark matter, even though it can't be accounted for with the current standard model of particle physics, is much less mysterious than dark energy. Neither of them absorb or emit light, hence the term dark, but dark matter refers

G. Bascom, *On the Inside of a Marble*, Astronomers' Universe,
DOI 10.1007/978-3-319-60690-3_6

to the stuff we can't see but we know is there, while dark energy is stuff that we can't make the fabric of space work without, somehow woven into empty space itself.

Here's what dark matter is. If you look out at a nearby galaxy and measure the mass composition of everything in it, even if it takes some educated guessing, and then use various tricks to measure how big it is, you can use all that information to calculate the max speed the whole galaxy can be spinning around its axis without flying apart. It turns out that if you do that, and then use red shift data to measure how fast the galaxy is actually spinning, for almost *any* galaxy we can see, things are moving much too fast for the gravity of the galaxy to hold it together! There's a bunch of mass missing! This missing stuff, i.e., all the mass we can't see, exerts gravity but does not interact with light, or heat up (which would theoretically produce some infrared light), leading to the technical name of Cold Dark Matter (or CDM).[1]

What's more, we can also use a funny effect called gravitational lensing to precisely pin-point where all the dark matter is in relation to the galaxy itself. In short, if a galaxy happens to be behind some dark matter, gravity bends the light that is traveling through the matter. From our viewpoint the galaxy will appear broken into different pieces, as if we were looking at it through a glass ball. The nice thing about this effect is that we can use it, together with the other inferred types of gravity calculations (like the one involving max rotational speeds), to get a pretty good estimate of where all the dark matter is, even if we can't look directly at it.

While many people are still working on exactly where it all is, the more inclusive questions have to do with *what* it is, how it got there, and why it's so cold. These questions are particularly intriguing because there's a *lot* of it out there. Specifically, there's about five times more of it than ordinary matter, and even more exciting, if you chart out where it is the universe starts to look a lot less sparse than we thought before. A giant sponge-like backbone of our cosmos emerges, threading through all the galaxies and super clusters all the way back to the edges, or we could say beginning, of the cosmos. In fact, all this missing mass starts to make our simulations of the early universe look a lot more realistic, accounting for much of the fine structure.

Dark energy, however, arises from something much more esoteric. It's true that we covered some practical effects of relativity in the text before now, but I spared you the formal derivations of space/time invariance relations, which is really where the idea of dark energy comes from. In short, when Einstein and colleagues were working to extend special relativity, which deals with local relativistic effects, to general relativity, which deals with universal relativistic effects, they were working on the equation that stitches the space-time fabric to the behavior of the universe as a whole, which is mostly dominated by gravity. They found that they had some leeway in how they could manipulate this equation, with very different effects on the

[1] It was originally called dark matter by Fritz Zwicky, who first predicted it in the 1930s.

outcome, i.e., what the equation was describing physically. In one case, if gravity was the only thing to dominate, that would describe a universe where the space/time fabric would stretch slightly with time, describing a non-static universe as a whole. Einstein, assuming a static universe, added a constant to balance the stability of empty space with the effects of gravity, leading to what he assumed was a correct picture of the universe, aka one that is static and unchanging.

Soon after, however, the expansion of the universe was observed by Edwin Hubble. Hubble, using recently discovered 'standard candles' and red shifts to determine the distance of distant galaxies from earth, along with their velocity. After plotting these distances against red shifts, he found that for every distant galaxy he looked at, it was not only moving away from us, but that the farther away it was the faster it was *receding* from us as well! The most common analogy I've heard to explain this effect is one involving cooking a raisin filled loaf of bread—if you are a raisin inside the loaf while it cooks and the entire thing is expanding, it will look like all the other raisins are moving away from you and the farther away they are the faster they'll seem to be running away. What's more, the same will be true for *any* raisin in the loaf, whether that raisin is in the center or not! This is what hubble found, that *all* of the galaxies are moving away from us, which means that space itself is expanding with time!

In short, Einstein was wrong about the static universe within his equations, a point that he later conceded to call his "greatest blunder." This led to him taking out the constant, now describing an expanding universe which was expanding at a relatively constant rate, but should be slowing down over very long times due to gravity. Since the 1990s, however, advances in telescopes, CCDs, and computational algorithmic power has led to the systematic searching for supernovae in even *more* distant galaxies than those looked at by Hubble, allowing for us to greatly extend Hubble's distance/speed curve, almost all the way out to the big bang. Unexpectedly, Saul Perlmutter and others found that the rate of expansion is actually *increasing* over long distances, sending all the cosmologists into a tailspin of excitement. In other words, Einstein's constant was correct all along, but it was on the wrong side of the equation! Importantly, though, the term is an energy term, meaning it is an energy that doesn't interact with matter but does pour in leeway for the stretching of space/time ever so slightly across large distances and times.

The other analogy people use is that if you were to throw a ball very hard into the air we could envision three scenario's. In one scenario, the ball falls back to the earth eventually, in another, it escapes the influence of gravity and starts floating off into space at a constant rate, and finally, a scenario where it escapes gravity, *and then starts speeding up*. This last scenario is the case of what happened with our universe, except the big bang is the throw and the speeding up refers to the expansion of empty space. What could make it be doing that? Regardless, the term looks like an energy and it doesn't interact with light, so we call it dark energy. We don't know what it is, it's more of an effect than a physical thing we can observe, as opposed to dark matter.

Suffice to say, however, that dark energy, whatever it is, is much more intrinsic to the whole system of rules and how we derive them than dark matter. Almost more excitingly, however, $E = MC^2$ allows us to estimate the equivalence that this energy has compared to the mass composition of the universe and the results are *staggering*. It would seem that dark energy makes up 63.8% of our universe! These two developments, along with the recent theory of inflation, make up the bulk of our current picture of the universe, which is generally called the standard model of cosmology.[2]

The Narrative as We Know It

There's one more recent development in cosmology that we should consider before moving on, and it has to do primarily with the early universe. It's not entirely canon yet, but it solves some problems so it's worth mentioning. In the late 1980s, Alan Guth developed an idea that would later solve one of the most puzzling issues with the Cosmic Microwave Background. In short, if the quantum fluctuations Stephen Hawking showed are necessary to form the inhomogeneities seen in the Cosmic Microwave Background (CMB), and therefore form all the galaxies and things we see today the CMB shouldn't as uniform as it is. The fluctuations needed to be in thermal contact for there to be so much correlation, but the time frame of when they had to be in contact didn't match any of the models we had at the time. In short, Guth and colleagues suggested the early universe underwent a period of rapid expansion, where space/time rapidly *inflates*. This leads to a new model, where most of the making atoms and photons all happens in less than a second, and then nothing happens for a very long time until galaxies start forming. For our purposes, we'll just say that in the same way the universe is expanding, and its expansion is accelerating, there was a time when it blew up very quickly and then slowed down, but then started to speed up again later.

Apart from inflation, however, the way that the big bang theory became accepted over the steady state theory I mentioned last chapter consists of two independent observations. One is the existence of the CMB itself, which was predicted independently and then later verified experimentally. The other is that the theories predict that the big bang produced all the light elements in certain abundances, and we've since confirmed those abundances by direct observation.

After we were able to confirm where the light elements came from, for a long time after the biggest question was how did we get the *heavy* elements. Later it was shown that stars produce the heavier elements like helium as byproducts of the nuclear explosions within them, and that even heavier elements are produced during their last final explosion, i.e., supernova, which then blasts those heavy elements into space where they collect into small rocky planets like ours.

Remember when I said in Chaps. 2 and 3 that a complete narrative history of our universe is impossible? What I meant was that a *precise*, deterministic narrative is

[2]This is formally called the Lambda-CDM model or ΛCDM where Λ is the term that refers to dark energy in general relativity equations, and CDM stands for Cold Dark Matter.

impossible. Using our trusty probability based tricks, however, we have been able to constrain the narrative to something cohesive, even if the story only says something about the averages as a whole, much like how we use math to describe something like a wave or a tornado. We aren't trying to trace the paths of individual hydrogen atoms from the big bang through a certain sun and then into a carbon atom and then into you, but we know that carbon had to have come, at some point in time, from a dying star.

To summarize, the view of our universe that has been validated by experiment goes something like this. The early universe, whatever it was doing, expanded super rapidly, like some sort of giant bomb going off, but not a matter bomb, but instead a *space* bomb, which means that instead of the early universe heating up, which was already very hot, cooled down and left a nearly uniform wall of photons that we call the CMB. It then continued expanding, although the rate at which it is expanding has gone down and then back up at least one time since then that we know of. Quantum fluctuations in the early expansion led to giant hot spots and cold spots sufficient to form the galactic fibers we now observe, except there's also this dark stuff threaded through the spots that eventually became populated with galaxies, and there's tons of unknown dark energy pouring into the whole universe in alarmingly high percentages. The best observations we have suggest that normal matter only makes up about 4.9% of the stuff that's in the universe, where dark matter makes up about 26.8%, and dark energy makes up 68.3%. What's more, the vast majority of the universal matter are light elements, and the complicated heavier elements are something of a special case arising from the way that stars go out rather violently, coughing up heavy elements which then form the small rocky planets we live on, which are only small pieces of the puzzle that we are considering here.

6.2 A Coherently Concurrent Universe

Now we're going to do something difficult, but hopefully you'll see all the previously discussed ideas come together. Remember the analogy we drew about making a movie you that you're also starring in that doesn't have a script? We're going to return to that analogy, but this time we're going to add some conditions to show how the problem becomes even *more* interesting when there are symmetries to consider, and then note that the resulting picture starts to look like something we see in statistical mechanics, as opposed to the more classical fundamental physics problems.

Consider, for example, the most basic problem we run into in statistical mechanics. Instead of being interested in a single definable object in focus, we have a very large number of atoms in question, in three dimensions, and they are more or less randomly ordered and go all the way to the edge of our field of inquiry. We are tasked with determining not only the identity of the object, i.e., whichever object these atoms collectively compose, but *also* what that object might be doing mechanically, if anything. Additionally, due to difficulties with how we interact with this system, we can either make freeze frame image type observations (i.e move around much faster than the atoms within the system) or we can keep our camera in one spot and wait a long time (i.e., move around slowly compared to the system) but no other options are available to us. If, in both cases, we take meticulous notes about what's happening in our frame, and use that information to deduce what is going on outside of that frame, can we build up an adequate picture of the system and its mechanical behavior?

Let's start with the slow moving approach, where we hold the camera in one place and wait indefinitely until we have enough information. How long will it take to decide what is going on with the system and what it composes? Depending on how limited the view is compared to the total size of the object, there are only a few cases that will allow us to decipher information about what might be happening to atoms very far outside of the frame.

Think of it this way. Let's say we identify the composition of atoms within our viewfinder, and we note that there is a mixture of silicon, potassium, carbon, calcium, and oxygen. We could be looking at limestone, glass, parts of a computer chip, or even sand. So we count up all the atoms and get a percent composition and say, okay it looks like the composition is closest to sand or glass, so it's pretty safe to say that we're looking one of those two correct? What if, however, we notice that while we're counting up the number of atoms within our frame, it's changing, because some atoms leave the frame and some enter, and they don't enter at the same rates? So we have to wait a while and continue to count, and eventually if the average stops changing, and the composition *still* matches sand and/or glass better than a computer chip or a solar panel, then we will confidently posit that we've narrowed our scope, and we're sure it's either sand or glass.

How about deciding between glass and sand however? Is it impossible to tell the difference if our frame of reference is too small? Even more tricky, what if the answer is that it's not glass *or* sand, but instead it is sand *in the act of being heated* from the outside and melting into glass? Just in case, maybe we should take a cue from our thought experiment from Chap. 4, and start cutting frames? This would allow us to screen a bunch of the local low-frequency modes and start seeing only the larger motions right? There are difficulties with this approach, as we saw in Chaps. 4 and 5. Every frame you cut out introduces a delay, so the very best you can do is report some portion of the total trend, and even then you have this frame matching problem—if something about the trends you are watching has a changing normal mode (fancy word for the average vibrational frequencies) then you will need to be actively changing the frame rate, and pretty soon you are very far behind what's happening in real time, only reporting a delayed version of the past. We may find that the object *is* glass when we cut lots of frames and observe the final form, but will obfuscate the possibility of observing that it *is* a mixture at the time we start observing!

Before doing that, seeing as it requires we wait until the whole mechanical process is done and over with, let's instead consider what the other option might tell us. In this case, we freeze the entire object and move the camera around. Notice how now we're going to start running into problems we ran into in Chap. 2, but we also gain some possibilities as well. We can no longer deduce velocity, which makes it difficult to track anything that is time-dependent or field-like, but we can check to see what the total density looks like at any given spot, and maybe we can find if there are any edges to our system, any place where there are fewer atoms on average than there are elsewhere. This might help convince us that the composition measurements we made before were accurate throughout the whole object, but it will do little to tell us about the 'having melted', 'melting' or 'not melted at all' possibilities to consider.

Maybe instead we should look at the boundaries, to see if we can see cracks or areas of low density which will indicate that it is sand and has not melted at all yet? Now we start to run into a similar problem as in Chap. 2, in that if there is a boundary that we can see now, it may not be a boundary in a moment from now, and what's more, from our viewpoint it's impossible to tell if a boundary corresponds to a crack forming, a preexisting area of low density like we find in sand, or sand melting *into* glass. They will all look identical!

So, in the end, we're going to have to use both, but it's going to be tricky. Now we move the camera slow enough that we can watch things evolve in time but we also allow the camera to move around. We follow cracks as they form (or perhaps they are *un*forming) but how can we know the difference without waiting until the whole thing is over? You may be tempted to measure the entropy of the system, but remember that in order to get an entropy measurement we have to know the total temperature, which may be changing with time, and the local melting might be finished by the time we measure the temperature! This is especially tricky if the item is doing something tricky, like being heated quickly and expanding simultaneously, which allows it to cool adiabatically.

Let's reiterate, what if our system is doing something that introduces a hierarchical tangle? Again, let's say the system was injected with heat, which caused it to expand, but in expanding it is losing internal pressure (or density if you will) so it is simultaneously *cooling* itself as well, and in an indirect kind of way the amount of heat put in determines the amount of cooling we should see? How could we determine that such an event was occurring in the system as a whole when we can only watch a single window, and only one at a time?

Well, what if we start by tracing some specific wave, let's say a wave that is focusing all its energy down into one specific location, like a whip crack that will result in a pop of atoms somewhere. So we have two directions we can move to follow the whip, we can either move towards the source, where we will find that we need to slow down and cut frames, or we can move away from the source and towards the target, where we'll need to continually zoom in and add frames if possible. In the case of slowing down and chasing the source, we're going to lose the specific direction of the wave, in the same way we missed the melting, like in Chap. 2. When we start adding frames and zooming in to chase the target, it will be difficult to know what our source looks like, similar to difficulties we ran into in Chaps. 3 and 4.

So let's chase the target. What if, as we add frames and zoom in, we realize that the target is spontaneously moving? Note that I don't mean any actual specific thing has moved spontaneously, I mean that the *projection* of where the whip will crack, might become spontaneously unpredictable. Let's call this a skip, because it looks like the determinacy of our whip is skipping around, or the *correctness* of our predictions is skipping around. If we really are in a system that is unstable and therefore undergoing hierarchical tangles (i.e. the injected heat is cooling down the system), we would actually *expect* to see these kinds of skips, and this will stand as evidence that our system is doing something like that.

Okay so we found the skips, but we can't simultaneously follow a whip so as to assign the skip label *and* slow down and zoom out so as to view the source of the wave, so how do we build up a complete picture of our system? Here's what we do, and it's all we can do, and hopefully it starts to sound familiar, because I laid out the whole process chapter by chapter for you but I just didn't give you this analogy yet. We start by writing down, meticulously, all the different kinds of indeterminate skips we can find, and we assume that each of these skips corresponds to a specific kind of change *in the system as a whole*, similar to our universal sources and sinks from Chap. 5, similar to the marble heating itself while simultaneously cooling itself. Then we start classifying the skips, looking for any underlying taxonomy. In order to do that, however, we have to come up with a way to compare the skips, and as such we're going to have to change our data into something we can actually compare.

For example, if we suspect that one spontaneous skip is the product of the system losing some energy as a whole, then we're going to wait until we think we have another skip that came from the same systemic issue. Then we're going to have to compare the skips, which is difficult because we can't just compare the position, or the velocity, or even the changes in velocity directly, we're instead going to have to take both waves, translate them so as to be in the same Cartesian position, rotate them so that you maximize their overlap (i.e., superimpose their progress on top of each other as best we can), and *then* we can compare the skips and decide if they look the same, i.e., if the skip is in the same direction as the velocity of the wave (energy was taken away from the system as a whole) or the skip is in the opposite direction of the wave (energy added to the system). Once we can start to see that there are layers to how many different kinds of skips we can observe (i.e., one skip looks like the obfuscation of one rotation and one translation unit, another looks like the obfuscation of one translation and two rotations, etc.), then we're ready to move onto the second part of the puzzle, i.e. tracking down the sources. This is when, finally, we zoom the camera outwards and cut frames to see if we can start to see energy going into the system and/or coming out of the system in a way that matches whatever we found in the skips.

Think of it this way. Imagine you have just moved to a new house and you're sitting around minding your own business and suddenly you hear a loud pop coming from inside a wall. If you know something about that house, or the environment the house lives in, you might be able to venture a guess as to what is happening. Perhaps the temperature just dropped and it's windy outside, so you can safely assume the house is readjusting to the system it lives in, hence the pop. The other alternative is that the source of the change came from *inside* the house, like say a resident in another room down the hall has decided to push on one of the walls, and this is causing the house to readjust its weight ever so slightly in such a way that it pops somewhere near you.

In keeping with our analogy, however, if you *don't* know anything about the outside of the house because the outside of the house happens to be insanely far away from you (because say you were the size of a flea, and the pop was the size of a fraction of a fraction of a grain of sand) it would be very hard to venture such a guess as to the source. You would instead have to resort to the process I described above. You would need to get in real close with the pop's and make some meticulous measurements, deciding if energy was being imparted to the system, or leaving the system, and then turn around and try to measure what kinds of sources are common ways for the house to gain or lose energy and try to match a source to your pop.

That whole process, as complicated as it is, is the most basic picture I can paint of what physicists are doing at the quantum level and cosmological level when we talk about what stuff is made of or how the universe started. The skips in continuity correspond to the four fundamental forces, or virtual particles (if the source of the skip is coming from outside the system in a hierarchical tangle), or the fundamental particles (if the skip is coming from inside the system but from some place a long time ago), and the process of superimposing the whip cracks so that we can compare them properly (aka lining them up to sit on top of each other) is called gauge theory.[3]

The most difficult thing to see, however, is that energy which appears to be moving in/out of the system as a whole but without a discernible source, must be entering due to hierarchical friction such as the marble heating and simultaneously cooling like we described earlier. These tricky little instances are what scientists call *virtual particles* because they seemingly pop in and out of existence, depending on how you interpret the math. It's important to note that the "popping in and out of existence" is engineering speak to say that in order for the calculation to work, or to smooth out the unpredictable nature of how particles interact with each other, we need to make a giant cosmological tweak in the indeterminate part of the narrative, i.e., add another particle somewhere in the past and then take it away again sometime in the future to make all the book keeping work out, just like we assume the house is readjusting itself on some timescale which is discernible to the pops, making them appear to move chaotically.

The house, in this example, however, is not the current observable universe, but the *whole history* of the observable universe. In the engineer's view of the universe however, it's not that the universe is 14 billion years old, but that we have about 14 billion years worth of tape to cut up and reassemble in a way that lets us figure out what the pops are and where they are coming from. Keep in mind, however, that if the beginning of the story is fundamentally unknowable, then parts of the middle and parts of the end will be fundamentally unknowable as well, and empty space itself, at all times, should look like a seething boiling cauldron of virtual particles popping in and out of existence, which is exactly what we see, and we call it the vacuum energy.

[3]This name was originally introduced in analogy with rail-road tracks, where the spacing between ties was referred to as the gauge. It's less intimidating than it sounds.

6.3 Inflating Quantum Space

The next question, although it may seem like a logical leap, is to ask what happens if we to take empty space and stretch it so fast that the energy of acceleration of the stretch is on par with the energy of fluctuations of empty space itself. Could we somehow get a signature of empty space that we could measure in our blown up system?

Since the 1990s, this has been one of the burning questions in cosmology. Alan Guth's proposed process of inflation posits that perhaps the early universe suddenly expanded in just such a way, and the search for direct evidence of the fact has become much of the focus of cosmological research in the last few decades. A few years ago an experiment called BICEP2, working with land based measurements from the south pole, purported to have found evidence of inflation based on polarization measurements of the big bang, which would have been evidence of gravity waves in the early universe. These results were then reported excitedly by news outlets all across the world, only to have other researchers like Subir Sarkar to point out that the source of the signal involved may have been intergalactic dust. After several months of intense interrogation, it was concluded that the source is indeed most likely dust, so the theory remains unverified by experiment. Future endeavors to find definitive proof of inflation are now being planned, involving a dedicated satellite like those that mapped the CMB originally (Wilson Microwave Anisotropy Probe or WMAP, and the Planck Satellite) but with the ability to detect polarization as well as intensity.

Let's note, however, that part of the reason we needed a dedicated satellite to map the CMB has to do with how fiendishly uniform it is. The truth is the variations in that signal are incredibly small, about half a thousandth of a degree Kelvin from spot to spot. The other thing to note is that when we map it, we're not mapping a three-dimensional space, as much as a two-dimensional surface painted on the inside of a giant sphere, of which we are on the inside. We are, in a sense, mapping the *relief*, of the texture of the big bang, more than we are an actual three dimensional system.[4] If you then assume that the hotter spots of the big bang correspond to what are now empty spots in our universe, and the cold spots in the big bang correspond to where there's lots of matter (dark or not), you can actually put together a simulation of the early universe that fits with observation.

Remember, however, that the CMB, as we discussed in Chap. 3, depends on something undetermined in terms of classical dynamics. It depends on something *quantum mechanical*, something fundamentally undetermined. So how can we get away with that? Shouldn't the indeterminate stuff not be able to predict where the determinate stuff happens? Here's how inflation solves this problem, and this is why it's the leading theory. Inflation says, as simple as it may seem, that *space* expanded

[4]To paraphrase Roger Penrose, instead of treating the big bang as a point, we really need to think of it as a surface. Even if that surface does collapse down into a very tiny space depending on how far back you go, it is still a surface more than a point.

really fast, fast enough to sort of "catch" quantum features of the early universe and blow them up to cover the entire inside of the sphere that is the observable early universe. The idea of space expanding is not new, we've had empirical evidence of the fact for over almost a century now, but the revolutionary idea, if you will, was that space expanded *so fast* that it literally *caught*, much like a dreamcatchers net is supposed to catch dreams, the natural roilings and broilings of empty space that we know go on at extremely fast time scales. In a sense, the claim is that the CMB, which is essentially a record of the hottest thing we know about, contains within it a signature of the *coldest* thing we know about, empty space itself.

Think of it this way. The early universe was so hot, so dense, that all matter must have been melted into a plasma. A plasma is the technical term for stating that all atoms have broken apart, and all the atoms have lost their electrons, so instead of individual atoms, you have naked nuclei and electrons, so dense that it's really hard to envision anything interesting happening in it. It must be almost perfectly uniformly spaced, so even though empty space is expanding (but at rates much slower than inflationary empty space), the resulting system should be perfectly uniform in every direction. But if everything was perfectly uniform as it expanded, then how could gravity make the atoms form clumps to form the first suns, and then later galaxies and planets and so on? The argument is that the expansion of empty space exploded so fast that tiny little virtual particles popping in and out of existence, or at least the field that causes them to pop in and out of existence, was stretched out across the sky, which made the ionized nuclei clump every so slightly more in some places (those places were empty space was a little hotter) than other places (those places were empty space was a little cooler), at which point gravity takes over and everything starts acting like we know and love.

In fact, this picture works very well, if you write down all the equations and take the CMB and use it to simulate the early universe, (adding in dark matter and dark energy) you actually get quite a nice picture of our modern universe popping out! The determinacy of the early universe holds, and the math can trace us all the way up to now.

What, however, does all this mean for our discussion of narratives versus engineered big bang events? We don't know! This is the part of the text where I get to say that we just don't know. In fact, we don't even know if inflation is the correct theory, since it remains to be verified experimentally, even though simulations provide pretty compelling evidence that we're on the right track.

Despite this picture seeming to work out, however, we have to keep in mind that the math, as correct as it is, has a hard time saying that we're really describing the *beginning* as opposed to the *recipe* for how to make a big bang work. What we still don't have any idea about, is whether we are really looking at the *beginning* when we look at the big bang, as opposed to looking at a list of the hottest things ever imagined, ordered in a list because we lack the ability to fully understand the narrative quite yet. The two main players are relativity, which gives us the idea that space is something that can contract and expand depending on the observer, and quantum mechanics, which gives us the idea that empty space has energy to be stretched out.

There is one last thing to mention here, however, before we get to move on to speculative theories about what all this means. The first is that relativity says two very important things that we have to keep in mind. The first is that whatever is true at the big bang, which we're now calling a surface, is true for *every* observer, *everywhere*, as long as they are looking far away from whatever place they are in currently without moving. So the same thing should be true for everyone inside the observable universe. The second thing to keep in mind is that while relativity seems to hold for small particles, we don't yet know what happens in places of very high gravity like inside black holes. So the thought that the *beginning* is what the big bang corresponds to in a relativistic sense is not necessarily true. This is precisely what the quantum gravity formalism is attempting to do, reformulate the mathematics such that it allows for the singularity to be treated as just another point on the timeline.

While it's still speculative, such a shift, namely moving from the big bang being the beginning of everything to the oldest we can see, would constitute something of a new rupturing of the giant glass ceiling the catholic church once imposed on scientists. It allows for the cosmos to be infinitely bigger in both time, and space, and helps solve some more problematic aspects of the big bang picture, along with introducing a whole host of new and perhaps even more exciting questions.

Chapter 7
Putting the Future at the Beginning

To close our discussion, we get to talk about the future of cosmological research, and this is where I get to finally give my honest opinion about several competing, albeit fantastical, modes of thought surrounding our universe and what it's truly made of. The holographic principle, for example, is often held up as a sort of inaccessible liturgy born of mathematics that nobody really knows how to understand; reminiscent of the days when lay persons were told to trust the words of the bible even though they were written in Latin. Simulation theory has increasing appeal as we sink deeper into our virtually constructed digital environments. Grandiose solipsistic interpretations involving giant watchful eyes or independent observers at each end of the universe seem to be as old as civilization itself. The multiverse is now a serious contender among scientific interpretations of the recently uncovered Higgs mass, and the list goes on and on.

7.1 Anthropic Notions

One thing to note, however, is that while these proposals are based in an effort to unify a maddeningly complicated set of seemingly incompatible ideas, very few of them offer convincing track forward for scientific inquiry. They have good intentions, and some of the more rigorous ideas, such as those coming out of string theory will come back to help us later even if not via the routes they were originally designed for, but the underlying framework of these fantastic ideas doesn't seem to fit the more basic framework of progress, and I'm going to take the following sections to explain, in my opinion, why.

To understand them, however, without delving too deep into another set of chapters, we're going to organize them loosely around what scientists have recently begun to call "the anthropic principle." Basically, when scientists were working on the equations of the big bang that determine the fundamental constants

G. Bascom, *On the Inside of a Marble*, Astronomers' Universe,
DOI 10.1007/978-3-319-60690-3_7

(the magnetic moment of an electron, the charge of a proton, etc.), if you change any initial conditions, those numbers come out vastly different, describing universes that presumably couldn't sustain life or planets or stable elements. This is unsettling for many cosmologists, and this in part led to the notion of a multiverse. The basic idea is that, all possibilities that *should* be possible, according to the math, *are* possible, they just exist somewhere either very far away or wrapped up in inaccessible parallel universes of some sort.

In other words, according to the math, our particular configuration of universe isn't particularly special. If that's true, and it may just be one of an infinite number of possible universal variations, then why did we end up in this one? You can see how in plain English this sounds a lot like a tautology, kind of like asking why does the word 'why' ask why? The only logical answer would be to give some history of the word why, but that's precisely what we're missing when it comes to the big bang, there's no narrative history for anything before it, and any speculative history is just speculative and not falsifiable yet. As such, the answer that comes to mind in plain English, is that 'we just are!' We observe *our* universe because it's the one we're in! Again, you see the tautologies inherent in this response, but despite the shaky ground that this argument lays, many scientists have built various notions based on it, and they fall under the umbrella of 'anthropic' principles, the coin termed to point out the anthropocentrism inherent in that answer.

We can break down the various anthropic arguments, however, into three classes: what I call creational, reductive, and narrative based anthropic proposals. Creational anthropic proposals place observers, namely human or some other form of life-like observers, at the end of each unknown. Reductive anthropic proposals place the hierarchy of laws at the end of each unknown leading to things like string theory, and narrative anthropic proposals propose an unseen narrative to explain why we are in this universe, leading to the idea of a multiverse. Here's an example. Say you woke up in a video game and somebody asked you for your top three hypotheses for why the video game is the way it is, and not some other way. You might answer that either (a) somebody made the video game and it's made in their particular style, (b) the rules inside the video game are such that they require the video game to be the way it is, or (c) there are lots of video games possible, but some specific story led to this game being the way it is. The first would be the creational video game argument, the second the reductive video game argument, and the third the narrative based video game argument. Each of the corresponding anthropic arguments have been recently taken seriously by physicists or philosophers, and as such we'll briefly discuss each in its own class. Then we'll propose an alternative notion, where a bona fide objective approach removes humans from the equation, *rejects the entire question* of tautological enquiries, and simply states that *the correctness of representation* is what we should be trying to understand, as opposed to asking why the word 'why' means why.

Creational Anthropic Constructions: Simulation Theory

The first class of cosmology based epistemologies are what I like to call creational anthropic arguments. The basic premise is that in order to make all the paradoxes with our universe work out, we need to place a conscious observer at each paradox, be that observer a deity, a future version of ourselves, or some malevolent set of A.I. machines harvesting our internal energy. In this view, anytime there's something you can't really understand, you can trust that the simulation masters are navigating things at the head of the controls of the universe. Note, first of all, that this theory requires that there *exist* any such controls, which immediately requires a rather uncomfortable pivot. It requires that someone, somewhere is either all powerful (like a deity), or much more advanced technologically than we are currently, hence them being from the future. The latter two versions of this thinking are at the heart of what has recently been rebranded as 'simulation theory,' also sometimes called computationalism.[1] It states that it is impossible for us to know whether we're actually living inside a simulation, and that if you run the numbers, the chances of us being in a simulation are very high whereas the chances of us being in the original reality are small.

First of all, it is not possible to construct hypotheses to test for blind or silent creational intentionality governing our universe without trying to get into the heads of our simulation masters, so to speak. The argument is infinitely regressive, making it very difficult to argue in detail. No matter where it starts, the conversation abruptly stops somewhere up the totem pole attributing all the unknowns to some constructed person whose existence we have no direct evidence for.

More importantly though—the whole line of reasoning resembles the notion of Descartes' demon. The argument is that if you put a brain in a vat and commission demons to try and trick the brain into thinking that it is actually in a place experiencing things, mainly by manipulating the afferent and efferent nerve endings coming out of the brain, the brain wouldn't know it was actually in a vat somewhere, right? To accomplish such a thing, how many demons would you need? How smart would they have to be? Without going into the details, no matter how smart they are, no matter how much information you gather and give to the demons, there will always be a tempting solution for the demons, namely to supplement the fake reality with something real. In other words, it will always be easier to supplement the construction of the *representation* of reality with *actual* reality. What's more, if you want a reality as big as the reality we're in now, it would require as much energy as our current reality requires, which means you should just use actual reality instead of the virtual reality! There's a lot to unpack in those statements and this text isn't really the place to do that, but just note that Descartes' demons are not unlike Maxwell's demons. The amount of information required to complete the representation of

[1] I use the word rebranded because it is, essentially, identical in form to almost every major religion since the beginning of religion, it just incorporates computers which seems to give it a shiny new validity.

reality becomes comparable to the entropy gained in cooling Maxwell's Demon's box, which means you can never make spontaneous energy, much like you can't make spontaneous reality that isn't based in actual reality somewhere, and *that* reality will require more energy to maintain than the real reality, so it will always be cheaper to just use actual reality. The argument against simulation theory isn't so much that it's not possible, it's more that it's not sensible for any virtual reality very large, and even less so when we have an abundance of normal cheap reality down here to exploit.

In fact, as we start to understand more and more about new emerging theories, and in particular information theory, we can now see that maintaining representations takes *either* energy *or* time delay (just like in Chap. 4), meaning that a perfect simulation of the universe would either have to exist somewhere in a place with infinite energy or be on a very long time delay from when it started. These are fun ideas in that they tickle our collective imaginations, but they really don't give us anything back in terms of solving theories or stitching our epistemology together, they're more just self gratifying thought experiments that lead us, over and over again, to that tautological precipice we grappled with in previous chapters.

Even if, given a whole bunch of allowances, creational anthropic arguments may be strictly *possible*, that doesn't mean that they are likely, or useful, in interpreting our cosmos in a way that allows us to move forward and deepen our understanding. We'll continue our discussion of this interesting version of Occam's Razor in the next section, where we'll note that a more capable description of reality does not always denote a more simple, or accurate, description of reality. The prime example of this, in my opinion, is string theory and the accompanying holographic principle.

Reductive Anthropic Constructions: String Theory and the Holographic Principle

Some of the more substantive anthropic arguments, however, are a bit harder to unpack. Included are arguments that place the system of rules, or the hierarchy that we attempted to rupture early on in this book, at the cause of knowns and unknowns, assuming that a perfect representation of reality is possible given enough energy and resources and initial conditions and math. This view, if you recall from the early chapters, replaces the idea of biology with applied chemistry, chemistry with applied physics, physics with applied mathematics, and then it's math all the way down![2] You will also recall that the point of this text was to reject such a tidy pyramid, simply by noting that when we include the specifics of a narrative, various supplemental observations rupture the structure, leading us to a deeper understanding of how we do science.

[2]Or up, depending on how you think about it.

If we suspend this suspicion, however, just for a bit, we can understand the basis of where the various complications that are string theory, and by extension the holographic principle, come from. The construction goes like this. If you find there is a physical system you cannot describe with traditional physical laws, the next step is to design some clever mathematics which accurately represent the system, and then re-interpret reality based on those new mathematics, which we are then tempted to think of as a ‘deeper’ notion of reality.

Take, for example, the idea that you can observe a particle that, instead of moving through space in a nice and continuous trajectory, pops in and out of existence between point A and point B. I can’t possibly make my physics describe such a thing without going back to question the entirety of what the universe is and how the whole system is irrevocably complicated, so I do something kind of rash and illogical, but that will solve the problem for the time being. I decide to just add a dimension, and define my three dimensions as being what I can measure, and the fourth as being hidden to me. Now I can easily write down a function that traces where the particle goes in four dimensions, and say that it only pops in and out of the third dimension where the path in the fourth dimension happens to intersect the other three.

There are a few things to consider here. First of all, if we reject the notion that the mathematics constitute the ultimate appeal to truth, and instead treat it as another *possible representation* of reality, we don’t necessarily think that the particle is actually popping in and out of some other universe or dimension or whatever, we just note that it pops in and out of existence at point A and point B, and that I can now tell a computer how to represent that trajectory without further caveats. Second, note how we’ve solved a problem in representation by *adding* a layer of complexity, as opposed to simplifying competing variables. Much like Ptolemy’s calendar, which is to this day the rigorous mathematical standard to which we compare all our astronomical representations, is not necessarily more *true* than the physical reality of how planets move, the mathematics is a correct representation of what the stars look like to us, and so we use it literally every day and have done so for thousands of years.

Essentially, this is what string theory is. It has, by adding more and more dimensions (there are about 11 in most versions nowadays), managed to predict all sorts of important quantities from first principles. In many ways, it’s like a very complicated computer program that, even though it goes about it by way of various algorithms where each step may not be totally necessary, manages to arrive at the correct solution to a very difficult problem. For example, say you asked a computer to add two numbers, and instead of the computer breaking down the two numbers into their individual components and combining those components and then returning the correct number, it instead mines the internet for instances where each number is mentioned in conjunction with the question asked, found the answers that people had given, and decided on the best answer based on probabilities and blind association, which is indeed the correct answer. It’s not that such an approach isn’t useful, or even incorrect, it’s that it doesn’t offer the deeper understanding that mathematics does where it anchors each operation to reproducible empirical observations.

String theory, without having a very good understanding of how it maps to the physical reality it is describing, uses extra dimensions to describe ‘strings’ which, when they vibrate in 11 dimensions can predict the charge of a hadron with high accuracy. If you then take that theory literally, and consider its interpretation the deepest and most correct representation of reality, you come up with the holographic principle. Holograms, without going into too much detail, refer to a constructed representation of a three dimensional object using more than three dimensions to do so. The holographic principle states, put very simply, that the extra dimensions described by string theory are literally real, but we can only see three of them, where extra information contained in the other eight dimensions is being projected onto our three dimensions. As such everything you see and interact with is more of a hologram, or a version of reality that doesn’t contain all the information that is governing its behavior.

Unlike the creational anthropic arguments, this has more meat. It very much may end up being correct, although recent trends are moving against it. Only time will tell, as the predictions that it makes are very difficult to substantiate empirically. Regardless of whether it ends up being true in a literal sense, however, doesn’t detract from the fact that the framework developed within it is very powerful mathematically, and it will be used for a long time in some form or another in a variety of disciplines. Perhaps most pertinent to our discussion here is the understanding that adding hyper-dimensionality to objects can enrich our understanding of them, even if they do not necessarily bring a deeper notion of a reductive reality.

Narrative Anthropic Constructions: The Multiverse

There is one last contender for alternative interpretations, and it is probably the strongest contender we can move forward with, even though string theory enjoyed a similar standing not so long ago. Narrative based anthropic constructions, admittedly where the term “anthropic” started being used in reference to cosmology at all, are very simple. They state that maybe we’re in the universe we’re in because it happened this way. In other words, instead of asking why things are the way they are, ask what happened, and as the *narrative* stitches together, perhaps we can use possible deviations from said narrative to construct alternate possible universes with different characteristics. The more speculative corollary to all this, and I emphasize the word speculative, is that once you *envision* different possible exotic realities, it’s easy to jump to *believing* that all possible universes exist somewhere, hence the term multiverse. The last part of that theoretical jump comes from a line of reasoning pioneered by Hugh Everett III proposed in 1957, in attempts to solve the Schrodinger’s cat paradox. Basically, he proposed that there might be an infinite number of simultaneous realities all sitting on top of one another, and they all exist every time a decision is made or something happens by chance, where the alternate reality lives somewhere out of reach to us.

Can you see the similarities with string theory? By adding some indeterminate number of possible alternative descriptions, you can envision (albeit less clearly than string theory) that you can solve some paradoxes, but only in increasing the complexity of the solution. The less speculative versions of multiverse theory claim that the parallel universes are not parallel, just in some place very far away where we cannot see or touch them, like our universe is one bubble inside a larger bubble of a universe with entirely different fundamental constants.

Similar to simulation theory, however, multiverse notions are difficult for many cosmologists currently because they are not falsifiable. This reason alone has split the scientific community directly down the middle, even though they have widely different interpretations of what a multiverse consists of in detail. The reason this line of thinking is the most promising, however, is that it relies on narrative, which is what the scientific picture is largely missing. It assumes that the mathematics cannot wholly sustain itself as the ultimate appeal to truth, that we must also have some Popper like empirical measurements, which are what leads to the possibility of observing different results for initial conditions and hence difference kinds of universes. Keep in mind, however, that the assumption that just because the math says it's possible that there are other universes out there, that does not mean that there actually are, nor does it mean that we'll ever be able to see them.

The more important question, instead, is what can we say about the parts we *can* measure and see.

7.2 Alternative Theories of Information

While these interpretations all have a basis in a deep desire to paint a coherent worldview, the math and the physics are less supportive. While they may *allow* for these interpretations (although the jury is still out on most of them), they miss some important points that need to be made along the way. In truth, we're due for a few revolutionary new ideas in thinking on these topics, but it's unclear exactly where they're going to come from.

An idea that revolutionizes our understanding of physics and cosmology will need to be holistic in the sense that it allows for greater flexibility in stitching the cosmic narrative to the behaviors of atoms and fundamental forces, but not in the sense that we need a mystical watchful eye do so. Instead, the best new ideas follow new modes of thinking brought on by advances in technology while allowing for an instantaneous integration with the existing frameworks, even if it stretches those frameworks in new and exciting ways.

For example, in Einstein's book, *Special Relativity*, Einstein opens by explaining relativity with observers on trains. While the examples are great ways to help rework our intuition, the setups look suspiciously similar to the kinds of inventions Einstein would have been reviewing in the patent office at the time he was developing some of his most famous ideas. Considering that the proliferation of continental travel had made time-keeping a new and challenging problem, combined with the fact that the speed of light was shown to be constant for all observers, one can start to see where these ideas began to germinate for him. Einstein simply extended a solution he worked out for a problem that emerged with advances in technology, namely one of timekeeping on trains, to a solution involving time-keeping with our own planet as a sort of train, moving through the solar system. Eventually, he extended this solution to *all* of time and space, even if it took him several decades to do so.

So what are the advances in technology that we have enjoyed recently that help reform old questions in new and interesting ways? The number one candidate so far: computation. In fact, advances in information theory, which deals with how we encode information in order to be processed mechanically, may hold one of the more promising keys as it is now being applied to the field of quantum computing. In short, information theory is the study of how efficiently information can be transferred from one encoding scheme to another, even if there is noise on the channel through which the message is sent. For example, if we assume that we want to send a message across a telegraph, but there's already lots of random electricity moving through the wire, then what's the most efficient way you can modify your Morse code to transfer the message? The answer, which is anything but obvious, actually relies on a concept pioneered by Claude Shannon in 1948. Shannon defined an important concept called *Shannon entropy* which is similar to the entropy you find in thermodynamics. Instead of saying something about the ordered-ness of your system, however, it says something about the maximum amount of information that can be encoded depending on the number of equally possible outcomes that encode a given *piece* of that information. You can also think of it as the ordered-ness of the information, or at least the code that we use to represent that information. Interestingly, it also gives you a relationship between say, how much heat your computer will generate in terms of how many operations it does in order to complete a task, and the efficiency of the code used to tell the computer how to perform those operations. Can you see how valuable that relationship is?

The concept has all kind of useful applications across the board, including neuroscience, thermal physics, ecology, cryptography and so on. The moment it becomes interesting to our discussion, however, is when it is applied to *quantum* computing. You see, in regular computing the most basic unit of information is the bit, which when encoded in binary (i.e., 0 or 1) will give you a nice Shannon entropy that is easy for coders to work with. When you increase the dimensionality of the bit to become more than two discrete states, however, the concept of Shannon entropy has to be extended to it's quantum correlate Von Neumann entropy. Von Neumann Entropy behaves differently and the details are pretty complicated, but the more interesting relationship arises when we ask about how to optimally encode information using qubits and then try and reconstruct regular bits from our qubits. What the theory says, as counterintuitive as it may seem, is that the optimal way of encoding *quantum* bits does not overlap with the optimal way of encoding *classical* bits—so even if you get a speed up in information transfer by using quantum bits, decoding the quantum message will always be the same speed or slower than using classical bits in the first place!

Now, this doesn't mean that quantum computing is useless, on the contrary it has very promising applications in all sorts of calculations, but what it means is this. No matter how you try, you cannot define a system of codes, even ones that use quantum information (which is theoretically not bound by normal speed of light laws), that transfer *classical* information faster than the speed of light. In the same way that Maxwell's demons cannot create spontaneous energy based on information alone, information *itself* cannot be created spontaneously via the method of encoding, only transferred, and that transfer rate will always be limited to the speed of light, even if the physical process representing that coded information is *not* limited by the speed of light.

Do you see the parallels with our previous thought experiments? How the fastest a change in representation can be achieved when you're trying to represent everything through the lens of cameras filming cameras is real time? How in each chapter we ran up against the same cap, whether it was fundamental friction or fundamental unknowables or fundamentally indeterministic quantities?

A message cannot be sent faster than the speed of light, even if entanglement can travel faster-than-light, but it is problems with the *encoding* phase that makes this true, not the physics alone per se. Representation itself, from an engineering perspective, cannot cross time and space faster than light, no matter what the system is that you devise.

But what does that mean? The striking similarities between these various concepts and epistemological quandaries found in cosmology often leads to the last fantastic notion that I'll introduce in this book, namely that the universe is *made* of information. The thought is that maybe the physical universe, and all the weirdness in quantum mechanics, is really just a reflection of giant quantum computations being performed by the universe in need of doing some calculating. What do you think? Does it sound a lot like simulation theory come out in a new form?

Let's think about it another way. To start, what do we mean by information? Information is, by definition, a system of encoding, meaning it is not an intrinsic thing that can operate in a vacuum. In the same way you can't use Newton's third law without *two* bodies, you cannot have information that exists without several working parts. You can't have semiotics without both the reference and the referent. In essence it goes like this—as long as this thing x is doing motion x, we can assume that this other thing y will be doing motion y. That is what we mean by information. The laws regarding the universe can be defined, in terms of information, by representing all of it's constituents as a reference to something else in some encoding scheme, and the encoding scheme will have redundancies and not necessarily be complete.

Now keep that definition of information in mind, namely one that requires a *system* of interacting objects, as opposed to some deterministic fundamental qualities that can be applied with infinite promiscuity, and think about a dry ice bomb going off under water. Have you ever seen one of those? The explosion doesn't happen cleanly, it expands rapidly, then shrinks, then expands rapidly again, and moves through several of those phases before calming down.

Now imagine that you are, and have always been, living inside the explosion, mid-explosion. Not only that, but your entire civilization and all the laws and rules of existence have developed inside the explosion, entirely before the initial phase before the explosion will reverse direction and start to implode. What will happen to the rules? Something very complicated. What information theory predicts is that the rules will stop working if you happened to imbue them into every object inside the explosion with an intrinsic reductive nature. If, however, you developed a system of *information*, where every object is defined in relation to another object within that system, then the rules stand a chance of correctly describing the underlying nature of the explosion and perhaps even predict the reverse of flow from explosion to implosion, because the process you are living in is one that has to be defined in real time, and there will always be some amount of inconsistency, relativity, or incompleteness in the rules. It's like going from a prediction about what an engine will do without interacting with it, to a prediction about *how a given trend will change* as you change something else that is intrinsic to the process of the engine, as opposed to just the individual pieces of gas igniting in the combustion chamber.

You have to allow for *hierarchical tangles,* which can happen in information space even if they can't happen in physical space. Then, using our tricks from previous chapters where we embraced the informational tangles and tried to build a taxonomy of them, we can move into probability space and possibly find a new theory that correctly understands the transition from explosion to implosion, even though we never had access to the outside of it and don't have access to the end of the movie that is still in the act of happening (namely the dry ice bomb going off), much like we tried to do in the previous chapter where our image of our system was limited by how we can interact with it. In essence, information theory, as opposed to reductive physics, treats this kind of thinking as the ultimate limit governing how we think about rules. We use probability, as opposed to intrinsic law, to determine the maximum rates at which you can rely on a prediction based on the information taken from measurement, noting that the system cannot be complete without *sources* and *sinks* we use to work with our hierarchical tangles and sloshing timescales to keep our book-keeping honest.

There are a lot of details to work out, but in my own opinion, information theory, and in particular its relationship to thermal entropy on the cosmological scales, represents one of the more promising ideas we may be able to use to move forward with the questions on hand. It helps us understand the universe as something bound by rules, even if they aren't rules based on reductive approaches. They are instead rules based on maximum and minimum possibilities having to do with the speed of light and the speed of information as a matter of book-keeping. The fastest thing that can be represented and the fastest a representation can be transferred into another representation, is the speed of light because that happens to be the rate at which the evolution of the universe is proceeding, the rate of the explosion we are all living in. In fact *light itself* is the act of making something change at max speed, not the other way around. The max speed at which informational tangles can be untangled is *the speed at which the universe is happening*, which is also the rate at which representation can be transferred. The universe has its own agenda off somewhere in the future, and we are stuck inside a delayed representation of it, based on about 13.8 billion years of tape.[3]

7.3 Conclusive Repetitions: A Periodic Universe

Despite my enthusiasm, however, information theory may not turn out to be the best way to understand the unknown narrative of our cosmos, and that would be okay. There *are* fairly concrete predictions we can make about the future of cosmology, but we should never think that the end is around the corner. We can predict that the future will not focus on tautological epistemologies like simulation theory, but instead it will focus on deciphering the moment that things go from being determinate to indeterminate in our universal timeline and coming up with new ways to grapple with that conundrum. We can deduce that the revolution will be in realizing that our representation of time breaks down at the extremes of measurement, but we cannot know what new puzzles this will bring. Perhaps the big bang will not necessarily describe the beginning, but instead something anthropic that looks like a beginning but also an ending because ultimately it is describing the cycles which we are observing and those cycles will depend heavily on the future, as well as the past that hasn't finished happening yet.

In a sense, the big bang surrounds and carries our local little bubble of observable universe through time, much like our planet floating through space. The point I tried to make throughout this text, however, is that the floating is from fast to slow in time as much as it is in space, gently carrying us from one moment to the next, smoothing out inconsistencies and making our little bubble seem conveniently smooth and classical on the inside.

[3]Along these same lines, I recently read that Alan Guth and Sean Carrol are working together on a theory that proposes that there may not exist a universal maximum or minimum to entropy, despite it having long been assumed that there is. Basically, from the limited material available so far, it looks like they propose a giant universal shift in our cosmic direction of thermal entropy (which happens at the big bang) kind of like how our magnetic north and south poles flip every couple hundred thousand years and we don't really understand why. Such a universe would place probability back at the bottom of our epistemological engine so to speak, displacing the more exotic possibilities like cosmic observers or 11-D strings. It would also make our timeline effectively infinite, the way that we think space is effectively infinite. The idea is very appealing, mostly because it does something that most cosmologists have been trying to do in some form or another for a long time, and that is to make our universal timeline cyclical and infinite, but *without* being an infinite cycle. The timeline itself is what becomes infinite, the cycle just one of some number of possible cycles. The neatest part, for me, is noting that the physical laws pop out of the book-keeping in these systems. Nothing *created* anything, the big bang was the act of it being rearranged, but the same elements won't necessarily rearrange the same way the next time around. Lee Smolin also has some interesting theories about a Darwinian mechanism pruning successive universes that offers more alternatives along these lines that are worth checking out.

The further we press against this nice neat classical bubble of an observable universe, however, the more we come back to our feeling that there must be more, the questions are never fully answered. When we imagine our universe in one smooth fluid movement from the beginning to the end, we'll never get it quite right, even with a lifetime of effort. Regardless of what we do or do not or cannot know about things like singularities, information entropies, tiny little atomic tornados or perfectly balanced wave crests floating through our empty space, the puzzle always deepens, always raises more questions to be asked. The march of inquiry moves forward, ever widening our universal intuition. As our equations, symbols, computers, and experimental setups become more and more sophisticated, our vision of the universe and how it is laid out around us sharpens.

The main difficulty, however, is that it's often unclear whether we're really looking at the beginning or the end of the problems when we focus our collective gaze, but there is beauty in that. In the way that there is excitement and satisfaction in realizing that one has come to the end of a puzzle through a hard won conclusion, these conclusions *always* raise more questions than answers, and the process goes on and on forever, kind of like the universe itself.

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