

H. Chris Ransford

The Far Horizons of Time

Time and Mind in the Universe

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Second - therein lies a tale. One of my earliest memories is a class at primary school - it had to be primary *one*, because that’s when they teach about time and clocks. The teacher, a kind old man - although any man at any age must have looked positively ancient to us youngsters - was telling us about the time and its subdivisions, an hour, a minute, a second, and how they were clearly marked on the faces of our then exclusively analog watches.

He then volunteered a pretty odd comment which instantly indelibly etched itself on my young impressionable mind.

I still see him, wistfully peering at the bleak outside weather lashing the classroom’s window panes with rain, when he mused half aloud, probably more to

himself than to us: *“Some people say that there exists a sixtieth of a second too, but that’s just much too small - it does not exist.”*

This odd pronouncement puzzled me endlessly, and the manifold questions arising from trying to make sense of it just wouldn’t leave me alone. We were also then learning about distance and I recall thinking that if I ran as fast as I could across the schoolyard, then a sixtieth of a second or perhaps even less would be the time it would take to maybe move by an inch or less. I also remember thinking that if we kept adding up enough however small fractions of an inch, then we would inescapably end up with the yard’s full measure - and then some, and that in order to run the length of the yard I had to run those small distances first, in whatever time it took to do so - much certainly less than a sixtieth of a second each. The more I thought about it, the less this pronouncement seemed to make any sense at all.

Then time passed and I learnt about calculus - i.e., adding an infinitely large number of infinitely small things - and then even about languages: whereas there is no formal word in English for a sixtieth of a second exactly - a number of words, such as a jiffy, have been proposed but somehow never jelled - a number of other languages, such as both German and French, do have a definite word for it. Thus, my old teacher’s pronouncement appeared doubly wrong - a sixtieth of a second did exist after all, it wasn’t too tiny, and adding up very many vanishingly small things did yield up measurable, ordinary, tangible outcomes.

And yet - because time is almost certainly discontinuous in our universe, the old teacher’s pronouncement was, in its essence, not so wide off the mark - albeit wrong by many orders of magnitude as to the actual measurement value of a time quantum. My kind old teacher, who set me wondering about time early on and whose name I now cannot ever hope to recall, rates a special acknowledgement here.

Last but not least ... the readers, who by reading science books demonstrate that the spirit of enquiry is alive and well, and that a society that keeps asking questions and investigating themes well beyond immediately utilitarian ones is a society that enhances human experience, as such eminently worth living in.

Introduction

This book is about Time. The mystery of what time actually is leads perfectly sane people to insist that time cannot possibly exist and is nothing but an abiding illusion. Others offer starkly contradictory theories as to what time actually is.

Trying to understand time, we must soon drill down ever deeper into the nature of reality itself, for time simply cannot be apprehended on its own. To understand time, it turns out that we have to understand wider reality, of which time is but one component. This quest ultimately leads to unexpected conclusions, which will be explored in this book. During this exploration, further questions will inevitably arise. Understanding the nature of time demands that we first apprehend the context in which it plays out – that we delve into the very weft and fabric of reality itself. We will on occasion find that some of the questions we ask have a way of shifting and reappearing elsewhere rather than simply resolving themselves.

A number of popular science books as well as more academic treatises have addressed the subject of time before – by authors such as Stephen Hawking, Dieter Zeh, Paul Davies, John Gribbin, Igor Novikov, Huw Price, Roger Highfield, Max Tegmark, Martin Bojowald, Adam Frank, Sean Carroll, Roger Penrose, and Lee Smolin, amongst many others. This book, while building on well-established findings, investigates areas of enquiry that have somehow been overlooked so far. By doing so we are able to present a new handle on time and how it may relate to the most complex structure in the universe, the human brain, and thenceforth to every single one of us.

The first six Chapters lay the necessary groundwork which will then enable the reader to seamlessly follow new ideas developed from Chapter 7. Chapters 10 through 12 build up the background to the main argument, which is explored in Chapter 13. The rest of the book deals with examining the main argument and where it leads.

Extensive use of end notes is made in this book and decision as to whether a particular passage belonged in the separate end notes rather than the main text was not entirely straightforward. Thereby three criteria have been used in determining where it should belong:

First, would the passage disrupt the smooth flow of the narrative or even lead to a wandering off-tangent. If so, the passage has been moved to notes.

Second, whenever a context or a proof or justification for a main text assertion is called for, but presenting the proof in the body of the text would disrupt its narrative, because the point of the narrative is *not* the proof of the assertion but rather the consequences that flow from it.

Third, whenever a particular passage entails further context or ramifications and/or consequences which are worth noting, but which would exceed the narrower scope, or point made in the main text. In such case this further context is mentioned as a note.

Within the main text some passages are indented. These passages delve somewhat deeper into the background of an argument being currently made, but may be safely skipped without impairing the ability to follow the argument.

Prologue: Walk Towards A Distant Star

For all the efforts expended into exploring and trying to understand what time is, open questions still remain. Far from being overly arcane, these questions - and their surprising answers - build directly from well-known and widely accepted results of science. As a case in point (amongst many others), let's look at the odd but by now well-known way that simultaneity, the quality of two events happening at the same time, works within relativity.

Start walking towards a distant star.

Because of the way time, distance, and relative speed interplay in Einstein's relativity, your current-time simultaneity with events and things (whatever they may be) on that star, relative to what it was a few seconds prior when you were still standing still, has *by the simple fact of the act of walking*, jumped ahead by something like a full day (1): you have instantly become simultaneous with events and things on that distant star *one day in the future* of the events you were simultaneous with just a few seconds earlier when you were still standing still.

Now turn on your heels and keep walking in the opposite direction - you are now walking *away* from the star, and thereby have become instantly simultaneous with events on that star which actually took place *yesterday* with respect to the time when you were standing still, and therefore with events no less than a full *two days* before those you were simultaneous with when you were walking *towards* the star. Why it is so is a well-discussed and understood consequence of relativity.

An intriguing question which immediately arises from this strange relativistic simultaneity can be presented as follows: what happens if you contrive to have parts of your body moving *towards* the star, at the same time as other parts move *away* from it? Or more specifically, what happens if you arrange for parts of your brain to move towards the star, while other parts of your brain move away from it, for instance by spinning around your body axis? You would then seem to be in the rather odd position of being fully simultaneous with events that are however not themselves simultaneous with one another. Such questions will be explored further in the following pages, which will lead to astonishing new landscapes of reality.

Of course, it has been known for quite some time already that time is not straightforward and cannot always simply proceed from past to future. The more simplistic notions of time have long since been laid to rest by a number of puzzling and repeatable experiments.

For instance, by a category of experiments called *delayed choice experiments*. Such experiments have a basis represented by the following example: Imagine that a group of teenagers are playing in a courtyard, idly kicking a football towards a wall. There are two open doors in that wall. Sometimes the football goes through one of the doors, sometimes it bounces back from the wall, and sometimes it goes through the other open door.

Now shut either one of the doors. Obviously the football will now either hit the wall or the closed door, or go through the open door.

At the atomic or subatomic level however, delayed choice experiments go like this: the football is replaced by a subatomic particle, and the doors by two narrow slits set apart from each other. Both slits are open and a totally random decision as to which slit will then be shut will only be made *after* the particle has gone through one of the two slits. The random after-the-fact decision as to which one of the two slits shall be left open turns out to somehow *always* coincide precisely with the slit which the particle has already gone through, as if nature itself could accurately peek ahead of time into the still unknown outcome of a *random* future event, thereby accurately knowing which slit was going to be left open. All kinds of elaborate theories involving the environment, thought processes, the measuring apparatus, the nature of randomness, and so on, have been investigated to try and explain this result. The bottom line is that there is no broad consensus as to which explanation is the right one, but what is certain is that all of these possible explanations shake at the notion of simple linear time.

The apparent odd nature of time also manifests itself in myriad other ways. For instance, through the so-called Bell inequality test, or Bell's theorem.

Bell's Theorem was discovered by Irish physicist John Stewart Bell (1928-1990) as a means of testing whether or not particles connected through quantum *entanglement* can somehow seem to communicate information faster than the speed of light. This involves a situation where two objects have somehow become associated at some time in their past, and thus become 'entangled', also sometimes called *correlated* (we'll explore later on what 'correlated' precisely means in this context. For the time being, in the absence of a precise, mathematically defined meaning, it's just a specific way of describing linked subatomic particles, associated in some mathematically definable fashion.) Now here is the odd part: experiments have confirmed that either one of the pair of these correlated objects always reacts *instantly* to changes affecting the other one, irrespective of the distance that separates them. In other words, a correlated object reacts *instantly* to a change affecting its mate, *before* any signal from said mate, traveling at the speed of light (that is, at the fastest possible speed of anything in the universe) could possibly ever have reached it. It works equally well with more than two correlated objects. Here again, many purely physical explanations were sought at varying degrees of complexity and exoticism, but a convincing ultimate physical explanation is still elusive. We will cite those attempted explanations in these pages, and find another explanation through the mathematics of something called the *wave function*, a mathematical entity associated with particles, molecules, and objects (which we will be looking at at some length in Chapter 7.)

From the twin consequences of Bell's theorem and how distance, speed and time interplay under the laws of relativity, we will be led in Chapter 13 to the conclusion that in order to resolve a conundrum in the physics of time, we are led by mathematics itself to postulate the prior presence of a consciousness before any physical reality

can be actualized (thereby rediscovering, as we shall see, results foreshadowed by other physicists, such as Martin Bojowald et al., who approached the question from a different perspective.) The conclusions discussed later in this book will in turn lead to further questions, such as what is the nature of the mind and thought, and crucially, what vehicles or media are needed to harbor them. On this basis, time could be seen as not being a fundamental and indispensable building block of a larger universe. Searching in depth for a definition or for the nature of time ends up shifting the problem over by one step: to understand time we are led to search for something further, and the findings of where the mathematics leads will be described.

It is worth noting here that a key point about science is that it is readily understandable by *anyone*, despite the oddly abiding conventional wisdom to the contrary. Relativity, in its main results, is a spectacular case-in-point. Arthur Eddington once famously opined that only three people in the world could understand relativity. Nothing could be further from the truth. Far from being difficult to grasp, anyone with just a little bit of common sense can immediately and even intuitively understand its key themes and outcomes, described further below.

The key first result of relativity is the invariance of the speed of light, regardless of the frame of reference it is measured in. The term ‘invariance’ in this instance is meant to state that its value does not ever vary, regardless of how and when we may be measuring it. Now this result seems at first sight very counterintuitive and hard to believe, so let’s look at it more closely.

If a car travels, say, at a speed of one hundred mph towards you and you in turn travel towards that car at 50 mph, then you are getting closer to each other at a combined speed of 150 miles per hour (which is the combined speed between the two of you.)

Following with the converse of this example, if the car travels towards you at 100 mph but you travel *away* from the car at a speed of 50mph, then the car nears you at a combined speed, i.e. at a relative speed, of its 100 mph speed minus your receding speed away from it at 50 mph; resulting in an overall speed of 50 mph.

So far, very straightforward.

But with light, it does not work this way. Regardless of whether you travel *towards* a light front travelling towards you (at the speed of light, about 186,000 miles per second, usually denoted c), or whether you travel *away* from that light front, that light front will always, in terms of its relative speed to you, be travelling at the same unchanged speed of light c . In each example the speed of light is constant, regardless of your own speed, which can be as close as you want to c itself (2).

Now this may sound counterintuitive, but as you will see, after a bit of thought it can be seen as obvious. For the time being, suffice it to say that the reason why it is thus is because speed alters time itself. When you travel towards the light front at any speed, this speed alters ever so slightly the ‘duration value’ of what your second is - just so that it comes out that the light front still travels towards you just at c , instead of the greater, combined speed: in effect, your time shrinks a little, and the

duration value of your second becomes slightly less: this is the reason why still only 186,282 miles are travelled within that second. Should you travel *away* from the light however, whereas intuitive thought would suggest that the relative speed between the approaching light front and you has slowed up a bit, in fact your time stretches a bit instead - just exactly so that during one second, light still travels 186,282 miles.

Subjective perception of time and speed, incidentally, do not change in the slightest at any rate of speed. For instance, if the Earth stood still instead of travelling at high speed through its surrounding space, we would age faster and yet would not perceive it at all: time would seem to pass at exactly the same rate of one day per day.

Here is a simple illustration as to how to intuitively apprehend this key aspect of relativity. The reasoning is through proof by contradiction, meaning that we will assume the opposite of what we want to demonstrate, to wit that the speed of light behaves like any other garden variety speed (i.e. the same as an approaching car's velocity). This will eventually lead to absurd inconsistencies, which will only be resolvable through the adoption of an invariant speed of light.

Let's say that a car crash occurs at point A (a location on a road), at exactly 12 noon. Two cars collide head-on and one of the two drivers, Mr. Paul, is instantly killed (we posit a fatality because this provides a stark, unequivocal, irrevocable event. No one dies twice, so that if two outside observers happened to somehow see this accident and Mr. Paul's death differently, this could only be attributed to the observers themselves or to their separate acts of observation, and certainly not to the independent, unique event of Mr. Paul's death.)

At point C, some distance away, an immobile observer sees the accident; she sees it at the moment when light, having reflected itself on the crash scene, enters her eyes (and is processed by her brain. Let's assume that the observer in C has superfast eyesight as well as a superfast brain, and is able to process instantly any information hitting her retina. This assumption is made for the sake of not carrying too much baggage around in this discussion - it does not alter anything in the unfolding argument.)

Thus, the observer at point C knows of the accident at time 12 noon *plus* a tiny fraction of time which we'll call ϵ , which is the time needed by light to travel from the crash scene to the observer's retina.

It so happens, however, that there is another observer at point B, midway between A and C:

A _____ B _____ C

This observer at B is not immobile, as C is, but mobile, and it so happens that she passed at point A precisely at 12 noon, at the very time when the crash took place. She took an instantaneous digital picture of the crash at A when it happened, and she is travelling towards C at almost the speed of light (actually, observer B's exact speed is ultimately immaterial to the argument.)

When she reaches B, she beams an image of the picture of the crash to C. This image is sent by radio waves (a form of light with a different electromagnetic wave frequency but the same speed as ordinary light - just like, say, red light and green light, or infrared or ultraviolet, have different frequencies but travel at the same rate of speed.)

Thus, the digital image taken by the second observer in A is sent from point B at the speed of light towards C, by an observer travelling herself at the speed of light.

Hence, the speed of the image travelling between B and C is twice the speed of light: this image arrives at C at a speed of one half ϵ (the time necessary to travel from A to B is half the time necessary to travel twice that distance between A and C, which is ϵ) *plus* one fourth ϵ , which is the time needed to travel between B and C at twice the speed of light, i.e. an overall total time of $\frac{3}{4} \epsilon$.

In other words, the digital image of the crash arrives at C *before* the direct eyewitness observation at C. Looking at the picture, the observer in C knows of the crash before she can see it.

So far, so good, this scenario is not obviously impossible, so let's keep going in a recurrent fashion: onboard the vehicle by which the second observer travels, there is a small rocket with another observer. This third observer fires off the rocket in B and starts towards C at the speed of light, and from this rocket sends by radio wave a copy of the digital image.

It can be calculated to show that this image now arrives in C at time $\frac{2}{3} \epsilon$, faster than the earlier $\frac{3}{4} \epsilon$ and also quicker than ϵ .

We can keep going recurrently, both by moving the point B all the way to A (the digital photo is sent as it is being taken) and by having a series of rockets which all serially launch themselves from their immediate foregoer. We end up in a scenario whereby the observer in C receives an image of the crash at the exact same time when it occurs (which would be equivalent to the speed of light being infinite.)

Now we can move the point C all the way to, say, Alpha Centauri (some 44 trillion kilometres, or 27 trillion miles, away from Earth) and observer C still sees the crash as it happens, since under this scenario the speed of light is infinite.

We reached however this conclusion that the speed of light is infinite by making the earlier assumption that it was finite (it took time ϵ to reach C) and that it spread outwards from whatever event it was witnessing, so we're seemingly ending up in a place where the speed of light is both finite and infinite. Something has to give. Since separate experiments show very clearly that the speed of light is *not* infinite, then it follows that the only implicit assumption in the above reasoning - that the speed of light is not an invariant - is false.

Ergo, the speed of light is unchangeable regardless of any circumstance - an invariant.

This can be interpreted in a number of different, equally valid ways. Brian Greene submits the following analysis:

A road leads due North, and a car embarks on a trip along this road. The driver travels at an unchangeable, set speed of 100 mph.

After a few miles, the car turns into another straight road that heads Northwest, at an angle of 45° to the previous road. The overall speed of the car continues to be 100 mph, but the speed component towards the North only is now only of 70 mph. The reason why the northward speed has lessened is that a part of the speed has been diverted, *drawn off*, and put to another use - to wit, creating a speed component towards the West.

Something similar applies in relativity: the faster you travel, the less you age (when seen by an outside observer), because a part of your speed of ageing has been *diverted* towards lending you physical speed. This illustrates the physical, material equivalency of time and space embedded in relativity. As Brian Greene unforgettably puts it: '*At rest, we all age at the speed of light*'.

This interplay between speed and time brings a host of consequences. Such as, the concept of simultaneity becomes relative and not absolute, and therefore dependent on speed and distance. In the foregoing example, Mr. Paul dies at 12 noon, but he is seen to die at 12 noon plus ϵ by the witness in C, and at other times by other observers.

Such usual sentences as two lovers saying, for instance 'at the very instant I was thinking of her, she was thinking of me' have become, in one fell swoop, meaningless - although not by much: under ordinary conditions of time, speed, and gravity the differences are vanishingly small. On the face of it, however, the sentence would seem to have to become a rather less romantic 'at the very instant I was thinking of her and travelling at a speed component towards her location at such and such numerical value....'

The difficulty of interpreting observation and experimental results is of course ever present in science. Even when all possible precautions are taken to shut out interpretations that accurately represent reality, long gone are the days when simple experiments could unambiguously settle a question or hypothesis one way or the other. The interpretation of experimental results sometimes seems to conjure up the old tale of the madman who was in the habit of hanging cloves of garlic over his door. When a neighbor asked why he did that, the madman answered 'to keep the vampires away'. 'But, there are no vampires', rejoined the puzzled neighbor. 'You see, it works!' happily quoth the madman. Sometimes, interpretation and analysis of scientific evidence carries strong whiffs of the madman and his garlic.

Further compounding the above, the issue of subconscious *cognitive bias* may sometimes color or warp ideas and interpretations and give rise to unwarranted and unrecognized, implicit assumptions. In his book 'A Tear at the Edge of Creation', Marcelo Gleiser argues that even the search for a 'Theory of Everything' (also sometimes called TOE for Theory of Everything, or GUT for Grand Unified Theory, a theoretical framework which would unite all of the various areas of Physics into one coherent whole), a search that underlies much research in current theoretical physics and is seen by some as its 'holy grail', in fact stems outright from cognitive bias in

the minds of physicists and that there are no *objective* prior grounds to believe that a Theory of Everything should exist in the first place. Whether or not we are suffering from implicit assumptions can be subtle and hard to recognize (3).

Quantum mechanics, physics' most successful theory so far and also one of the most counter-intuitive, originally arose from the necessity to explain *experimental* phenomena that could not be understood any other way. As the physicist Dieter Zeh once put it, 'Believe me, quantum mechanics was based on observation - no one in their right mind would have ever have come up with such a weird theory of reality if it had not been squarely based on repeated observations and the need to explain puzzling experimental results.' And yet - the *incontrovertible* experimental results of quantum mechanics have so far given rise to no less than about 30 different formal interpretations, and counting, of which some fourteen are major, 'mainstream' interpretations. These interpretations are often mutually contradictory and exclusive, yet every single one of them is predicated on the selfsame observations and experiments.

Staying within the realm of quantum physics, the interpretation of the basis underpinning quantum computing (4) constitutes a further corroborating point (one of many, and we'll meet with a few more along the way). David Deutsch, a well-known Oxford scholar and pioneer in the field of quantum computing, says that the fact that quantum computing works *proves* that parallel universes exist, that there is no way that quantum computing can work other than by taking place, at least in part, somewhere in other, 'parallel' universes. Other scholars disagree. Both sides present compelling arguments.

But it's time to look at time.

1 Time - *Part 1*

The question of what time is has long fascinated philosophers, poets, songwriters, and scientists. For the latter, the question is slippery: time is a non-observable, i.e. something that cannot be observed or apprehended by means that do not, directly or indirectly, include itself. Every direct scientific attempt to grasp time seems to wind up somehow depending on time itself, so that such attempts lead to circular definitions, whereby time ends up being both a means toward *and* the object of its own definition: judge and party, as it were.

We will review the various guises of time: time as an emergent property of non-empty space, as an extra dimension or dimensions, or as something else. Sometimes proof seems to be found that time, in fact, does not exist at all and is but an abiding illusion, nothing but a mirage arising from being caught within the confines of three dimensional space. But we age, remember yesterday, and witness the effects of time everyday, and this just cannot be the whole tale.

As we shall see, all of these interpretations and approaches work to a degree and tend to be correct at some level or other and work well within a set context, but they never seem to give the full answer; they leave us with a nagging feeling, buttressed by other considerations firmly rooted in physics, that they do not reveal the whole story. A coherent understanding of what time is must work across the whole gamut of both science and human experience.

2 When is Now?

Time is regularly separated out into three distinct components, the past, present, and future. We may seek an answer to the question of what time is by looking separately at these three components.

The *past* still only ever abides in our *present* memory or memories of it. It is as though we live in an eternal present, and reality, life, and time itself all stream past before us, carried along by an ever-changing swirl of events. It would be tempting to believe that we somehow live outside time (solipsist philosophers have tried this approach), but unless we are not our bodies, it does not work: we grow, age and die, thereby somewhat unfortunately proving how firmly anchored within time we are.

We live in the present: our whole lives happen there. But if we think about it for a minute we must surprisingly conclude that the *present does not seem to exist*. Had not Einstein once commented in frustrated puzzlement, in a conversation later reported by Rudolf Carnap, “*There is something essential about the Now which is just outside the realm of science*”?

The French poet Alphonse de Lamartine echoed the same feeling when he once pled “O Time, please just freeze for a moment!” (5) There is no single instant of time, however small, that we somehow can seize hold of and safely call ‘the present’. By the time we even begin to perceive a moment in time or apprehend an event, no matter how short, it already firmly lies in a fast-receding past. As the boundary wedge between the past and the future, the present needs to have a *non-zero* thickness to lay claim to actual existence. But no matter how close and hard we look, the edge between the immediate future and the fading past seems to have no materiality at all and no existence.

Maybe a good way to try and analyze the issue is to again reason by contradiction, and put what-if scenarios to the test: if the present does not exist, then perforce we *live either in the future or in the past*. Do we then exist in a fast receding, very recent past, or in a not yet materialized future, rather than in a non-existent, indefinable and ungraspable present?

We demonstrably cannot be living in the future. However immediate, the future is not yet materialised, and we do not live our lives immaterially. Hence, we do not live in the future.

Could we then simply define the present as an arbitrarily short time-slice of immediate past? This does not work either. There is no *qualitative* difference between a point in time one second ago or 5 million years ago: the difference is only *quantitative*. To say that we actually live within a brief slice of time bounded by two time boundaries which both lie within the immediately recent past, is not qualitatively different from saying that we live sometime last week or last year.

Moreover, there is mathematical proof that we do not live in the past. Downstream in time, the past is now set and immutable: it is cast in stone, and we can no longer change it (6). However, our lives are *demonstrably* not robotically playing out

foreordained scenarios: Heisenberg's Uncertainty principle, which we will cover more at length later, effectively forbids immutability, and indeed, predestination (7). Therefore physics, via the uncertainty principle (named after the physicist Werner Heisenberg) demonstrates that we actually do not live in the past.

There are a few possible ways out of the conundrum of what the present is.

One possibility consists simply in resolving the whole issue by taking the view that time does not exist. Time itself would then be an illusion. This approach has been tried in various ways, such as eternalism, also called the *block universe* view, or in a different rendition, the *growing block universe* (8): The block universe view directly derives from viewing time as a dimension, qualitatively no different from height, width or length: the universe is made up of a block of four dimensional space-time, where the four dimensions, three spatial dimensions and one of time, make up a coherent, four-dimensional space-time. Following a recurring theme when discussing time, it will be shown in this book that there is overwhelming evidence both that this view is at least in part correct, *but* that it is not the whole tale.

Yet another possible solution consists in saying that within our universe, time is not continuous. Under this view time would be made up, for lack of a better image, of a strobe light-like succession of extremely short moments frozen in time, when nothing can change, anywhere in the universe. Time would then proceed from one moment to the next by discrete quantum 'jumps' from one node to another, a succession of infinitely small frozen presents on an underlying time grid-like loom: the weft of time would be discontinuous (also called *discrete*.)

Various combinations of these interpretations could also work: time could be a discontinuous dimension in a wider block universe already containing a future, or an emergent property of the universe whereby time is either continuously created, or generated by a succession of frozen instants, or something else.

Before we can proceed and explore these and other solutions to the conundrum of now time, we *must* arm ourselves with a few simple tools.

3 The Time Explorer's Toolkit

The French philosopher Auguste Comte was probably the first to observe that there is a top-down (broadly pyramid-like) hierarchy in how nature builds upon tiered foundational layers to yield up the rich, multi-tiered reality we experience. Closer to us in time, the physicist Richard Feynman once described the universe as an endless series of onion-like layers, each layer presenting us with a fresh set of comprehension challenges.

This hierarchy is directly reflected in the sciences. Simply put, physics, or equivalently the laws of physics, allows physical chemistry to happen, which in turn enables chemistry which then enables organic chemistry which enables biochemistry which enables biology which enables psychology which enables, say, criminology. Of course, in reality it is slightly more complex, both because there are many more layers and any given layer may spawn several parallel sub-layers, in such a way that smaller pyramids begin at every level, but also because of the phenomenon of 'emergence', which we will be looking at more in depth later on, but which in essence means that at any deeper level of the pyramid, new phenomena that were in principle not foreseeable at the immediately higher-up level might crop up.

The question is, of course, what sits on top of physics, the uppermost layer in the foregoing paragraph. Then the next questions will be what, if anything, sits at the very top above all the other layers? How can we prove that any given layer is at a given place, and not located somewhere else - further down or further up - in the hierarchy?

For instance if, as we shall now see, mathematics sits on top of physics, the immediate and legitimate question that arises is - how do we know that mathematics enables physics and not the other way around? We could legitimately hold that mathematics was invented to count physical things - such as pots and bushels of corn and other material wares - and thus that mathematics is an emergent, artificial property of the physical world, made up by the humans who emerged from nature's evolutionary processes, and not the other way around. As we will prove however, mathematics sits atop the pyramid above physics, which in turn enables the physical world. The next legitimate question will be whether there is anything that sits above this layer, and (where) does the pyramid stop?

Before we can explore mathematics further, a word about what it actually *is*, is called for.

A trawl through online discussions on the subject quickly shows that the very word 'math' can mean quite different things to different people. Only one narrow, precise definition holds here, so it is essential that we first specify what mathematics is, specifically: how *valid* 'mathematics' or *valid* 'mathematical equation(s)' are defined.

There are broadly speaking two kinds of mathematics, quite separate in their very essence as well as in their approaches and uses: *pure* mathematics on the one hand,

sometimes called *abstract* math; for instance pure geometry or number theory; and *applied* mathematics on the other hand, often called *mathematical modelling* when used to analyze something or when applied to the engineering description of some phenomenon, system, or machine (mathematical modelling routinely makes use of all kinds of sub-categories of applied mathematics, such as numerical analysis, finite element analysis, and so on). Pure mathematics is what we are dealing with here.

Broadly speaking, mathematical modelling consists of using numbers to roughly represent how an evolving system behaves, to predict its evolution, or the evolution of its parameters and properties in time; most often at the cost of making simplified assumptions. Briefly described, producing a mathematical model for a given phenomenon or evolving system involves combining a set of equations that relate known inputs (such as speed, temperature, or mass) in such a way as to calculate the resulting values of sought-after outputs describing changes to the system over time (such as trajectories, chemical, or geometrical changes). From this understanding it can be seen that the values of the outputs are inferred from the set of inputs and the evolution that these inputs go through in time as the system evolves. For our purposes, this is *not* what we will call mathematics here. Hereafter the book refers to mathematics in the sense of the laws of *pure* mathematics only - unless specified otherwise.

No one has put it better than David Hilbert: “We are often told that pure and applied mathematics are hostile to each other. This is not true. Pure and applied mathematics are not hostile to each other. Pure and applied mathematics have never been hostile to each other. Pure and applied mathematics cannot be hostile to each other because, in fact, there is absolutely nothing in common between them (9).” Mathematical modelling does indeed use a subset of math, much the same as, say, surgery uses a subset of biological science - but it is a wholly different animal from pure math. Whereas mathematical models of reality are obviously man-made and constitute attempts to understand and predict how nature operates, there is an ongoing discussion among scientists whether pure mathematics is in fact innate to nature, rather than a mere product of human intellect and thoughts.

In the sciences, experimental evidence is used to confirm that a theory is usable, at least within its given domain of applicability. If a theory is ever *proven wrong* by experimental evidence (also called *falsified*), then the theory is either wrong or is an approximation, with a validity zone (within given thresholds of accuracy) limited to a specifiable and calculable domain.

Physical reality conforms only to *correct* and *applicable* mathematics, and could even conceivably reflect all of mathematics: Miles Blencowe and Michael James Duff stated in their paper ‘*Super-branes and Space-time Signatures*’ that “we could think that external reality requires that more than one theory, and quite possibly *all* theories allowed by mathematics, be true.”

But how do we determine what ‘correct and applicable’ means? The question mostly arises with mathematical modelling and applied mathematics. Pure mathematics only *is*, and is always valid on its own abstract terms. Any practical

validity it may turn out to have is often found afterwards, sometimes serendipitously - no intended use was sought during its formal development.

As far as applied mathematics is concerned, it can so happen that it is formally correct yet bereft of meaning, in other words that it is correct in terms of fitting the logical rules which lie at its foundations, yet lacks any predictive or explanatory value, as follows:

Imagine that there are 2 dot points on a blank sheet of paper and you are asked what curve or drawing passes through these two points. You could say a line, or equally well a circle, a squiggle, a Picasso sketch, or otherwise.

In math terms, the two experimental points constitute two *variables* (the 2 points). These two variables will satisfy any number of 'equations', i.e. the many different curves and drawings that can pass through these two points, and at this stage of the proceedings you have really no way of knowing what the larger picture is.

The same holds in mathematical modelling: let's say that you conduct a lab experiment that yields a total of 10 values, and that you are trying to work out the physical laws that govern the experiment; all you have to do to work out a mathematical model that seamlessly and perfectly fits all ten points is to define 10 variables. An equation with 10 points and 10 variables can be solved every time, and will yield a mathematical law fitting to a tee to your experimental results.

You now conduct one more experiment and you find an eleventh point that does not conform at all to what you would have expected from the model you worked out from the first ten experimental points. Well, not a problem! All you need to do is just add one more variable, and presto, you quickly end up with a new law that fits seamlessly all 11 points.

The example provided can be expanded to any number of experimental points: one can always come up with a mathematical model that fits all of any given set of data - but the model is however may yet not be applicable to a wider scope of its use: the next experimental point will likely not fit the model that was created from all the previous experimental data points. In other words, the model in this example has no predictive power and thus does not reflect the underlying reality behind the experiments (this can be imagined otherwise as if we had inferred from 3 dots that the curve on the above sheet of paper was a circle, but the fourth data point seemed to indicate a square, 1000 dots hinted at some pointillist drawing, or, you may theorize on the basis of many points that an unknown figure is a squiggle. Yet, confrontation with experiment - *aka* seeing the real drawing - shows that it is in fact a Piet Mondrian cubist drawing, and so on). Underscoring the danger of falling into this trap, some critics say that a similar phenomenon currently plagues some areas of string theory.

This is one of the reasons why an underpinning of models by using experimental data is required; any number of fitting laws and models can be inferred from any finite number of experimental points - laws which may however turn out to be sorely wide off the mark. The purpose of mathematical modelling is never to understand or explain reality; it is to provide a workable model of something that may be utilized within a given range of uses and operating environments. Mathematical modelling does not care if it is only approximate or only approximately valid within defined ranges: the only thing that matters is whether it is useful.

There exist many examples of phenomena that can seemingly *only* be explained by nature's necessity to conform to valid mathematics. We will cite the 'quantum jumps' of atoms, the explosion of nuclear bombs, but there are many more. The Big Bang itself is likely one such phenomenon, as we shall see.

In the competition between physics and math to determine which comes first and sits atop the other in the Auguste Comte hierarchy, it turns out that the evidence in favour of mathematics sitting at the apex is overwhelming – even when allowance is made for the widely different interpretations that even incontrovertible experimental results can conjure up. This is why the famous mathematician Carl Gauss, and indeed many others such as the Oxford mathematician Marcus du Sautoy, have called math the 'Queen of Sciences'. One of the great current debates in science is, in essence, whether math is *invented* or *discovered*. If it was invented - originally a language meant to count wares and money, then it is just that - a descriptive, utilitarian language made up by humans with no further value. If it was and is being discovered, then it is of central importance to any hope of understanding reality. Math, ranging from the simple to the complex, has been found to be deeply embedded within the natural phenomena which we have observed so far, and appears to be independent of us. To take but a simple example - the sequence of Fibonacci numbers is found in many natural structures in nature, such as fauna shells, can reasonably be seen to be innate. Man's contribution to these numbers does not extend any further than the fact that we labeled those numbers - we made up a name for them. If humankind were not around at all, the Fibonacci numbers would still be around, unnamed and unrecognized.

There are also whole swathes of pure math that still lie wholly unexplored and there exists whole new landscapes of math that remain to be discovered in future – of which we have as of yet no clues whatsoever to help us reveal. There are quite possibly areas of math that will *never* be uncovered by humankind.

Of those areas of which we *do* have an inkling, there are many where our abilities prove, at the very least, not to be adequate. For example the remaining so-called 'millennium' problems, which we are as yet unable to solve despite the efforts of stellar mathematicians who have spent their lives and careers attempting to solve. If math were purely man-made, we would likely solve those problems. What we discover at every corner of our exploration of math is that it is immensely bigger than us, and try as we may we cannot bend it to our will: its existence lies outside of us.

As Max Tegmark, a professor at MIT and a founding director at the Foundational Questions Institute, puts it: if we distinguish between two ways of viewing a physical theory, the *outside* perspective of, say, a scientist studying the math equations describing the theory, and the *inside* perspective of an observer living inside the world described by these equations, then we can take two opposite views: one possible approach is to say that the inside view is the real one, and the outside view with all its math baggage just an approximation made by humans trying to make sense of their world (this latter view sometimes known as the Aristotelian view.)

The other approach is the exact opposite: the outside view is real and reality is at its base nothing but an abstract mathematical structure, whereas the inside view, along with all its complex human baggage, is but a by-product of the structure and nothing really but a series of side effects - or *epiphenomenons* - i.e., useful approximations used by humans to describe their coarse perception of a precise underlying mathematical edifice. In that scenario, also known as the Platonic view, we are self-aware substructures (SAS) within a mathematical multiverse. The word mathematics, *aka* math, shall be consistently used here in the Max Tegmark meaning of an underlying structure to reality – irrespective of any other vocabulary used to describe it.

There are those who adopt the viewpoint that all of mathematics is wholly artificial, and that it is impossible to prove any truths whatsoever - both *within* the fields of mathematics and logic, or *by means* of math or logic. Under this view, sometimes called the Münchhausen trilemma, or equivalently Agrippa's trilemma, the proof of any theory rests on circular reasoning, or on infinite regress, or on arbitrary and unproven axioms; and numbers and other mathematical constructs are pure figments of the mind. *Axioms* are the unproven statements (albeit most often derived from observing nature) which provide the formalized foundation upon which any branch of mathematics is built and put together. A good example would be the foundational axioms (also called postulates) of Euclidean geometry, such as 'a straight line segment can be drawn joining any two points'. This is an affirmed but unproven, and indeed unprovable assertion, which therefore cannot be used as such to demonstrate the fundamental truth or reality of anything.

However, far from being unproductive – the very fact that axioms are unproven has enormous value as it permits to delineate an overall envelope of possibilities - i.e., to circumscribe the outer limits of all the domains of possibilities and impossibilities within a relevant context (for example, geometry). This realm of possibilities and impossibilities can usually be precisely scoped out and the areas of 'impossibility' under a specific class of axioms can be investigated. This concept pushes the envelope and allows for exploring possible alternate realities, including such domains as may be not apparent or initially appear counterintuitive.

For instance in geometry mathematicians have been able to explore what happens when the base axioms of Euclidean geometry are held to be invalid precisely because these axioms are unproven but merely asserted. This analysis gave rise to valid *non*-Euclidean geometries such as the Riemannian and Lobatchevsky geometries, as well as higher dimensional geometries; all of which turned out to have real-world applicability in specific environments. Thus, it helped precisely scope the domains of the possible - and no further geometries were found to be conceivably able to exist beyond these three.

Other branches build from straightforward vocabulary definitions describing an otherwise irreducible underlying reality (such as the assertion that *by definition* 'one and one is two'. Two is thus defined as being one and one, and it does not matter

whether two is called 'deux', 'zwei', 'ni', 'iki', 'dwa', 'molemmat', or anything else: whichever label is used, the underlying reality is the same and is not, regardless of label, subject to any assumption or further interpretation). Some people still *do* take the view that numbers and arithmetical operations such as, say, addition, do not reflect an objective external reality, but are merely axioms - namely Peano's axioms. The Italian mathematician Giuseppe Peano (born 1858) formalized arithmetic and numbers through statements which he called postulates, or axioms.

We shall simply disagree here with those who say that both natural numbers and their relationships as expressed by the arithmetical operations of addition, subtraction, division and multiplication are fully axiomatic, but take the view that, irrespective of the latter-day formalization of arithmetic as laid down by Giuseppe Peano, there does exist independent *de facto* sets of numbers and arithmetic identities. Consistent examples can readily be found in nature; whenever a 30-strong pride of lions breaks up into two prides because it has become unsustainably big, the resultant two prides still have a combined total of 30 animals irrespective of whether addition and subtraction were duly formalized within an axiomatic framework. Hadn't Carl Gauss, one of the greatest mathematicians of all time, once claimed: "mathematics is the queen of the sciences and number theory is the queen of mathematics"?

At the outset, numbers look straightforward enough, but interesting and sometimes surprising properties soon emerge naturally from their simple existence.

For instance, prime numbers emerge naturally. Primes are numbers which are only divisible (so as to yield whole division results) by themselves and by 1 (e.g., numbers such as 13, 17 or 3181), as opposed to numbers such as, say, 6 - which can be divided by 3 or 2 to yield a whole result. In turn, further results and theorems and questions emerge based on the existence of primes. One of these follow-on questions is the so-called Riemann hypothesis which is named after the mathematician Bernhard Riemann, a hugely difficult and as yet never solved problem (which has to do with the way prime numbers are distributed within the wider set of whole numbers. The Riemann hypothesis is one of the pending 'millennium problems': anyone solving it would immediately become eligible for a cash prize awarded by the Clay Mathematics Institute, and win a place in History. For a solid and very readable exposition of the problem, see Keith Devlin, 2002.)

Simple whole numbers naturally and inevitably lead to a whole *ménagerie* of other numbers - fractional numbers, irrational numbers, imaginary numbers, transcendental numbers, transfinite numbers, aleph numbers, beth numbers, and more. From a simple definition of one and two, a whole unexpectedly rich branch emerges, complex theorems arise, hugely complicated and as-yet unsolved conundrums crop up - which soon include side or meta questions which vastly exceed the narrow confines of pure number theory itself.

So far, attempts to answer questions about the nature of reality from an *Aristotelian* perspective have failed. Armed with a purely materialistic view, we don't understand why delayed choice experiments work, we don't understand why Bell's theorem works

(which we will deal with in a moment), we don't understand the Big Bang, and many other things beside.

Our toolkit therefore must be the alternative Platonic view, aided and enabled by pure math (10), with this we'll now try and explore whether this approach can help us understand nature's baffling phenomena – first and foremost the nature of Time itself. Abstract math is, at its core, just abstract numbers.

Keith Devlin, a mathematician at Stanford University, wrote his book 'The Math Gene' because of what he perceived as a deeply regrettable and unwarranted feeling on the part of many people that math is hard to learn. His book-length argument is that we are all potentially gifted mathematicians and only an undue lack of self-confidence, and/or bad and unimaginative, boring teaching can lead to the wrong but somewhat widespread impression that we're not good at math.

Because of his enthusiasm for math, Dr. Devlin has become an evangelist, exploring novel ways to teach and communicate math to various audiences. It is easy to share his enthusiasm because math rewards any effort put into learning it. Of course, as in everything else, there is always the early, plodding phase of learning when we must walk unsteadily before we can run. It's the same in everything; we can't expect to just take up ice skating and immediately axel and glide gracefully in the rink, we can't play a musical instrument after cursory practice, nor can we engage foreigners in stimulating foreign-language conversations after but a few hours of half-hearted, boring rote learning of stultifyingly dry grammar. Mathematics, like music and skating and everything else, will surprise us by just how *not* boring at all it eventually reveals itself to be, however, it demands that we first pay it a modicum of dues.

Many physicists are baffled by, as Nobel prize-winner physicist Eugene Wigner once put it, "mathematics' unreasonable effectiveness in the natural sciences." Stephen Hawking once asked "What is it that breathes fire into equations and makes a universe for them to describe?" to which Tegmark answers: "There is no fire-breathing required, since a mathematical structure is not a *description* of the universe - it *is* the universe." He adds: "Everything in our world is purely mathematical - including you".

Much earlier, Galileo Galilei had opined that "mathematics is the language with which God has written the universe." This very feature of reality also seemed to also have stunned Einstein: *nature scrupulously obeys abstract mathematical laws.*

The effectiveness of mathematics in describing reality might, at first blush, seem totally obvious - after all, mathematics was first developed as a handy tool to describe nature and was derived from counting things which are 'out there'. But math soon took on a life of its own and became more and more abstract. Mathematicians began to explore increasingly abstract worlds which soon opened up new unforeseen vistas, which in turn posed new questions and challenges and begot wholly new and unexpected landscapes of thought. These unearthed new unforeseen questions and challenges, led to rigorous and non-trivial abstract theorems dealing with wholly

abstract mathematical objects which are found to routinely establish unforeseen logical bridges to other branches of mathematics and even, as we shall see, physics and everyday applications.

The reason why pure math so often manages to describe the world, and even to foreshadow how and why it works the way it does (sometimes surprisingly so) is neither trivial nor obvious. But it goes even well beyond that: pure mathematics *by itself* seems to be in principle capable of creating material universes. As we shall see, the obedience or conformity of physical reality to abstract mathematics does manage to explain everything we care to look at in-depth – including how whole universes can be created from seemingly nothing, above and beyond, say, Shing Tung Yau's geometry (11): *a universe will pop into existence from nothing so that some valid applicable mathematical equation not be violated.*

Mathematics has never been falsified: there is no known example of some *valid* mathematical equation predicting that something would happen and then somehow that something fails to happen.

Even particles - the fundamental constituents of all matter - are no longer described materially. The modern description of particles is purely mathematical – nature is now described in terms of *fields*. A 'field' is a zone in space where numbers are attached to the different points of that space. These numbers describe the values of certain properties at that point - a bit like, say, the space in front of and around a playing band or orchestra might be described by a sound volume field, with decibel numbers indicating the sound intensity attached at each point within the zone surrounding the band. The energy of a field is usually not continuous (it is '*quantized*', which will be looked at shortly) and the quantum excitations of the field create the particles out of whole mathematical cloth (for instance, electrons are the quantum excitations of the electro-magnetic field, quarks the quantum excitations of the field associated with the strong force, and so on.) An even more modern view abolishes even the concepts of particles, fields, and quantum jumps altogether, to replace them by the effects of something called decoherence (we'll be revisiting these concepts below).

The sun shines, or, broadly equivalently from a purely physics standpoint, an atomic bomb goes off, because of nature's necessity to conform to what is the most famous equation of all time: $E = mc^2$ - and for no other known cause. There is no explosive within an A-bomb, at least not in the traditional sense of what an explosive is, but only a bit of matter (12): what explodes in an A-Bomb is a mere lump of matter (13). The blast only happens because matter conforms to $E=mc^2$ (14).

As it happens, the mathematical description of physical events and phenomena through equations routinely throws off extraneous terms. To attribute a physical reality to such terms is seldom straightforward.

$E=mc^2$ is one such term, the leftover terms of the mathematical expression of the energy of a system when at rest. It is left over when all the speeds are set at zero in a calculation expressing the invariance of the laws of physics - the fact that they apply equally in different environments, or 'frames of reference'. (In essence, in equations that say that the laws of physics and their

applicability do not change when circumstances and environments change. As an example, the laws governing, say, your body balance are the same irrespective of whether you are walking on a street, at rest in an airplane seat, on a moving bus or for that matter anywhere, whether at rest or not. The term $e=mc^2$ is a remnant from such a calculation.

If we accept math as sufficient on its own, as explaining a reality that will conform to it without a need for further explanations, then in one fell swoop apparent mysteries that still bedevil physics today become suddenly comprehensible. It explains physical laws that appear, from a purely material standpoint, baffling or incomprehensible, yet have been demonstrated time and again to be valid, sometimes spectacularly, as we'll see.

'Scalar' fields, for instance - abstract fields made up of numbers associated with every point in space-time (15) - are invoked to explain a number of observed phenomena, but no one has necessarily much of a *palpable* in-depth understanding of the whys and wherefores of such fields, or of the mathematical operators (*aka* the equations of transformation) that hold sway within them. It just works beautifully mathematically, which is, most often, all that counts.

Thus, most tangible phenomena are now apprehended, or at least calculated, in terms of pure mathematics, reviving from a different angle a temptation on the part of professional scientists to 'calculate and shut up' (16): if mathematics is the sole reality, why bother and seek any further explanations? Reality is, there might just *not be* a deeper why and wherefore. Pure math might just be a sufficient explanation for the occurrence of any phenomenon, in which case it is not the physical phenomena but the associated pure math that must be looked at in depth. Even extremely recondite mathematics at the outer reaches of pure abstract thought - the kind of math found in Fields Medal (17) submissions, for instance - is routinely found to have totally unforeseen but tangible and immediate applications in physics and the real world (18). A discussion in an on-line research forum recently tried to find areas in pure abstract mathematics that would *not* have a practical application. It found none (19).

Bell's theorem is one of the spectacular *smoking guns*, as it were, for the dominance of pure math over everything else. The theorem shows that something happening anywhere in the universe can affect *instantly* something else just anywhere in the universe, no matter how distant, provided that these two 'somethings' are *mathematically correlated*. We will look later on at a precise definition of what is meant by 'correlated' - how and why 'somethings' or 'some things' can become 'correlated', what it is that establishes a correlation. Unsurprisingly, this correlation comes about by the establishment, or prior existence of, a mathematical relationship between these 'somethings': their substantiated inclusion as variables within an equation called Schrödinger's equation, named after the physicist Erwin Schrödinger.

How can such immediate effects occur over arbitrarily long distances, if no signal can ever travel faster than the finite speed of light? Can it be that the explanation is indeed purely mathematical and that the search for a non-mathematical explanation is futile and misguided - nothing but a reflection of cognitive biases favouring material

explanations because we evolved in a world macroscopically perceived by our limited senses as only material? If there is a purely mathematical structure underpinning the material structure of the world, perceiving that structure would afford zero survival advantage and it would hence be easy for a subconscious cognitive bias to develop against the useless awareness of such a structure.

Alternatively, isn't placing a math layer at the top of the reality hierarchy just a way to paper over our ignorance? We might just not know which arcane *physical* theory explains Bell's theorem, for instance, nor any other of the unaccounted real-world cases where math seems to dictate to physics, and hence to reality itself.

Notwithstanding, the physics community have tried, hard. Physical, 'material' explanations for Bell's theorem were sought – all the harder because the instantaneous, much faster than the speed of light, influence at a distance between correlated objects was repeatedly observed in the lab, repeatable at will. All the possible 'material' explanations failed:

- First, these explanations entailed extraordinarily contrived constructs and hard to believe baggage, all of it seeming furiously *ad hoc* (20). None of these scenarios are anywhere near proven or even provable.

- Another major issue is that none of the attempted explanations can explain any of the *other* smoking guns, all the other baffling phenomena we observe in external reality. Therefore, new *ad hoc* explanations have to be sought in every individual case, and some of these explanations are soon found to be incompatible with or even *contradictory* to earlier attempted explanations relating to the other phenomena for which a physical explanation was sought.

In some cases, looking for a physical reason would be tantamount to looking for so-called hidden variables - hidden variables which (here goes math again) are in most cases ruled out by something called Gleason's theorem (21), named after the mathematician Andrew Gleason. Moreover, even if for some reason Gleason's theorem did not apply in some exotic cases, it wouldn't help anyway: Renato Renner and Roger Colbeck in Zürich have convincingly demonstrated that no possible hidden variables hypothesis could possibly improve the *significant* outcomes produced by current theories. Thus, our search for a *physical* explanation fails. Some inescapable explanations lie squarely with pure math.

So we are seemingly left with a reality that just conforms to math, with at this time at least, no credible other option.

It could even be put more starkly. We could say that the equation (Schrödinger's equation) which makes Bell's theorem work - i.e., which predicts that two correlated 'things' are going to react *instantly* to changes affecting one of them across any arbitrarily long distance or expanse of space so that the equation binding them seamlessly continues to be valid - should be falsified by the laws of physics which mandate that nothing travels faster than light. But the incontrovertible fact remains that a status change initiated at an object located at a specific location in space is always proven to affect instantly another correlated object at another, arbitrarily

distant other location. We must therefore, at least provisionally, conclude that *math has falsified our physics*, not the other way around. Hence math sits, for the time being, squarely at the top of the pyramid.

Before we proceed, we must look at infinity - and infinities.

4 Infinity & Infinities

As we shall see, time within certain closed environments in a host spacetime can lie beyond the *infinite future* of time in the host spacetime, or equivalently time in the host lies in the infinite past of the closed environment. But what does infinite, or infinity, mean?

Infinity in all its guises turns out to be a challenging and treacherous concept for the human mind to deal with, perhaps because evolution has not seen fit to prepare us for it; trying to tackle the concept can often lead to seemingly stark contradictions and/or puzzling outcomes, to some measure of frustration, or worse (22).

Two attributes are associated with infinities: first, rather surprisingly, their size (meaning the *infinite* number of elements that a given infinity contains) often called *cardinality* (a word that quickly caught on because most mathematicians feel a bit uncomfortable speaking of the different sizes of infinity); different cardinalities are proven to exist whenever certain infinite sets cannot be matched one-on-one to certain other infinite sets. Should we try to establish a one-to-one pairing, or matching, between the constituent elements of a given infinite set with those of another infinite set and an *infinite* number of unmatched leftover elements would happen to remain, then the cardinality of the latter set would thus be proven to be bigger - '*stronger*' - than that of the former.

The second attribute is their quality - i.e. what a given infinity contains or includes; for instance, the *infinite* series of natural numbers, 1,2, 3 obviously does not contain the number, say, one half.

Incidentally - the infinite series of all the whole (*aka* natural) numbers plus, say, one half ($\frac{1}{2}$), or for that matter that of all the natural numbers and all these numbers and a half, have the exact same cardinality as the series of natural numbers without the added halves, because an endless one-to-one correspondence between the elements of both these sets can be established.

Here are some instances of infinities of different cardinalities:

1. A line segment, however short, has an infinity of mathematical points, and indeed exactly as many points as *any* other line segment of whatever length. It also has exactly as many mathematical points - the same infinity of points - as a two-dimensional *square* of *any* size. In turn, it has as many mathematical points as any three-dimensional cube of any size. This result, as we shall see, will turn out to be important in a following Chapter.
2. The above, however short, line segment has a *larger cardinality* than the infinite set of all rational numbers. (Same as with the word 'size', mathematicians also tend to feel uncomfortable using the word 'larger' where infinities are concerned, hence speak of a '*stronger*' cardinality rather than of a bigger one, the essence of the meaning being, however, exactly the same.)

3. The infinite number of all possible geometrical curves is bigger than the number of mathematical points on a line segment (and hence of course bigger than the infinite number of rational numbers as well.)

All three infinite numbers in 1), 2) and 3) above are called, respectively, Aleph-zero for the infinite number of whole and rational numbers (i.e. all the numbers that can be exactly expressed by some ratio), Aleph-one for the number of real numbers (which also include all those extra numbers that cannot be expressed exactly by some ratio) and the number of mathematical points on any line segment, and Aleph-two for the number of geometrical curves (written respectively as $^0\aleph$, $^1\aleph$, and $^2\aleph$)

Here is a brief but stark illustration of just how counterintuitive infinities can be:

1. The so-called '*natural numbers*' are defined as the infinite set of *whole* numbers: 1, 2, 3, 4
2. The set of *rational numbers* is seemingly much larger than the set of natural numbers, because, whereas natural numbers contain *no* numbers between any two numbers (there is no natural number between 1 and 2, for instance), rational numbers do contain an *infinity* of numbers between any two natural numbers. Yet natural numbers and rational numbers can be matched one-to-one, and no leftover infinity of remainders remains.
3. The number of *prime numbers*, i.e. natural numbers only divisible only by themselves and by the number 1 (such as e.g. 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 53, 59, 61, 67 ...) is demonstrably infinite, but their incidence - i.e. the number of times they crop up among the other natural numbers - becomes smaller and smaller even as the numbers become bigger: they progressively become scarcer - fewer and farther between (23). There are 168 prime numbers below 1,000, in other words 16.8% of all natural numbers below 1,000 are prime, but only 9600 under 100,000 (in other words only 9.6% of all numbers under 100,000 are prime), and 78,000 under a million (i.e., 7.8%) The further up we go up the scale of ever bigger numbers, the smaller the percentage of primes becomes. Yet, the cardinality of primes is the exact same as that of rational numbers. Which is really quite very baffling.

Infinities themselves can collapse into ordinary, finite values. Say that you have to walk two yards: an easy task, effortlessly accomplished. To do so, you must travel first half the distance (one yard) then half the remaining distance (a half yard) then half the remaining distance (a quarter yard), and so on - an infinity of half remaining distances: hence, the infinite sum of 1 plus 1/2 plus 1/4 etc. and so on *ad infinitum*: $[1 + (1/2) + (1/4) + (1/8) + \dots]$ equals 2. The Greek philosopher Zeno of Elea famously failed to understand this. He thought that somehow an infinite sum must be infinite, hence he called such results as this latter example a 'paradox' - which of course it isn't. Calculus, first fully formalized in a treatise called *Yuktibhasa* in India in the 16th

century, is the branch of mathematics that deals with infinitely many infinitely small quantities. It resolved the seeming paradox.

For the sake of completeness, let's note in passing that this neat solving of Zeno's paradox by calculus is not quite universally accepted as being the whole tale. In a further illustration of possible controversies in the interpretation of experimental results; here, the experimental result that we can indeed walk the two yards' distance within finite time - a few scientists insist that the fact that the calculus works and faithfully reflects experienced reality, *proves* that space is discrete, i.e. is made up of a very large but finite number of nodes upon an underlying grid of space-time. Under this little-known minority view, if space were continuous we would never be able to walk the two yards, or for that matter any distance, within finite time because to cover any distance we would need to walk through an infinity of points and spend an exceedingly small but non-zero span of time to move from one point to the next.

What follows from the above is that there is an *infinity of infinities*, whether we consider infinities as being separate on account of their different qualities, or indeed, of their different cardinalities (24).

Should we however parse that statement, it immediately underscores how slippery and counter-intuitive dealing with infinities can be: while the very sentence an '*infinity of infinities*' makes full intuitive sense, it is mathematically utterly meaningless.

Here's why. It is quite meaningful to speak of, say, five different categories of categories. For example, if we classify the cars in a car yard by both make and color, there may be, say, five makes of car and six colors, so we would classify all the cars in the yard within five categories of six categories: thirty categories in all. Every car would thus be accounted for and belong to some category encompassing two sub-categories, one specifying the make and the other one the color. Should we then add the models, assuming that there are seven models per make, we could further specify that we have in fact five categories (makes) of six categories (colors) of seven categories (models) - which would still make perfect sense, with any car in the car yard belonging to any one of $5 \times 6 \times 7 = 210$ sub-categories in all (as per color, make, and model.)

Try that with infinities, however, and it utterly fails.

As indicated, there exist infinities which, while being all infinite, demonstrably do not however contain the same *value* - or cardinality - of infinity. Let's call A and B two such different-value infinities (such as different aleph numbers.) If we say that there is an infinity of infinities - a reasonable statement which is otherwise quite true - then do we mean by it that there is :

- 1- an A-Infinity of A-Infinities, or
- 2- an A-infinity of B-infinities, or
- 3- a B-infinity of B-infinities, or
- 4- a B-infinity of A-infinities?

All those infinities are quantitatively different. The broad statement '*there is an infinity of infinities*' has therefore just become, mathematically at least, utterly meaningless, since we cannot possibly decide whether it is 1), 2), 3), or 4) above which is meant.

Inevitably, the concept of infinity can extend into other explorations of reality and eschatology - the realms of philosophy and even theology. For instance, a godhead or deity could be defined as an entity with certain infinite attributes. For instance, a godhead should by any definition have an *infinite* IQ, irrespective of the particular scheme used to define an IQ. Analysing the consequences of an infinite IQ and other attributes would lead to surprising insights.

Another, oft-overlooked property of infinities is the way they can disappear from a given framework to pop up again in a different guise elsewhere. We will encounter manifestations of that property as we drill further down into some aspects of physical reality. This property may also weaken certain arguments that are traditionally used, such as the famous Hilbert Hotel *gedankenexperiment*.

This famous 'thought experiment' goes like this: A hotel has an infinity of rooms, all of which numbered with even numbers only. A bus - a 'hyperbus' - comes along with an infinity of guests, who are numbered both with odd and even numbers. The first bussed-in guest Nb 1. moves into the first even-numbered room (numbered 2), the second guest (Nb. 2) moves into the second even-numbered room (Nb.4) and so on. The hotel will obviously be able to accommodate all the guests, therefore the even infinity is as big as the (even *plus* odd) infinity - the infinite number of arriving guest from the hyperbus.

But this scenario does not quite work: either the occupying of the rooms happens *instantly*, in which case the only way all the guests can be put up is if they are 2 to a room. Or, we proceed by means of the above sequential scenario: whatever time is needed to perform this serial occupying of room is non-zero. Even if vanishingly small, the upshot is that it would take an *infinite time* to occupy all of the hotel rooms: under this scenario, the hotel is *never* fully occupied, and the guests are *never* all lodged: *we have, in effect, swapped a numerical infinity with an equally intractable time infinity*. The Hilbert hotel scenario thus does not quite prove what it had been designed to do, to wit, that 'different' infinities are equal.

A further relevant question is whether infinities materially exist within our universe, as opposed to their virtual existence in the abstract world of numbers and mathematics. In our known universe, the answer depends squarely on whether space-time is discrete or continuous. If, as is likely, space-time is discrete (or 'granular'), then the number of possible points in our space-time is very large but not infinite, and all we can ever find in our universe is a finite number of *material* things, irrespective of what the things may be.

If our spacetime happens to be continuous however, then it is infinite, but in a very specific way. It is easy to visualize why and how a line segment would have an infinity of points in continuous space, but only a finite number if space is discontinuous: color two halves of a line segment in two different colors. A 'point' is then represented

by the dimensionless border between the colors. If the position of that border can be slid continuously along the line segment, then there is an infinity of positions at which the color border can be halted (i.e., a stop mark can be set at any of an infinity of available values between the ends of the line segment. That infinity is aleph-1.) If space is discontinuous however, then the pool of available halting positions is finite.

Therefore *physical* infinities in our universe are most likely limited to aleph-1 infinities (an immediate if slightly odd upshot would be that our universe *cannot* contain all possible geometrical curves, whose overall cardinality is aleph-2.)

What, then, of thoughts? Can there be an infinity of them? Something called the *Bekenstein bound* limits the amount of information that can ever be embedded in a material universe within a finite region of space (or, equivalently, the maximum amount of information needed to fully describe any dimensionally finite physical system, such as a brain, a computer or a black hole.) For a human brain, this upper limit would amount to about 10 to the power 10 to the power 42 - an unfathomably, hugely vast number, yet a *finite* number. What the Bekenstein bound thus does is set an upper limit to the number of thoughts that we can possibly hold at any one time, irrespective of the *origin* of thoughts, i.e. whether our thoughts are locally generated inside the brain or whether they somehow take their source elsewhere, with the brain only serving as a kind of relay to intermediate them (a question which we will need to look at further on.) What the Bekenstein bound in effect says is that there is a limit to the amount of information that can be either generated or intermediated into our material world by a finite-size brain at any one time - that even if the source of the brain's information were infinite, only a finite part of it can ever be midwifed into materiality.

It's time to take a first look at quantum mechanics.

5 Our Quantized Reality: Life in the Strobe Lights

Although we perceive that, generally, everyday life and things are continuous - energy, movement, etc., a bit of scientific analysis of numerous phenomena shows that in many cases it just cannot possibly be so. This realization gave rise a few decades ago to the new science of quantum mechanics. Quantum mechanics has proved so far to be hands down the most successful theory in the history of physics in explaining reality, but it's also by far the weirdest, leading many to question whether this can be the ultimate explanation of reality.

Historically, quantum mechanics arose to try and explain how atoms and electrons behave. Matter is made up of atoms, i.e. electrons spinning around nuclei. But how can electrically charged electrons go on spinning, at high speed, without steadily losing energy? According to all the laws of classical physics, electrons ought to slowly wind down as their motion should lead to a never-ceasing leakage of energy. Straightforward calculations in classical physics tell us that they would quickly collapse onto the nucleus - which they obviously do not.

Neither human intuition nor classical mechanics can describe nor explain how matter behaves at that level, but quantum mechanics does (25).

In the illustrative case of the atom, quantum physics demonstrates that there are a few privileged individual orbits around the nucleus within which electrons never lose their energy, regardless of speed. (As mentioned earlier, the modern description of electrons is a bit more complex, as electrons are described as quantum excitations within a field rather than physical particles. This modern description does not invalidate this discussion.)

But it also proves that any other orbits other than those few privileged spinning orbits are no-go zones for the electrons; indeed, electrons can never be found at any such other orbits. Different 'allowed' orbit levels around the nucleus correspond to different energy levels of the spinning electron: The further away from the nucleus an electron spins, the higher its energy level.

This property is by now well-known and is routinely harnessed in mundane applications such as light bulbs; when electricity is fed into a bulb filament its energy is used to move electrons up to higher orbits. Electrons on these higher orbits are perched precariously on too-high orbits and tend to 'fall back' to a more comfortable, less excited lower orbit. To do so, however, they need to shed energy which they do in the form of light – presto, an illuminated light bulb.

Beside the few allowed orbits where electrons may be present, the rest of space is taken up by no-go spatial zones above and beneath every allowed level. If electrons somehow could ever stray into the unallowed zones, they would be instantly destroyed - as would then matter itself.)

Whenever an electron jumps to a higher level (because it absorbed energy from the electrical power fed into the light bulb) and when it then jumps back down to a lower orbit (releasing energy in the form of light) it does not, and cannot, actually *jump*: it seemingly dematerializes from one level and rematerializes in the new orbit. This seems to be nonsense, of course, and it is – all the attempted physical explanations of this phenomenon break down at one level

or another, unless the explanation is taken to be purely mathematical and that electrons are viewed, as they now are, as purely non-physical excitation states of a mathematical field (26). It can be said, therefore, that electrons are not objects at all, but mathematical entities, quantum 'excitations' of an all-pervading field, the fermionic matter field. A field is a purely *mathematical* construct - a mathematical description of reality (27).

The ultimate explanation for *all* known physical phenomena appears to be ultimately purely mathematical. Both straightforward as well as sometimes seemingly weird properties of the physical world arise just so, because of nature's obedience to mathematics.

Let's illustrate briefly just how pervasive the presence of quanta and of *quantization* - lack of smooth continuity - is in our everyday lives and how surprising and often counterintuitive it can be. Consider something very simple and commonplace, somewhat clumsily called the *quantity of movement*.

The 'quantity of movement' (QoM) of an object is defined as the product, i.e. the result of the multiplication, of the object's mass by its speed: the instantaneous quantity of movement of, say, your arm at any point in time is thus the product of its mass by its instantaneous speed. When your arm is at rest, its speed is zero, and therefore its quantity of movement at this particular moment in time is zero: its mass (broadly, its weight) times its speed (zero). Since its speed is zero, then its QoM is the product of zero times something (its mass), hence it is also equal to zero.

Now move your arm from a first position at rest (where its speed is zero) to another position at rest (where its speed becomes again zero). Its quantity of movement started from naught, rose up, went through a peak before decreasing and finally coming back to zero again when the arm comes again to rest. If the value of its quantity of movement were plotted against time, the graph would appear more or less bell-shaped.

Nothing special there *except* that the values of its quantity of movement are not continuous at all, but are *discontinuous*: the QoM kept 'leaping' in tiny discrete jumps from an authorized value to another authorized value. Of course, the individual jumps are extremely tiny and the 'authorized' values are numerically very close - thus lending the illusion, at a macroscopic level, of smoothly continuous quantity of movement values.

The words 'quantized' and 'discrete' are sometimes used differently, although both words mean discontinuous. All *dynamic* processes in the world are quantized (such as the quantity of your arm's movement). This does not mean however that the underlying environment - the space-time - within which your arm moves is necessarily itself quantized: the weft of the space-time within which your arm moves could well be continuous, or not. The quantization of a dynamic event or process is more often referred to as its 'quantizedness' or quantization, whereas if the weft or fabric of the 'background stage' itself, such as the space or time within which some events happens, is itself discontinuous, this granular quality of the background is more usually designated by 'discreteness'. 'Discrete' is also sometimes called 'granular'. 'Granularity' often refers to the dimensions or size of the discrete parameters, whereas 'discreteness' refers to the quality of being discontinuous, irrespective of the associated values.

Why are so many things discrete in nature? There is a simple answer that the quantization of many things in nature comes from the presence of finite boundaries encasing the sweep or scope within which these things can exist and evolve in time. To understand how it works, consider a rope.

Let's fasten the end of a rope to a wall, take the other end and shake it up and down. A pattern of stationary waves will quickly form with the rope taking on the broad shape of a stationary sinusoidal curve (a sine curve). If we lazily shake up and down the loose end of the rope, it will take on the shape of a half sinusoidal curve, with only one point at rest (the rope end fastened to the wall). Now if we shake the unfastened end more forcefully (i.e. input more energy to the rope) a pattern will form whereby a new stationary, immobile point will form in the middle of the rope rather than only at the wall end. This comes about because 'amplitude waves' travel to the wall from your hand and reflect back, and the forward and backward waves interfere with each other.

The amplitudes travelling back and forth cancel out at some point on the rope and create an immobile point. The more energetically we shake our end of the rope, the more immobile points form along the rope. The rope takes on a stationary sinusoidal shape, with more points and higher energy travelling back and forth along it. Note that the formation of a sinusoidal pattern along the rope does not even depend on the end point being fixed: one could dangle the rope in a void and shake it, say from a high vantage point, and a similar pattern would still form – with the far end of the rope taking on the position of maximum, rather than zero, amplitude.

This pattern formation arises solely *because* the rope is *finite* in length, not because its end point is fixed, and the waves that you send travelling down the rope by shaking it reflect back off the rope end regardless of whether that end is fixed or loose.

By shaking one end of the finite-length rope, what we have created is a quantization of the rope's movement amplitudes (and several other attributes besides). Only certain energies can stably create this quantization (extra energy might be reflected back to you and travel up your arm) and the quantization happens in the first place only because the existence of the rope's boundaries enable quantization.

This principle is general: quantization of something's attributes or its properties is often created by finiteness, and continuums blossom best within infinite environments (the precise conditions of applicability of this broad principle depend on the particular attributes at hand. There might exist continuums of certain parameters or properties within our finite universe).

Another telling and equivalent way to look at the role of finiteness in creating quantization is to look at numbers: Unless we extend any number to infinity, there is no continuity in numbers and they proceed from one number to the next number in line by quantum jumps: If we keep, say, 30 decimal places after a comma, then the number, say

1.11111111111111111111111111111111

moves on to the next one in line, to wit

1.11111111111111111111111111111112

6 A Surprisingly Puzzling Reality

Seldom do we pause to wonder how and why things work the way they do – they just are that way. However, scratch the thin surface of reality and it quickly becomes odd.

Here is a case in point.

Why does a football - an object that has exactly zero memory or consciousness of how it was kicked in the recent past, ‘know’ in which direction or with which force to go following that kick?

How does it independently ‘know’ the direction it should go and with which speed? Does it somehow possess a memory capability that it can tap and then use and act upon? (The answer to the latter question, as is expected, is a resounding *no*; the football has no clue whatsoever of how or if or when or with which energy or in which direction it was kicked, and has no capability to store any such memory in a useable or actionable way (29). How does it then obediently proceed in the direction it was kicked, after a direction-imparting event (the kick) which it cannot and does not remember?

To try and answer, let’s imagine a thought experiment: some kind of futuristic operation has left you with vastly enhanced eyesight and extraordinary signal-processing abilities within your brain to match. You are now able to see a snapshot of anything before you by batting your eyelids from a shut-eyes position back to a shut-eyes position in less than a billionth of a second.

Someone fires a perfectly spherical bullet across your face when your eyes are shut, and you bat your eyelids.

What you catch a glimpse of is a perfect metal sphere hanging motionless before your eyes.

You have no means whatsoever of knowing where that bullet is going. You have absolutely no clue where the bullet is headed. Yet, you have infinitely more memory and more intelligence than the bullet itself.

How does the bullet know where to go?

The same of course applies to any projectile – to anything that was given an impulse at some time in the past. How does an inanimate object ‘know’ or ‘remember’ the direction it was fired, or for that matter the speed it is supposed to assume (e.g., imparted by the quantity of explosive in the cartridge)? How is any trajectory ever kept to?

The answer is astonishing. Indeed, the bullet or football or arrow does not know at all where it was fired or kicked to. It is simply not equipped to have the faintest clue that it was acted upon in any way.

The inescapable - and in fact correct - conclusion is that the object “recalculates” (for lack of a better word) where it should go (i.e., its trajectory) *at every instant in time*. How it quite does that, and exactly what ‘every instant in time’ may mean (what it is that triggers the instant of the recalculation) is not fully understood. The mathematical equation which describes the ‘recalculation’ that the object undergoes is, however, well known.

This result has been proven both theoretically and experimentally. We will look at it more in depth in a minute.

But first, before we delve further into material reality and what weaves it into being or at the very least makes it tick, we must look again at mathematics.

7 Wave Functions: Mathematics Is Reality

If the ultimate reality of anything is mathematical, it ensues that there must be some kind of 'personal' mathematical 'object', or property, or 'signature', attached to everything and anything, i.e. to any object or person or any definable, correlated collection or assembly of things - in brief, to every conceivable thing, object, or correlated collection of things in the universe. Indeed, that mathematical object must be, in some sense, more real than the object itself, because it must describe and determine that object across the range of all its possible realities, both actualized and potential, within any applicable dimensionality.

The term correlated, or *entangled*, in the context of this book means that the correlated entities share the valid mathematical relationship we touched upon earlier and which we'll discuss further. To reflect real-world reality, such mathematical objects must be able to change and evolve over time. To link up with any new objects to which they may become correlated through physical interactions, they may reversely give up, at least in part, erstwhile associations which have become no longer fully current, and so on.

This mathematical object indeed exists: it is called a *wave function* (30).

A specific wave function is associated to every particle constituent of matter anywhere and wave functions are also associated with any coherent assembly of particles - that is to say to any collection of particles, atoms, molecules or collections thereof, (*aka* objects - an atom, two atoms, your brain, your mind, your whole body, you, your neighbour(s), this physical book, this e-Book, a teapot when empty, a teapot when full, the universe itself, etc).

In order to be or become associated within a *collective* wave function (i.e. a wave function attached to a specific set of constitutive items or elements) there needs to exist some correlation between these elements. For instance, there is no association or correlation whatsoever between, say, a leaf on some tree and a rock on the moon. There is therefore no dedicated wave function linking up these items, even though these two objects would be very loosely correlated within the wave function of the whole universe (also *see indented §, note 90*). There is, however, a clear association between, say, the atoms within an existing lump of metal, such as a currency coin. These atoms are at the very least correlated by the existence of the electric forces that keep the lump together. They are also spatially correlated – when one atom in the coin is moved in space, all the others concertedly move. There therefore exists a collective wave function grouping up the constituents of that lump of metal - i.e., attached to the lump of metal.

The wave function of something affords an immediate mathematical way to calculate the probability of the presence of that something at any given location in space. Indeed, a somewhat rough-and-ready way to determine whether the separate constituents of some collection are bound up within a valid wave function describing

jointly that particular collection is whether these constituents are bound up in *space*: all the parts of a defined ensemble move concomitantly if any one constituent of the set changes position. On the other hand, a plate, say, can be removed off a tabletop without causing the table to move: the plate and the table are hence not part of a simple, unique wave function encompassing both, and *only*, the table and the plate - although they may be constituent parts of a wider, more complex wave function, such as the Universe's (obviously, if the Universe were to disappear, both the table and the plate would disappear too.)

Measurement or observation in quantum mechanics means the establishment of a correlation or entanglement between an observer or measuring apparatus and a measured phenomenon, or more precisely, between the wave function of a measuring apparatus and that of the 'measured' or 'observed' phenomenon. There could be a simple kitchen-top experiment that demonstrates the existence of the wave function attached to your teapot - for instance the teapot that you just filled with water and put on the heating range.

There is an 'old wives' saying' which, interestingly, exists in many different human languages: *a watched pot never boils*. Of course there is a strong element of the psychological perception of time embedded in this saying - time seems to pass more slowly when one is impatiently looking forward to something pleasurable happening, such as dinner being ready. But this impatience does not quite necessarily account for one hundred percent of the perception of longer time spans - there might be an actual, small, measurable effect; referred to as the Quantum Zeno effect, which can be easily tested by anyone.

The name Quantum Zeno effect was coined (after Zeno of Elea) by the two physicists who first incontrovertibly established that an unstable particle, of which it is known that it decays swiftly, simply never decays if it is observed (or measured) continuously.

At the time it was not obvious that the halting, or 'freezing', of the particle's overdue decay was due to the observers' consciousness watching the particle - it could quite conceivably have been produced by some perturbation of the system caused by, say, the measuring laser used in observing the particle. Yet the effect has since been observed with large systems, without a laser or any other mechanical measuring apparatus being present. You can, albeit somewhat coarsely, test it at home using a pot and a heating range. To do so watch the pot continuously and have someone time yourself from the instant heat is applied to the pot until the moment the water starts to boil. Now perform the same experiment with all parameters being equal - same heat, same pot, same amount of water, etc. but instead go and check briefly, every 25 seconds or so, whether the water has started boiling. Time yourself too.

Here's why it works.

It does not matter whether the measuring apparatus is made up of a laser, or, say, a set of lasers with processing computer, or all of the above including a human observer - say, the operator of the apparatus - as long as human consciousness - the human brain - also has a wave function. In this way the measurement comes from

the establishment of a relationship between the wave functions of the measuring apparatus and the measured phenomenon. All the myriad other parameters being equal, the water pot's wave function can reflect two states: water boiling, or not boiling. By observing and measuring the pot continuously, you interfere with the pot's wave function to an extent that it makes it less likely that it will become enmeshed - tightly associated - with its environment, in this case the heat underneath it. The immediate effect of your interfering is that the pot becomes less seamlessly able to associate with, or be interfered with, its environment beyond yourself - in technical terms, to *cohere* with its environment towards the state of 'water boiling'.

The Quantum Zeno effect has also been found to play a part in a number of other astonishing cases, and is suspected in more (31).

Now any wave function, such as the one attached to the water pot in the above experiment, can quickly evolve from its earlier state and thus 'dissipate' away the values of its previous parameters by interacting with its environment – this is what physicists call *decoherence*. The words 'dissolve and dissipate' are not quite meant in their ordinary sense, rather, they mean here that according to circumstances the wave functions may evolve in such a way that they absorb new influences (or in other words, new *variables*) from their environment, and they might also shed past associations. By doing so they evolve and fundamentally change.

For instance, if we call some wave function Ψ (psi pronounced sye) which relates to a set, or collection, of two elements which we'll name *a* and *b*, then we'll write out this wave function, in shorthand, as $\Psi(a,b)$.

Now let's say that a couple of external agents, which we'll call *x* and *y*, interfere with and impact Ψ – Ψ decoheres from its formerly exclusive involvement with *x* and *y* only and expands its former identity to now become $\Psi(a,b,x,y)$. It could even decohere further to the extent that *a*, say, could become wholly lost to it, and the wave function would then have evolved into $\Psi(b,x,y)$, and the element *a* would have branched out to live its onwards life first as a new wave function altogether, let's call it $Y(a)$, which could soon become entangled with other and new environmental influences, which we'll call, say, *z* and *zeta*, to become $Y(a, z, \text{zeta})$.

There is a key hidden background element in the above, it is the behind-the-scene role played by the deliberate volition of a sentient being in enabling the emergence of the group wave function, here the wave function associated with the water pot. Without somebody filling the teapot with water, the wave function of the system made up by the teapot filled with water would not have come about. Of the fourteen mainstream interpretations of quantum mechanics, two (the Copenhagen interpretation and the Penrose-Ghirardi-Rimini-Weber) attribute a *causal* role to consciousness, more specifically to the consciousness of any participant involved, and three more interpretations attribute to it a conditional, co-creating or incidental role (32).

Interestingly, if and whenever we try to shy away from a role for consciousness in how reality weaves its own fabric, for instance by favouring an interpretation of

quantum mechanics that does not give a role to consciousness, such a role somehow seems to always reappear and re-enter the picture, as it were, through some other door. Indeed, although the few interpretations of quantum mechanics which put consciousness at its core and thus call for a sentient consciousness to play its key enabling role, do not seem to constitute its most convincing interpretations, some key role for consciousness seem to become inescapable anywhere we turn. We'll explore this more in detail soon.

But what does the wave function actually materially mean? The short answer is: *everything*: nothing material has any ultimate materiality but for their associated wave function.

The long answer, explored at length in the literature of physics, is that a given wave function provides a means of calculating everything that pertains to the object this particular wave function represents (even if the actual calculations are as a rule far too complex to perform): importantly, the *probability of presence* (33) of the object at a given place and time, but also much more besides, including non trivial parameters, such as the likelihood of presence in possible parallel realities, and the likelihood of the existence of such parallel realities to begin with.

Closer to home, the wave function also explains the above-cited mystery of why a football or a bullet would obediently speed off to their intended destinations at the imparted direction and speed and energy without knowledge of such destination or energy. (The foregoing sentence is actually not *exactly* right: they dash off *more or less* to their destination at *more or less* the energy intended - within the error margins of their constant 'recalculating'.)

Here's how: The wave function indirectly indicates the likelihood of presence of its associated object within a certain area of space-time.

The wave function continuously 're-calculates' itself (for lack of a better word), by constantly "calculating" the instant probability of the presence at each and any point of space within the whole universe of the object attached to the wave function in question. The *boundary conditions* used in the calculation (technically a calculation called an *integration*) are the geographical limits of the space we are looking for the object in, and within which we calculate the probability of the object's presence. Note that if the size of the universe itself is used to set the boundary conditions of the calculation, then the calculation always yields one, because there is a one in one chance, a one hundred per cent likelihood, that we'll find an object within the universe if that object exists: an existing object has got to be *somewhere* in the universe (34).

As it evolves through time, the wave function thus 'recalculates' itself at every 'instant' (whatever that means) and takes on an instant, 'spot' value also impacted by the various properties which pertain to the calculation - including the so-called *boundary conditions* attached to the integral terms. As it happens, these boundary conditions evolve over time - they are newly set at every instant of time, and any drastic change in the object's environment or conditions, such as a kick, immediately

causes a change in the values of these boundaries. *The mathematical effect of the kick was to alter the boundary values governing the integration.* The kick did not affect the ball directly, but affected it *indirectly*, via its associated mathematical reality.

Because of these newly-set boundary values, the self-calculating highest values of the wave function, corresponding to the peak probability of presence of the associated object, position themselves on the desired trajectory. Likewise, all the other associated parameters, such as force, momentum, energy, direction, etc., will *manifest*, or actualize themselves - show up - into reality with values which statistically will most often lie within very close range of the highest probability values calculated. These parameters are all part of the information embedded within the wave function.

Some information is always lost whenever information is relayed indirectly: it's always better and more accurate to hear someone speak directly than being told by a third party what that person said, or, say, to read an original text rather than a translation.

The same applies here. Experiment have been conducted to observe the trajectories of electrons after they have been emitted. Electrons are so light that any fleeting instantaneous random deviations from an intended trajectory can be observed, and, because the wave functions of electrons can be explicitly calculated, these deviations can be statistically computed and predicted. The random instantaneous deviations that can thus be theoretically predicted have been observed in experiments and they behave exactly as is expected from the calculations – the electrons are observed to continuously stray from their intended path, seeking out their trajectory in real time, and always reverting, more or less, to their intended (imparted) trajectory. The statistics of the experimentally observed deviations from the imparted trajectories, in terms of the directions and amplitudes of deviations, match within a very narrow margin the values expected from the calculations of the wave functions (35).

A question of course is what is it that prompts the wave function's self-recalculation to launch, stop, and begin again? Is there a mechanism that allows this to happen, to in effect isolate and privilege a given succession of otherwise indistinguishable time-points when a wave function executes a continuing series of recalculations? If time is discrete, it is relatively easy to conceptualize that a recalculation is reset at each actual instant of present time. If time is continuous, what mechanism triggers the 'recalculation' and when?

In any space-time, where for whatever reason, the recalculation mechanism would *not* be enabled, reality would become weird and objects (if they could exist in such a space-time) would not be able to self-calculate their own wave functions – they would drift about aimlessly, regardless of any past history. A kicked ball or a fired bullet would just float about rudderlessly. Matter as we know it would be unable to exist in such a universe in the first place: such a universe would only ever be able to host *virtual* matter.

Regardless of whether time is continuous or not, there does exist a zone where time simply stops: the spherical two-dimensional 'event horizon' around a black hole (also called the Schwarzschild horizon, after astronomer Karl Schwarzschild.) Any two-dimensional object, perfectly precisely poised at a Schwarzschild horizon would be unable to recalculate its wave function (quantum effects however would soon destroy the perfect poise there.) We'll revisit black holes shortly (36).

Since consciousness keeps putting in appearances, be it at the core of certain interpretations or at their outer edges, it is time we briefly looked at the material seat of human consciousness: the brain, which indisputably is...

8 The Most Complex Object in the Known Universe

The human brain contains eighty-five billion or so neurons, each of which are directly linked with thousands of connections to other neurons. A ‘brain state’ is defined as the snapshot of the brain’s *configuration* at any given time. Configuration in this sense is defined as the three-dimensional map in which neurons happen to be firing at a given instant and of which inter-neuronal connections and axons are either active or idle at that time.

Collaborative neuron ensembles, once established, enable the brain’s owner to acquire specialized skills which can then be summoned up without deliberate thought (whence the expression ‘*I could do that in my sleep*’) and to store memories. Practice and habits are the traditional way whereby resonant ensembles of neurons are progressively established within the brain.

The number of possible brain states is gigantic: it is estimated at about 2 to the power 85 billion configurations, a straightforward calculation if we model the brain as having 85 billion neurons, each of which capable of being in either one of two possible states (i.e., active or idle).

The time it takes for two neurons to communicate (in other words for data transfer between neurons to occur), and for an individual neuron to shift from active to idle status or reversely, is about one hundredth of a second. since it is estimated that between one and ten percent of total brain capacity is used at any instant of time, up to ten percent of the brain can change its status every hundredth of a second. On the basis of these and other considerations (such as thermodynamics within the brain), it is estimated that the maximum number of different brain states that can arise per second is roughly equal to ten to the power twenty (10^{20}) per second. A human being is thus not equipped, and hence unable to perceive, any event or occurrence of any kind that would happen faster than 10 to the power minus twenty seconds (in reality our scale of perception is much coarser, because billions of neurons need to be collectively involved for a conscious perception to register.) In other words, we live within our own discrete time, although we are unaware of it, with a small but incompressible biological quantum of time equal to about ten to the power minus twenty seconds. If a physical quantum of time exists and is shorter than that limit, we just cannot perceive it and will perceive time as continuous. As we’ll see, various calculations of an upper limit for a physical quantum of time in our universe yield values which are, as it happens, far smaller than this biological limit.

Because of quantum effects in the brain, there is a far greater number of ways by which different neurons can communicate with one another, and immensely many more resonant ‘collaborative ensembles’ of neurons can be established than would be the case if the brain were a mere (non-quantum mechanical) chemical machine. Many authors have argued that the brain is the ultimate quantum information-processing machine (37). The essence of how quantum effects can enhance the way information is exchanged in the brain lies in the way synapses “fire”; the mediators of information

exchange are particles (ions) and therefore they are, first and foremost, *wave functions* rather than material particles. Owing to quantum effects, the “firing” of a donor neuron does not necessarily occur towards the immediately facing receptor synapse but may involve any other synapse located anywhere within the brain (i.e. not directly facing the donor synapse) and can simultaneously involve any ad hoc group of synapses, which leads to an immense number of possible firing configurations. Being essentially wave functions, the brain’s data-mediating ions are able to link up and communicate with any synapse and establish collaborative resonance patterns with any group of neurons anywhere within the brain. This quantum trick immensely multiplies the number of possible ‘brain states’ – and hence the brain’s data-processing power.

A number of different mechanisms have been put forward to describe the manner of neuron interactions at the quantum level – the bottom line being that such effects would work mainly through the existence of chemical exchange processes within the brain involving spread out wave functions; because wave functions associated with data exchange can, and do spread out, communications between ions do not always necessarily involve the immediately facing synapse when a neuron fires. Ultimately, any synapse anywhere in the brain can participate in any data exchange, thus multiplying the number of receptors able to become involved in any particular communication originating from any given neuron.

Some other researchers, such as Victor Stenger, do not believe that such quantum effects occur. The gist of their argument is that the timescales of events within the brain are sluggish in comparison with those involved in quantum effects and that action distances in the brain are longer than the usual distances over which quantum processes take place (this latter objection can, thanks to Bell’s theorem, be safely ignored.) There are, generally speaking, many ‘quantum effects’ in biology which we once did not think possible and are just only beginning to discover. Photosynthesis for instance essentially depends on quantum effects, whereby the most efficient itineraries for ion exchange are ascertained quantum mechanically. Or, Luca Turin published a 2011 paper convincingly showing that the astonishing human ability to smell a *trillion* separate odors, or so, stems from quantum processes in the nose - an ability which could otherwise never arise from the lone means of the 450-odd separately specialized chemical receptors we have in our noses. Such processes do not operate by absolute thresholds but involve probabilities of occurrence and involve odd quantum effects such as tunneling, whereby an effect can happen even if the energy necessary for it to happen is not there. Whenever the relevant numbers involved are huge (such as the number of neurons that may participate in a thought, or, say, the number of atoms in a tunnel diode or a field-effect transistor, or the number of participants in a Lotto draw), rare outlier events at the extremes of statistical probability become routine. As mentioned earlier, experimental traces of quantum effects in the brain (such as the observer-generated so-called quantum Zeno effects) have been ascertained. If the brain followed strictly classical chemical and biochemical laws, any donor neuron synapse could fire and exchange a chemical carrier of information (an ion) only

towards the synapse immediately facing it. Were it not for quantum physics, it is quite possible that our data and thought-processing power would be more limited, and that we'd be less intellectually nimble than we actually are.

A brain's, or to put it in a more holistic but roughly equivalent way, a *person's* wave function describes and governs the way a person interacts with their environment. Associations with other wave functions from the environment are established, evolve, and then may dissolve (*decohere*) in an ever-shifting dancing landscape of wave functions.

Somewhat frighteningly, a person's wave function can itself decohere and split into independent sub-wave functions. These *sub-wave* functions can remain loosely associated with a 'parent' wave function, or between one another, or alternatively become wholly independent - *decohered* - from one another.

Simple deliberate volition can cause 'internal brain decoherence' to take place, and, as the psychiatrist Dr. Mark Salter of the Homerton Hospital in London once put it, "it is scary".

This following conversation with Mark Salter is cited by William Storr who was interviewing Dr. Salter in the context of people who seemed to change personalities when performing on stage:

Dr Salter: Call it Multiple Personality. We can all have them

William Storr: I don't have multiple personalities

Dr Salter: Well, try a little trick for me:

Just imagine a version A and a version B of yourself and have a conversation in your head between them as you drive home from this interview. You know, like,

"What are you doing tonight?"

Well, I thought I'd write up this interview

Well you could, but there's some great TV on

I know, but I have a lot of backlog work to deal with ..."

Carry on like that for one hour and I promise you, *you'll scare yourself*. Before long, the first voice will become, say, more outgoing and develop a liking for art and German techno music; the second one will be introverted and prefer science and South American heavy metal.....

Most often though, and very sadly, split personalities are precipitated by traumatic events as the brain seems to try to protect its owner by *decohering* and thereby sheltering them from the bad experiences that sprung from the outside environment – by establishing new wave functions untainted by bad memories and links with other wave functions and realities (38).

We will encounter below much odder, and as yet not fully explained, ways in which the brain deals with time (specifically, by processing so-called *saccades*.) But before we can return to time, we must look at another essential feature of reality: the so-called uncertainty principle, *aka* the Heisenberg principle.

9 Heisenberg's Uncertainty Principle (*aka Indeterminacy*)

There exists in nature *pairs* of properties of things, also called parameters or attributes, such as values of speed or time durations or location, which *cannot* be known with arbitrarily high precision when they pertain to a same object. Such quantities are *incompatible at the limit* - meaning that the level of accuracy with which we can know and measure one of the attributes is limited and directly affected by how precisely we know the other attribute within the pair. For instance, we cannot know with an arbitrarily high level of accuracy an object's speed and its geographical location *at the same time*. If we need to increase the level of precision with which we measure, say, the object's instantaneous speed, this will come at the cost of decreased accuracy in our knowledge of its instantaneous location.

This 'fuzziness' has nothing to do with an inability to carry out proper measurements: it is built-in within nature. With an ideally perfect measuring apparatus, we still could not reach an arbitrarily high accuracy for both measurements. Properties that belong within a pair of attributes that are 'incompatible at the limit' are sometimes called 'orthogonal', or alternatively, 'conjugate' attributes.

Here's an example: let's take two attributes of a sheet of paper – its colour and its surface area. These two properties are orthogonal. Indeed, take the sheet of paper and cut it in half. Then again. And again, and again, and so forth... There will fast come a time when what is left of the sheet has become too small to be able to tell its colour: all that's left to see is a tiny, darkish little dot of paper. This is in no way because of imperfect sight which could be improved by, say, the use of a microscope; if we keep cutting the shrinking paper remnant again and again there will eventually come a time when its dimensions are smaller than the amplitude of the light rays needed to reflect and convey the paper's colour. There is a threshold of compatibility, a certain value of the surface area, below which we simply *cannot* tell the colour - or in other words, there exists an incompatibility at the limit between size and colour, below a certain value threshold. The thresholds' numerical values depend on the particular attributes. For instance, in the above example the precise surface area from which the colour would become indistinguishable depends in some measure upon the particular relative colour.

Heisenberg's Uncertainty Principle expresses the theoretical thresholds and establishes the theoretical limits to our ability to know the value of one attribute depending on the precision with which we know the other (39).

There are many such pairs of incompatible attributes in nature. John Barrow gives an example of the odd consequences which the orthogonality of speed and geographical location can bring about in a billiards game. Should one play exactly the same game - hitting the balls at *exactly* the same spot with exactly the same energy imparting the exact same speed, with exactly the same cue and everything else being exactly the same - the billiards game will still become a totally different game after the very first cue stroke. After a mere *twelve* cue strokes, the theoretical cumulative uncertainty attached to the location of the ball becomes *bigger* than the width of the billiards table itself.

The French astronomer and mathematician Pierre Simon Laplace (born 1748), famously once said that if we were to know all of the universe's atoms and constituents' exact locations and exact momentums at any particular point in time, we would then *in principle* be able to compute and predict with infinite accuracy the state of the universe at any arbitrary point in time henceforth - if we only had the requisite computing power at our disposal. We now know this to be just plain wrong: with an infinitely precise snapshot of the state of the universe at any point in time, we could not in principle determine the exact state of the universe even one split second later, let alone much later – it's fundamentally and intrinsically impossible to do so (40).

An interesting feature of this real-world uncertainty is that it allows all kinds of phenomena as long as these phenomena remain 'under the radar' of direct perception by reality itself, as it were. For instance, because *span of time* and *mass* are orthogonal attributes, unseen 'virtual' particles and masses continuously pop in and out of existence, and can keep existing as long as they remain in their virtual existence for a shorter time than the associated orthogonal duration of time. The existence of these virtual particles is well established. They give rise to all kinds of real-world phenomena through their indirect effects (41). This all-pervading 'sea', or froth, of virtual particles and masses popping in and out of existence is often called the 'quantum foam'. As we shall see, the existence of this quantum foam entails all kinds of measurable effects and real life phenomena even in our everyday macroscopic reality. In fact, as we shall see, it goes much further than that; macroscopic reality itself is an emergent phenomenon from quantum foam, sometimes therefore called pre-reality. We'll revisit this issue later.

10 Time - *Part 2: the Guises of Time*

10.1 Time as an Emergent Property?

All of the possible configurations of the universe - all the possible values that anything within it can ever assume - are collectively defined as its 'state space'. A universe state is the snapshot of how the universe is at any particular point in time. The state space represents all the possible values that universe states can ever assume - all of the conceivably possible snapshots that can ever exist.

Our universe is made up of a gigantic but nevertheless finite collection of objects (there are some 10 to the power 80 atoms in our universe - ten followed by eighty zeros), all of which are evolving along their own timelines, i.e. living their own existences in space and time within their local space-time (there are immensely more possible universe states than the mere number of atoms within it.)

By this definition, an upper boundary on the possible value of any quantum of time would be the span of time that would elapse between one given universe state and the immediate next - whenever any constituent particle of matter or any property such as a speed or a quantity of movement of anything, anywhere within the universe, has an altered state.

Time thus emerges every time some change happens to a universe state - every time some 'state change' takes place within the universe, no matter how small or elementary. Time seems to emerge naturally as a side consequence, and measure, of anything happening anywhere in the universe.

Under this definition, it is easy to also envision how time would have to be discrete since the number of constituent elements and/or associated properties within such a universe is finite – or put equivalently, but in more modern terms – the number of different excitation modes of various fields within our universe is finite and as such any time span between one attribute changing and the next one changing is also finite. Following this process, the smallest possible such time interval can be is equal to the largest possible value of the time quantum (which could well, however, be smaller). With 10^{80} atoms, we can arbitrarily but reasonably place an upper boundary value of ten to the power 'a few hundred or so' possible field excitation modes within our universe.

The maximum value of the time quantum is then represented by how long it takes for the universe within a given configuration state to move to any next configuration. However, even if we could measure it, this would only be a 'maximum value' - an upper boundary - because there is no reason why the universe would always move to a next state at the same speed or rhythm.

Let's think up, as a mind experiment, strange universes (irrespective for the time being of whether such universes are actually possible). Let's conceptualize, for instance, a universe of any size that has only one possible state. Nothing ever moves,

nothing ever changes in this universe. Its time quantum becomes infinite: time is frozen. Nothing ever happens. Time does not even exist – such a universe would be truly timeless.

Alternatively, let's imagine an infinite universe with an infinity of possible states. Time in such a universe would be continuous (42).

Let's now envision an *empty* but infinite universe. Such an *empty* universe could incidentally be very much like our own universe a few thousand billion years in the future, desolate and essentially 'dead' under the so-called 'cold death' scenario; after its matter has diluted to nothingness owing to its relentless expansion and dilution, and all that is left is quantum foam (this 'residual' universe would however be of gigantic dimensions, but nevertheless not infinite). In an infinite but empty universe, time also becomes frozen; in effect continuously frozen because nothing ever happens (any quantum of time thus becoming infinite).

In an empty but finite universe, the existence of boundaries hints at the possible existence of an underlying discrete time grid, but emptiness ensures that time within such a universe cannot be emergent, unless it is *virtual time* (see below).

But there is a key issue of how a single status change happening somewhere in a corner of the universe could somehow bring forward, instantaneously, time everywhere in the universe. There are not many ways whereby one single configuration change, brought about by one event happening somewhere in some corner of the universe, can instantly affect time everywhere else in the universe. We'll revisit the issue soon, but for the time being suffice to say that if time can begin at some point in some far corner of the universe, then time in other locations of the universe can also probably emerge there, independently or not, and 'flow' at different rates - leading to all sorts of scenarios such as simultaneity being different depending upon where you would happen to be in space. If you are at a given location, say you would see two events A and B occurring in that order, i.e. A before B. Another observer at another location would however be apt to see B happening before A, whereas yet another observer at a third location could see the two events as taking place at the exact same time. We are unexpectedly rediscovering Einstein's relativity.

If time is an emergent property, then time is both necessarily *local* and necessarily discrete, with the value of the time quantum being at most the shortest amount of time between elementary events. Under the emergent time scenario, unless we discover a separate mechanism allowing for instantaneous equalization of time across space, clock time would be different everywhere in the universe, and would 'flow' at different rates everywhere in the universe.

Furthermore, a nagging thought does not seem to simply go away; there is a chicken-and-egg quality to the emergent time scenario. For some change, any change, to be able to happen in the first place within a universe, is it not a precondition that something very much like time already pre-exists, thus allowing any changes caused by any other independent agency to happen?

Whereas pre-existing time cannot cause by itself anything to happen, is time itself not a prerequisite to permit changes to happen *in time*? To be able to take place, there must exist some allowance mechanism whereby changes can occur. Indeed, emergent time *cannot* arise in the two-dimensional frozen-time world of the Schwarzschild horizon, because time is frozen there to begin with. Rather than two-dimensional objects being able to evolve and change in the Schwarzschild horizon, and thus generate time there, the frozenness of time prevents such objects from ever coming alive.

Could it be that we are really committing a classic cognitive bias type mistake by trying to materially understand something, time, that can only be apprehended mathematically? At the very least, when we try to apprehend or even define time through state changes of the universe, we seem to be attempting to observe a non-observable.

We could try, for instance, to say that if there are, say, 10 to the power 5000 possible universe states, and all of them change, say, over the course of one second, then the emergent time quantum could be something like 1 second divided by 10^{5000} . But it does not work: we have used the very concept of time (one second) to define time. Using *something* to define the very *something* we're attempting to define constitutes the very essence of non-observability, a situation where the concept which we are trying to get a handle on becomes a 'judge and party' of itself in hopelessly circular reasoning.

The attempt to insert workable outside elements into an attempted definition of time is also fraught with traps. For instance, we could attempt to independently define the tiniest possible change in the universe as the time it takes for the fastest signal in the universe, light, to travel the tiniest distance possible - say, the quantum of length in a quantized space-time (43). And again, it does not work: the quantum of time is inextricably bound up with the quantum of space in a quantized space-time, in which non-observability rears its head again.

Even if we found properties or variables not directly linked with time, but which enable us to indirectly measure it, apart from the purely experimental difficulty of measuring anything at those scales there is an inescapable reason why we could not achieve this with enough precision even if we had ideally perfect measurement capabilities. The attributes themselves that we need to use to define time precisely are fuzzy, bound together within Heisenberg's uncertainty principle.

If we could independently estimate a floor value for a time quantum, and if we found this floor value to be greater than naught, this would at the same time demonstrate the discreteness of time. It is sometimes theorized that our universe was born of a quantum fluctuation. Whereas there are many other ways whereby a universe can be born - different scenarios which we will also be looking at later on - a quantum fluctuation can indeed give rise to a baby universe from a parent universe, provided that time is discrete in the parent universe. We'll see how below.

In the case of our particular universe, and equivalently of all bounded universes with a (3,1) signature (44), a simple way of estimating a lower boundary of a time quantum's value in the parent universe is provided by plugging in the value of the mass of the universe in Heisenberg's equation linking mass with time, and deriving the corresponding threshold time value (45):

With the mass of our universe estimated at about 10^{54} kilograms, a straightforward calculation yields a value of the time quantum of about ten to the power minus one hundred and five seconds (10^{-105} s), this value applying then to an original "matrix environment" or 'mother universe' that could have given rise to our universe. This value of ten to the power minus 105 seconds is a lower boundary (minimum) value for the time quantum (a lower boundary value rather than the exact value, because the original huge virtual mass may have been arbitrarily bigger than was strictly necessary to trigger the actualization of the virtual mass into real mass under the Heisenberg equation, so that even a somewhat lesser mass - and hence a longer value of the correspondingly allowed conjugate time duration - could have been enough to trigger a Big Bang.) Of course, this is but a *gedankenexperiment*, for we do not know whether it was in fact this scenario, sometimes called a Tryon scenario after cosmologist Edward Tryon, which actually triggered our particular Big Bang (see *Chapter 12*.)

In our universe, even if we possessed ideal measurement capabilities we could not in principle measure time durations below the co-called Planck time, equivalent to roughly ten to the minus forty-four seconds (10^{-44} s). If Planck time is taken as a reasonable approximation of the time quantum in *our* universe, a calculation exercise shows that Tryon scenarios originating from the quantum foam of our universe could spawn separate baby universes from our universe with masses of about... one ten thousandth of a gram! (Max Planck was one of the pioneers of quantum physics, which earned him the Nobel Prize in 1918. Importantly, he gave his name to the fundamental Planck constant, which associates energy and electromagnetic wave frequency in quantum mechanics.)

Let us recap briefly what the 'emergent time' approach has so far shown, regardless of misgivings as to whether it is the whole story.

In a nutshell, under this approach time is seen as an emergent property arising from a 'live' universe - from any elementary change in its configuration. As long as nothing changes anywhere in the universe, time is frozen and for all practical purposes does not even exist. Whenever the state space describing the now configuration of the universe undergoes any change, then time itself happens and 'notches up' one tick (at least in the 'neighborhood' of the change). The instant anything changes anywhere in the universe, the configuration space of the universe alters accordingly, which gives rise to a bit - a quantum - of 'time flow'.

Under this scenario, the larger and more complex the universe, the *shorter* the Time quantum, because more events occur to notch up more and shorter ticks of Time. If the universe happens to be infinite, then the time quantum becomes nil - in keeping with quanta, or quanta, arising because of the existence of boundaries.

Time as an emergent property thus provides underpinning not only for the existence of a time quantum - the amount of time it takes for the configuration space of the universe to move from one 'node' to the next one - but also for rediscovering certain aspects of Einstein's relativity. Because time notches up a tick at *the particular spot* where the change in 'state space' occurs, time within space-time begins in a specific place and then somehow spreads, distributes itself, unevenly throughout the universe.

What seems indeed certain at this point is that the time, say, at your left ear is not quite the same as time at your right ear, even if it is infinitesimally so, because time depends on location in space. Under relativity, time throughout space is best represented by a *field* - a different clock number is associated to every point in space (46). So what is the mechanism whereby evolving time changes propagate throughout space?

Let us define a 'time cell', or a 'time bubble' as a zone in space where clock time is the exact same throughout. Do such bubbles of time exist?

Unsurprisingly, pure mathematics re-emerges here with a vengeance. It shows that whenever certain zones within space, however far apart, are somehow linked within a certain mathematical equation (47), then they live, tick, and operate *under the exact same time clock*, and keep to that same time *instantly* regardless of physical distance.

This has been proved beyond a shadow of a doubt in laboratory experiments, which establishes experimental corroboration for what the mathematics says. And again, we would be hard put to find a physical, or material, explanation of any kind. There is just pure math, embedded as we saw earlier in Bell's inequality and in the laboratory experiments that have demonstrated it.

In essence, Bell's theorem, equivalent to or underpinned by Bell's inequality, shows that whenever two or several separate entities are entangled, or *correlated*, the effects on time of the physical space separation between them are abolished. Correlated in this sense of the word is defined by two or several entities in question being linked within a currently valid wave function which obeys Schrödinger's equation.

How do they become correlated? What is the agency that permits the correlation between these entities to become established? A correlation which will embed itself mathematically within a unique valid wave function is something we will explore further on.

Briefly recalling here that by 'entity', we refer to any real physical system: a particle, a desk, a person. We can call its wave function anything - say, snoopy, or Φ , or Ψ , or Y - let's arbitrarily say Ψ , and let's call the entities A and B bound together by Ψ . The wave function is then denoted as $\Psi(A,B)$, read as " Ψ of A and B". Bell's theorem says that if we impose a change on A, then B will react instantly, regardless of physical distance, to those changes made on A - as long as Schrödinger's equation, when applied to the wave function of the system constituted by A and B, seamlessly continues to be valid.

If A and B become separated further outward across the vastness of space, B will still react instantly to any change imposed on A regardless of the distance between them.

B will always react instantly, i.e. *faster* that it would take for a signal starting out from A and spreading out from A *at the fastest possible speed in the universe, the speed of light*, to reach B.

What it says is that the mathematical truth embedded in the wave function works, even if we can't yet work out how it does so physically.

Bell's theorem has been repeatedly tested in the laboratory, originally and most famously by Alain Aspect, and compellingly convincingly by a number of researchers, including Nicolas Gisin at the University of Geneva in 1997.

Physicists everywhere have been scratching their heads in puzzlement, and more often than not in disbelief, trying to understand how and why this works. Nothing can travel faster than the speed of light, and hence A demonstrably does *not* communicate to B at any time whatever it is that is happening to it. Yet B reacts instantly to anything happening to A - just so that a valid mathematical equation, in this case their joint wave function - not be violated. Again, we might be simply barking up the wrong tree, and trying to solve the wrong problem when we strive to find material explanations where there may be none (*also see note 20*). Beyond trying to understand the elusive and likely largely meaningless *physicality* of what is happening here, should we not be investigating instead the question we keep coming across - why is it that math always seems to make physical reality conform to its abstract dictates, no matter what, no matter how odd? Why is it that related events occur instantly across vast distances, Big Bangs occur, nuclear reactions occur? A simple answer is to take a view similar to that championed by Max Tegmark; that the universe ultimately is nothing but a pure mathematical structure. This comes at a price, or, at the very least (and depending on your preferred *weltanschauung* or view of reality), it leads to non-trivial consequences which we will look at when we examine the resultant possibility of a multiverse.

So, does the 'Time as an emergent property' scenario work? To work fully, two requirements should be satisfied.

First, it can *only* work fully if time is propagated instantly throughout the universe. It can work only partially if time is not propagated everywhere instantaneously, but gradually; in the real universe, this is exactly how things seem to occur. Through both full and partial and evolving wave function coherences of subsets of the universe - individual objects, collections of objects, etc. - time eventually spreads throughout the universe.

The second requirement is much more of an issue. So as to obviate the circular reasoning of time being needed in the first place to permit time to happen, all elementary changes taking place in the universe *must* be fully instantaneous - that is to say, these elementary changes must take place *outside of time*.

To put it another way, all elementary state space changes must happen instantaneously, i.e. with a time difference exactly equal to zero. But this would then require the superimposed coexistence of 2 elementary state spaces of the universe. For a state change to occur in zero time, the original state ends up having to coincide

in time with the destination state. It *cannot* happen, because it would inevitably lead to physically impossible situations - where the so-called Pauli exclusion principle would be violated (48).

It therefore seems that Time as an emergent property just cannot be the whole story.

Paul Davies, UCLA physicist Itzhak Bars, and others speculate that there may be more than one dimension of time (49). Time can also be virtual: some of the exotic virtual objects that pop in and out of existence in quantum foam may be evanescent time dimensions.

10.2 Time as a Dimension?

Let's look at time as a pre-existing dimension rather than an emergent property. Perhaps an easy way to understand time as a dimension is to look at what kind of space-time we'd be living in if there were *several* dimensions of time, rather than simply several dimensions of space (50).

Could this question be ascertained experimentally? Let's look first at our everyday experience in the way we sometimes experience time so differently: could there ever be *objective* grounds for the subjectively different perceptions of time which sometimes occur?

The relativity of the *perception* of time, if not of time itself, has long been known and rather familiarly experienced. In Indian mythology, King Kukudmi had a beautiful daughter wooed by many suitors. At a loss as how to choose the right husband, King Kukudmi took her daughter to see Brahma - the creator himself. Understandably busy (he has universes to rule) Brahma asks the King to 'wait a second' till he can attend to him.

After a short while Brahma finally frees himself up from his other chores and makes himself available to the King. He hears the King's story out, and soon bursts into rueful laughter. "King", says Brahma, "during your short wait here, many eons have elapsed on Earth. All of your daughter's swains are long since dead. Please go back now to Earth and wed your daughter to Balarama (Krishna's brother)."

It's probably fair to say that many of us have had similar experiences of uneven time. We might for instance wake up half-way in the early morning, then go back to sleep and experience a most elaborate dream, to wake up again later on. The dream may have been so vivid and detailed, we sense that we've been dreaming for an hour or so, and we're thoroughly baffled when we see from the bedside clock that only a couple of minutes have gone by. The opposite happens as well. We half wake up, go back to sleep for a second, and when we wake up again we're stunned to realize that we've actually been back under for a couple of hours. Interestingly, Marcus Chown, the well-known science journalist and author, makes the following contrary statement: "We'll never be able to enjoy a few extra hours in bed courtesy of 2-time

physics". Yet many people are convinced they routinely experience exactly that - or the reverse.

UCLA physicist Itzhak Bars is convinced that there are two dimensions of time. Calculating how reality behaves with that extra time dimension seemed to throw up a number of wayward hindrances at first - such as negative probabilities and mandatory time travel into the past - until Itzhak Bars realized that mathematically, the extra time dimension imposes far tighter restrictions on allowed 'degrees of freedom' than is permissible in our ordinary space-time. These restrictions would, for instance, allow us these few extra hours of sleep within our ordinary-time short blink, but would effectively prevent us from waking up *before* we went to sleep and veered off at the fork into the other time dimension.

The two time dimensions hypothesis also seems to neatly resolve an issue for which there is, as yet, no known solution. In a nutshell, the so-called strong force - which binds neutrons and protons within an atom nucleus, and quarks within hadrons - should, according to calculations in QCD (quantum chromodynamics), favor certain reactions over others; a bias that has however never been observed experimentally. This lopsidedness *disappears* when a second dimension of time is introduced in the QCD equations.

King Kukudmi's experience above can however be interpreted in two very different ways (beside the obvious and realistic statement that it's only a legend). One would be to say that when he went to visit Brahma, the King set off in a different dimension of time, unfolding along an axis Y, whereas back on Earth, time continued to proceed along its usual X axis. The particular geometry, or topology, of the axes is such that at least one of the axes, when seen from the other, would appear to loop back, thus giving it the ability to intersect the other axis at arbitrary time intervals, either shorter or longer than they are on the linear axis - thus letting the King leave again the Y time-axis and rejoin X at some point much further along, and depositing the King far later than where i.e. when he originally exited that axis.

Another quite different scenario would however lead to the same perceived experience of two-speed time: if Brahma lived close to a black hole, or at least in a region of space-time with such extreme gravity that it warps time way out of its wonted kilter. Relativity mandates that whenever gravity grows in strength somewhere, time there 'flows' more slowly, an effect known as time dilatation. At a black hole, time dilatation becomes infinite. If Brahma's office was located near a black hole, then the effects on King Kukudmi and his daughter would have been exactly those described (if Brahma's office however had been inside the black hole, or in technical terms inside its Schwarzschild horizon, then the King would not have been able to return to Earth ever - and should he through some miracle have still been able to return to his world, he still would not have - instead, he would have found that the universe itself had long vanished, along with his daughter's swains and everything else.

If time is a dimension, then time travel could *in principle* be possible. Physicists have long tried to devise a workable time machine, at least on paper, but the proposed

designs have all kept tuning out impossible or at least highly dubious for some reason or another. Heinrich Päs, a physicist at the University of Hawaii at Manoa, and his colleagues think they have found a testable way forward. They think that our rather flat, plain vanilla universe is immersed within a much more distorted higher-dimensional mother universe whose geometry and dimensions are severely warped. In other words, our universe is a smooth four dimensional bubble floating within a wrung-up higher dimensional matrix. Within this higher dimensional matrix, shortcuts between locations would be possible - a bit like the distance to bring a pen tip from the top of a sheet of paper to its bottom is much shorter if one simply folds the page over. Seen from our universe, and hence from a lab on Earth, anything that would take a shortcut through dimensions would look like it traveled faster than light. The experiment proposed by Päs et al. to test this hypothesis would involve tricking ordinary neutrinos into first flipping into a different kind of neutrinos capable of taking a shortcut through the higher dimensional matrix, beaming them towards a distant location, and then flipping them back into ordinary neutrinos at that location and measuring the time it took them to reach it. Any faster than light travel would then be detected (and calculations show that because the earth rotates, some of these neutrinos would then be seen to arrive before they left.)

Päs also says that his picture of our universe being a smooth-space bubble adrift within distorted higher dimensional space solves a number of issues that still beset our current understanding of the universe based on Einstein's general relativity. It would for instance do away with need for the theory of inflation (see note 83), artificially developed to explain some otherwise unexplainable features of the universe: for instance, the fact that faster than light travel would otherwise be necessary to account for the observed evenness of temperature across the universe - including across far-flung corners of the universe where, save for inflation or any other *ad hoc* explanation, there is no reason why their reigning temperatures should be the same as elsewhere, and yet they are.

But what of our time-warped dreams? Snugly ensconced in bed, we have definitely not been going anywhere near a black hole. So the dream experience says that either the time *perception* of a slumbering brain is different, or, if the way the brain processes information is not significantly different during sleep (be it during REM or light early morning slumber) and hence cannot account for wildly different perceptions of time, then we may have somehow slipped into or tapped into other time dimension(s) during dreams. To try to determine which, let's look briefly again at how the brain functions.

Information exchange and processing in the brain is mediated by the firing of neurons, which communicate with other neurons. Symbolic-data processing and exchange is mediated by chemical signals. Processing information in this way is incidentally not limited to brain cells alone; ants, for instance, exchange information in a rather similar fashion, by swapping chemical signals between two and/or several ants, often serially but also concurrently. In the human brain, the chemical signals

take the form of ions crossing the synaptic gaps between one neuron and another one (the synapses serve as the portals between different neurons.) Meaningful information exchange and processing requires a vast number of synapses firing collaboratively, in a not yet fully understood choreographed and hierarchical exchange of information.

How are the brain's functions affected by sleep? Different brain waves emerge during sleep, depending upon the sleep phase (there are five major phases of sleep, during which different brain wave patterns arise, such as theta and delta waves), so we know that a slumbering brain functions differently from a wakeful brain. How these different brain modes affect and alter the way data is processed is not fully known and further study is needed. Although it is very likely that it is in the end a matter of perception, we still need to understand also *how* the brain generates such different perceptions.

And indeed, the plot, as ever, considerably thickens.

The brain quite routinely makes us believe in things that supposedly occurred in a past which can quite easily be demonstrated *has never existed* (51).

Then the plot will thicken yet further: there is an unresolved question as to whether the brain does not, in fact, both routinely and often travel back in time in the *waking* state...

Our eyes are key data-acquisition sensors for input of external data which is then conveyed to the brain for processing. The eyes do not look at the world in the way we would instinctively believe they do; they look at the world in intermittent moments, often and continuously interspersed with short instants of blindness. The brain then braids, splices, and weaves the intermittent strobe-like images it acquires from the outside world into a coherent - but slightly *false* - whole.

Our eyes undergo frequent breaks in perception whenever they flit about, in blind jumps called saccades. To immediately experience this temporary blindness, do the following: look at your own eyes in a mirror and shift the focus of your sight from one eye to the other one. A person standing beside you watching you will effortlessly see your eyes flit and shift from one direction (line of sight) to another, but you will never see your own eyes move - even though they demonstrably do move and are indeed seen as such by the other person. You have not either experienced any instant of blindness during the short instant when your eyes moved, nor have you seen your eyes move. You have experienced continuous visual input of seeing your immobile eyes looking back at you: unbeknownst to yourself, you have been lied to by your brain which has seamlessly woven disjointed and incomplete visual data into a smoothly flowing and coherent whole.

Even more stunningly, nearly everyone who owns an old-style analogue watch has had the slightly odd experience of looking at their watch, and believing that the watch had stopped because the seconds hand seemed stuck. Then, after a perceptibly longer time than a second, the 'second hand' of the watch starts moving again and all subsequent measured seconds last for, well, a second. The extra time upon first looking at the watch can last up to slightly over a tenth of a second, long enough to be perceived.

This well known effect occurs because the brain fills *backwards in time* the period of time when it was blind with ‘more of the same’, to wit, with the first image it saw when the saccade ceased. So far, so good, although we can wonder at how the brain can fill time backwards in our perception. But at least this is an explanation that only involves our brain and perceptive skills.

But then this explanation breaks down, because of something called the dead phone illusion. It’s a similar effect, which can happen when picking up a telephone handset with an intermittent dial tone (pause/tone/pause/tone ...): the first pause seems longer than the subsequent ones, and the explanation by saccadic eye movement does not apply.

Kielan Yarrow et al. have investigated further fully reproducible similar cases, such as when tactile perception actually precedes the time of actual physical contact, and so on.

An ultimate explanation for this chronostasis - the impression that time stands still - is still elusive (52). What this highlights, however, is that we must not only be wary of what our instinctive understanding of external reality seems to suggest to us, but also of our direct perception of it.

In the absence of definitive, explanatory proof, whether we just perceive time differently when in dreamland, or alternatively somehow manage to tap into different dimensions of time, must remain a matter of conjecture.

It is interesting to note that the English language had, and indeed still has, a word for a visionary or *premonitory* dream, a word that has now largely fallen into disuse: a *sweven*.

Sir Thomas Malory wrote in *Le Morte d’Arthur*, his 15th century compilation of tales of King Arthur and the Knights of the Round Table “All who heard of that sweven said, it was a token of a great battle to come”. But surely, if we can lunge backwards and/or forwards along one or several time dimension(s) during sleep, rather than simply perceive time differently, it stands to reason that there should be then provable instances of foreknowledge or precognition, shards of information from a future brought back from our swevens? Many people claim that exactly such a thing happens to them - such as a Mrs. Mary Wollens of Toronto who won the lottery twice over on September 30th, 2006, with numbers she had dreamt of. There is, of course, no hard evidence that she did other than her say-so - although there is a bit of oddity in Mrs. Wollens’s story which makes it compelling among a handful of other such tales; she bought 2 tickets with the same number sequence, so convinced was she that she’d win, in order to dilute the share of any other possible winner (as it happened, there was another winner, so that Mrs. Wollens’s share amounted to two thirds of the jackpot).

Some interpretations of quantum mechanics depend on time being a dimension. We also briefly encountered the Transactional Interpretation of Quantum Mechanics (TIQM) in note (7). A straightforward calculation, combining two forms of an object’s wave function, yields the probability of finding the particular object governed by that

particular wave function within the block of space-time defined by the set calculation boundaries (53): one of these two forms of the wave function is interpreted under the TIQM as being a wave *emanating from the past*, whereas its other form (technically its *complex conjugate* form) is held to be the same wave emanating *from the future*. The merging of these two waves weaves material reality into existence at every instant - the present being thus created from a merging of the past and the future.

So far, so good.

The kicker, however, comes from shifting a little bit the value of the mathematical variable expressing time within these equations: there is indeed no reason whatsoever why our very own, particular point in time - our particular position on the dimension of time - should take on any particular significance. So let's shift it a bit by replacing the value of time, t , in the calculation by, say, time minus ten seconds; the calculation remains valid and weaves a reality 10 seconds ago, *at the very same location in space*. In other words, the equation seems to say that a reality separate in time can be woven into reality at the very same location in space, but at a different time. An infinite number of separate realities, unfolding at other times, can take place at the very same place where our reality occurs.

We are now thus facing another kind of parallel universe. Parallel universes happening at our very location in space, but at distinct and separate times. At points in our time or in our future which have happened, or will happen, when we were there, say, 10 seconds ago or when we'll get there ten seconds hence. These parallel temporal universes exist here at *other* points along the Time axis (54). For lack of a better word, we could say that these different temporal universes happen simultaneously along with our very own, in our very location (although the word 'simultaneous' breaks down here. Perhaps *superimposed* would be a better word).

This very scenario has been used in literature by fiction writers with little background in time science, and a few allegedly non-fictional, experiential stories have described it as well (55).

Since, within the framework of time as a dimension there is no objective special significance or particularity attached to our particular moving time point along the time axis, the same lack of particular significance also holds for another moving time point, say, 10 seconds earlier, or 10 seconds later, or whenever; we are left with a time axis exactly similar to a dimensional axis where no point has any particular prior mathematical significance. There is an infinity of such time points and therefore an infinity of distinct temporal universes can overlay themselves at any given spatial location.

But as we will see, when the effects of Bell's theorem are combined with the effects of relativity (56) which in both cases have been shown to exist both theoretically and experimentally, the results become nothing short of stunning.

Whenever multiple objects or entities are defined as the variables of a joint wave function, these entities are 'entangled' (those 'entities', for lack of a better word, could be anything - two particles, two universes, two people.) When entangled, they

keep to the same unique time clock – this is why Bell’s theorem works. This instant entanglement has baffled generations of physicists, including Einstein who famously mused about spooky action at a distance. It creates the equivalent of time-like bubbles across spatial space; geographical zones distributed within three dimensional space ticking to a joint, common time-clock, never mind any limitations which may be due to relativity and/or the speed of light. Disentanglement nevertheless (*aka* decoherence) can of course occur, typically through the advent of new, separate entanglements of A or B with new entities within their respective local environments, and a concomitant drift away from prior entanglements whereby the earlier common temporal synchronous *takt* may become diluted or lost.

Before we look deeper into time bubbles across spacetime, we must look at alternative scenarios whereby universes can be born out of a quantum fluctuation, bearing in mind that should there be several universes out there within a larger *metaverse* (57), nothing forbids separate universes from being born in different ways.

11 Gödel Universes?

Despite some current minority theories that a Big bang never happened, there is overwhelming evidence that it was in fact a Big Bang that gave rise to our particular universe, some 14 billion-odd years ago (58).

Taken on its own, that simple fact gives rise to a host of obvious questions, such as - if it happened once - could it then happen several times (we're reminded here of Voltaire's quip, "it is no more extraordinary for a man to be born twice than once", which could be paraphrased into "it is no more extraordinary for a *universe* to be born twice than once"). Will it happen again, and if so, in what future? Did it *already* happen more than once? Are there different kinds of Big Bangs? Does a universe need a Big Bang to come into existence in the first place, or is it just one of the myriad ways universes can be born?

The subject of whether there is a single universe, ours, versus the possibility that this universe is in fact only one of many within a larger metaverse has been the subject of sometimes heated debates (59). Some have argued that Ockham's razor (60) militates in favor of only one universe, whereas the Copernican principle, also known as the principle of mediocrity, favors a metaverse (61).

The Ockham's razor argument, however, has been effectively turned on its head by Max Tegmark (62). Regardless, objections against even the possibility of a metaverse are routinely raised, some of which may stem from ulterior agendas, such as perhaps a preferred worldview based on other-than-scientific considerations (63), but there also exists an understandable reluctance towards what science seems sometimes to mindlessly affirm - specifically the issue of the infinite proliferation of exact copies of everyone across an infinite multiverse, an issue we'll revisit at some length in Chapter 14.

If there are many universes, some could be far away in space - so distant that any contact would forever be impossible. Separate universes could also be three-dimensional expanses of space within a four-dimensional hyperspace matrix - something akin to individual soap bubbles separately drifting in the air. Or they could be forever sundered from other universes by lying irrevocably in their infinite future or their infinite past: much like King Kukudmi could never return to Earth if Brahma's office were inside a black hole, a universe created from inside a black hole demonstrably exists beyond even the infinite future of the universe whence the original black hole formed.

One obvious way to approach the question of whether parallel universes can be found anywhere or 'anywhen' else is to use math. Although this approach has been used in a number of valid ways, one novel way would be to ask whether the built-in fuzziness we discovered within the physical world can be mapped *upwards* into mathematics itself. If physical reality is *fuzzy*, as demonstrated by Heisenberg's uncertainty principle, does this fuzziness exist within mathematics itself? If such fuzziness exists within math, could it open a door to other places where other universes

could nestle, much like fuzziness in the physical world makes up the necessary room for virtual events and particles to be able to emerge.

As it happens, it does, with a vengeance. Fuzziness is built into math, which thus demonstrates that it itself cannot be complete, that there exist areas of reality, absolutely proven to exist and to have precise values but which remain forever beyond the ken of mathematics. Mathematics is thus seemingly *intrinsically unable to encompass or describe all of external reality*. But can this be true? On the basis of overwhelming evidence so far, we were strongly leaning towards the ‘Platonic’ view of a mathematical structure underpinning all of physical reality.

But we can breathe a sigh of relief: there is a way out of the conundrum: mathematics is *proven* to be an open, intrinsically incomplete system (see below). Inasmuch as math maps onto physical reality, it means that physical reality itself is an endlessly open system. Any attempt to close this gap of knowableness *in principle* will shift the problem up into another, wider reality encompassing the whole of the reality we started from. And so on, recurrently.

Here is a deceptively simple proof that mathematics is perforce incomplete, known as Gödel’s theorem, named after the logician Kurt Gödel:

1. You are introduced to a Universal Truth Machine (UTM), a machine reputed to be capable of correctly answering any answerable* question at all. This machine of course stands in for mathematics (and hence physics) and is supposed to be able to answer any question provided it is proven to have an answer within reality (* bearing in mind that some questions, such as ‘*how long is a piece of string?*’ do not have answers.)
2. You now write out the following sentence: “The UTM will not say that this sentence is true.” Call this sentence S (say for sentence, or for showstopper, or serum of truth, etc.) S is equivalent to: “UTM will never say that S is true.”
3. Now you ask UTM whether S is true or not.
4. If UTM says S is true, then S (“UTM will never say that S is true”) is actually false. Therefore UTM will never say that S is true.
5. If UTM says instead that S is false, it would immediately be in contradiction with itself since this statement then means that UTM says that it will say that S is true - not false as it just did.

Therefore: UTM will never say that S is true, *although S is factually true and everybody knows it full well*. Here’s reality then: the UTM will never be able to formulate this truth, a truth that you and all sundry know full well, which is that the statement S is true.

In other words we positively know a clear-cut truth which UTM can never call. Therefore UTM does not really know everything that is knowable, and is thus not really universal. A universal truth machine simply cannot exist. In other words:

Universal math encompassing all of reality within a self-contained theoretical receptacle cannot exist.

Incidentally, Gödel developed a complex polynomial equation that has a solution if, and only if, S is true. In other words, S is not some verbose non-mathematical sentence, but a rigorously defined mathematical problem that we absolutely know the answer to, even though UTM *does not*. Therefore UTM does not, and cannot, embody a complete and final theory of mathematics... Although we defined it so at the outset, and our definition itself was falsified, *we showed that no 'universal truth machine' can possibly exist in reality*.

Interestingly, Gödel's incompleteness theorem is only one among several pieces of reasoning which underpin a general view that whenever something in external reality becomes infinite in some way (bearing in mind that there are infinities of different infinities, as exemplified by e.g. the different aleph numbers, and more), then that something can become indescribable in principle - *open* in unforeseeable ways.

For instance, Russell's paradox, named after Bertrand Russell who first cited it in 1901, prevents things out of infinite sets from always becoming readily classifiable or categorizable into clear-cut classes, as follows:

Let's take the finite collection, or „set“ of, say, all the hats in the world.

We'll call any set or collection of anything an „insider“ if it happens to be a member of itself, and an „outsider“ otherwise. The set of all hats is clearly not itself a hat, and therefore is not a member of the set which contains all hats. So it is an „outsider“. On the other hand, if we take the infinite complementary set that contains everything that is not a hat, that complementary set is clearly one of its own members because it's not a hat. It is, by the definition above, an „insider“.

Now let us consider the infinite set of all outsider sets, which we'll call SAOS. Determining whether SAOS is an outsider or an insider leads to a contradiction, and cannot be done: If SAOS were an outsider, it would by definition be contained in the set of all outsider sets (itself), and therefore it would be an insider; yet if SAOS were an insider, it would not be contained in the set of all outsider sets (itself), and therefore would be an outsider. This leads to the conclusion that SAOS can neither be an outsider nor an insider: this is, briefly, Russell's paradox.

Mapped onto physical reality, if we accept the view put forward by Eugene Wigner and Max Tegmark and many others that ultimate reality is a mathematical structure, this directly means that a universal, all-containing universe cannot contain itself: any universe has to be subsumed within a larger metaverse, and so on recurrently. The metaverse has become never-ending.

It also says, interestingly, that the wave function of the universe cannot contain itself.

Put another way, the wave function of the universe is not convergent, as follows: if we call the wave function of our universe Ψ , and write it out as being a function of everything in our universe, denoted: $\Psi(\text{all})$, where *all* means everything in our universe, we have just shown that $\Psi(\text{all})$ cannot be equal to $\Psi(\text{all including } \Psi)$. If the universe were self-contained, its wave function would be convergent, in the sense that $\Psi(\text{all})$ would be equal to $\Psi(\text{all plus } \Psi)$ which in turn would be equal to $\Psi(\text{all plus } \Psi \text{ plus } \Psi(\text{all plus } \Psi))$ and so on *ad infinitum*. It is demonstrably not the case.

This hints to what the physicist David Deutsch intimated when he expressed belief that the universe may well have an infinity of dimensions, stacked atop each other in a non-visualizable way, each with a different wave function. It also harks back to what was suggested earlier in these pages: there are many other (and more interesting) ways for the universe to be infinite than mere spatial 3-D extension.

There just might already exist circumstantial experimental evidence for neighboring universes, be they higher-dimensional or interstitial. Two mysteries continue to vex modern cosmology: dark matter (a whopping 95%-odd of the measured mass of the universe cannot be found anywhere), and dark energy.

The overall mass of the universe can be inferred readily from astronomical observations. These observations show the gravitational pull and effects of a huge amount of mass which, try as we may, we do not manage to find anywhere. Cosmologists have looked at all kinds of possible exotic objects; super-heavy particles, mini black holes, and the like in a bid to locate the missing mass. The laws of physics themselves have been rewritten, bent, tweaked, and warped in a bid to account for the dark mass. As of this writing all efforts have been in vain, despite a growing intensity and creativity in the search.

But there is, perhaps, an exotic (but somewhat trivial) solution beside the other possibilities seen, inasmuch as looking at the laws of gravity we use today at being somehow wrong. If we write out the equations modelling what an interlocked universe in up to 10 dimensions could be like, we stumble upon mathematical areas where interlaced universes containing mass could exist – in which the only thing that the math would allow to leak between both universes would be... a gravitational field. Could we be experiencing, via the enormous but elusive dark matter, seepage of gravity from other-dimensional universes parallel to our own?

If that is the case, *where* are these dimensions?

There are at least two distinct kinds of answers, depending on the signatures of these additional universes. A multiverse can house several kinds of parallel universes: universes much like our own, able to contain and accommodate matter, and other, more exotic universes with signatures different from (3, 1), which may or not be stable. Any additional universes with extra dimensions corresponding to a higher signature than our pedestrian (3, 1) are exotic and it is not entirely obvious how their dimensions are distributed. Such universes are, of course, hard to visualize (64).

If space-time is discrete, then there exist gaps - *interstices* - within its weft which can nestle up to an aleph-one infinity of parallel universes. These interstitial universes may be either of the same signature (3, 1) as our universe, or of a different signature altogether. They would be both extremely close, and, in terms of our ability to interact with them, extremely remote.

Any such interstitial universe would be every bit as *material* as our own. In quantized space-time, the feeling and impression of materiality acquired by our senses arises from the underlying 3-D grid and reality rests upon separate underlying prop

points throughout space-time. There is infinite (aleph-one) scope for similar universes staggered within the space-time gaps and cracks opened up by discreteness.

Hugh Everett's well-known 'Many-Worlds Interpretation of Quantum Mechanics' (65) attempts to force determinism back into the subject, which at this point is a probabilistic and non-deterministic theory. To become deterministic, reality needs to continuously create new universes at every instant some reality-governing event happens to allow for different possible outcomes. In a many-universe metaverse, all possible outcomes manifest themselves into material reality somewhere, continuously giving rise to further universes. On the other hand, if there is only one universe, only a single outcome is favored which materializes at every step, and that particular lone outcome occurs on the non-deterministic basis of probability.

Loath to accept that random quantum events determine how a lone reality unfolds, Hugh Everett's theory posits that all possible events occur and that every time there a 'fork in the road' is encountered (i.e. a choice involving quantum events) the universe branches out into as many universes as there are possible decisions and instantly creates parallel universes to accommodate all such possible decision outcomes. Thus, the loose probabilistic unfolding of life is done away with and causality restored; at the exorbitant price, however, of new universes continuously popping into existence and branching out – quickly becoming totally unrelated and soon living out their own reality separately.

However objectionable the notion of endlessly multiplying universes may appear, discrete space-time can actually fully accommodate all such universes; a finite but large number of intertwined universes would allow for steady parallel universe creation, calculable through the (low) probability of a universe being born multiplied by the (high) number of universes ensconced within the discrete lattice of space-time. The highest possible number of such interstitial universes would be specifically *aleph-one* infinite. If the number of aleph-one universes could ever be reached (which it cannot be in finite time), we would end up in a situation where new universes would then be popping into existence *all the time*: the probability of a universe 'big-banging' (under whatever scenario) is extremely small, but non-zero. These small odds, multiplied by an infinity of universes (wherein the big banging could take place), would yield infinity: a situation where universes would infinitely multiply at every instant (Hugh Everett's scenario is of course only one among a number of possibilities, and there is no proof whether it is for real).

Can higher dimensional universes (universes with (4, 1) and perhaps higher signatures) somehow make an appearance within our space-time? They may be indirectly seen in how large supernovas first explode and collapse.

Penrose's theorem describes the rip which a collapsing supernova causes in the weft of space-time (66). To illustrate simply how it works, draw a map of a world hemisphere on a half-sphere, such as half an orange - complete with an outline of its continents, countries, and so on. Now try to flatten this half orange to make a flat half-world map which could be pinned to a wall. It does not work and the orange rips.

Transition from a world of three dimensions such as the orange, to a lesser dimensional world (as a flat map is, with only 2 dimensions of width and length, without depth) cannot occur smoothly continuously (67).

When a supernova explodes and then recontracts or shrinks back onto itself to become a black hole, something similar happens, with one extra dimension. This extra dimension rips and creates an edge, called a singularity. These space-time singularities cannot be accommodated in our space-time of (3, 1) signature; these singularities exist, and disappear wholly from our space-time.

'Black holes' are by now widely known about and have been described at length in many texts. In a nutshell, a black hole is an area of space where gravity has, for whatever reason, become so strong that nothing can ever escape from it - whence their name of 'black' hole as they cannot be seen directly based on a black background of space. They can be indirectly observed owing to the very real effects that their intense gravity field exerts on their neighboring regions. They usually form when massive stars explode into supernovas at the end of their lifecycle, and may continue to increase in mass by consuming nearby stars and matter long after they are initially formed. Their size varies from supermassive (there is for instance a huge black hole at the center of our Milky Way galaxy, some 26,000 light years away from Earth, whose mass is more than 4 million times the mass of our sun, itself about 330,000 times more massive than the Earth), to much smaller, such as the small black holes that have been observed in a number of binary star systems called microquasars. The size of a black hole is usually measured as the radius of the sphere around the black hole where light itself becomes trapped in by gravity: this sphere is its event horizon, *aka* the Schwarzschild horizon. Incredibly enough, a black hole may entirely 'evaporate' over eons of time owing to small quantum effects at the event horizon, known as Hawking radiation.

There is a more exotic alternative explanation than mere dimensional rips as to what may happen at the centers of black holes. Because of quantum effects, the singularity may morph into a full-fledged separate baby universe rather than become a mere higher-dimensional rent in space-time. If this is the case, it would also solve one of the abiding mysteries of time: time's arrow. We will be revisiting the issue in Chapter 14.

Some physicists have speculated that the only way a universe can be stable and not dissolve is if an infinity of higher dimensional universes sit atop it. The interstitial universe scenario is that of an infinite, staggered, and interpenetrating Russian-dolls metaverse, and as mentioned, there are many other complementary ways a multiverse can accommodate extra universes. As ever, understanding the universe has largely become a matter of how we interpret mathematical results (68). None of the various multiverse scenarios, of course, meet with consensus.

12 Big Bangs

We are now better equipped to revisit issues related to the Big Bang (69). Is the Big Bang, as was long believed, a one-off phenomenon, or can it occur again at any time and at any place, here, now, anywhere, anywhen? Can it happen right here, right now, in your home or office, either in staggered space-time or in a present that will instantly split from ours to become an infinite future? Can it be the case that, as the cosmologist Sean Carroll once put it at a meeting of the American Astronomical Society, in a remark that was later lampooned, “a universe could form inside this room and we’d never know” (70)?

Unless we discover convincing grounds to the contrary, there is little reason to believe that there is anything unique or special about the one Big Bang we are aware of. A Big Bang can well happen in a parallel universe, either elsewhere in space and far beyond our ability to ever perceive, or in a very close interwoven universe staggered within the discrete texture of the space we find ourselves in, in such a way that no physical bond or interaction exists or occurs between the two.

Big Bangs can in principle be caused by widely different mechanisms. Roger Penrose and many others have described how Big Bangs can occur under a variety of scenarios. We will be looking in Chapter 14 at some of the other ways universes can pop into existence, and how these possible birth mechanisms impact time within the newly-born universes. In the meantime, to illustrate how readily Big Bangs can happen, let’s look at an alternative scenario: how a universe can be born of a random quantum quirk - some quantum fluctuation.

If Big Bangs can come about from a quantum fluctuation from within a matrix universe, what is the statistical law governing the frequency of occurrences of Big Bangs from within one given matrix universe?

To be able to decay, an atom within radioactive element must borrow energy from nearby virtual particles, and therefore rudimentary statistics of some of the attributes of virtual particles could, within at least a certain range, be inferred from the half-life values of different radioactive elements of different molecular weights and the corresponding different levels of energy that need to be borrowed from the quantum vacuum to bring about decay. From this, we could conceivably extrapolate a rough approximation of the theoretical frequency of the emergence of outlier virtual particles, possessing attributes which may lead to a quantum fluctuation powerful enough to give rise to a Big Bang.

If a Big Bang could statistically occur, say, every 10 billion years, a new one would be long overdue within our own universe and we could expect a new one, soon to happen in some living room, or near Betelgeuse or Sirius or elsewhere. A good place to start is to understand the many ways whereby Big Bangs can occur in the first place.

Another approach was taken by Sean Carroll and Jennifer Chen at the Enrico Fermi Institute at the University of Chicago, who made a calculation of possible Big Bang occurrence statistics based on a scenario of a Big Bang arising out of quantum fluctuations of vacuum energy. To

estimate the requisite boundary data values however, Sean Carroll and Jennifer Chen estimated a vacuum energy per an arbitrary volume unit deduced from the observed acceleration rate of the universe - and then calculated the probability that a fluctuation would be large enough to trigger a phenomenon of space-time *inflation*. The result of their calculation was exceedingly small but non-zero: in other words, they found a mathematically *non-zero*, albeit small, probability of a Big Bang happening.

In the putative ‘matrix universe’ whence a quantum fluctuation may have given rise to our universe, 14-odd billion years ago, the laws of physics were not necessarily the same as those we now know. They, or at least the certain values of their associated constants (71), may have been different. But under the *current* laws of physics, there is nothing extraordinary about a Big Bang happening from a quantum fluctuation, thereby creating a new universe.

Recapping where we are:

1. The traditional view until recently was that the Big Bang emerged from nothing - from an environment where there was no environment, no matter, no time, and no laws of physics at all, and everything - including the laws of physics themselves - were born with the Big Bang.

It is however very likely *not* the case that absolute nothingness was ever possible, let alone is or will ever be:

“Whether there can be ever be absolute nothingness” is really two separate questions, as follows:

1a- First, can there ever have been absolute nothingness, i.e. if there had never been a universe the way we know it to begin with, *and*

1b- Given that something now exists, or equivalently has existed at some point, can it ever be that full nothingness can re-establish itself at some point.

Tackling question number 1b first - there is no credible mechanism for full dissipation of what already is (at any arbitrary point in time when something happens to be). The only way to reach full nothingness would be to dilute everything to a fully vanishing point, but then because of infinitesimal residuals all the conditions needed to create at least one element term of the Heisenberg equation would be there - thus immediately giving rise to quantum foam, which would, by definition, not be pure nothingness. It’s too late for pure nothingness to ever exist.

Which leads us to the first question (1a): Could there ever have been full nothingness in the past (which would demonstrate that time had a beginning; if there ever was absolute nothingness, then time cannot stretch backwards to infinity.)

Martin Bojowald et al. theorized that time, far from being created alongside space at a Big Bang, must *precede* a Big Bang for a Big Bang to be able to happen. We will discover in the next Chapter further inescapable *pre*-conditions for a Big Bang to occur.

This leaves open two possibilities for absolute nothingness: either math is not of universal applicability, and the equations that mandate the emergence of some material reality are not

valid mathematical equations in circumstances other than ours or in other universes, or, any Ur-universe - the first universe ever to exist, be it our universe or any other - could not have emerged via a Big Bang.

But upon examining, this latter condition does not hold and it is relatively easy to dismiss: *pre-conditions* can also be formulated for every conceivable non-Big Bang universe birth scenario. Which leaves us with the former condition, which can be equivalently reformulated as: *for absolute nothingness to ever have existed, the universe must not be a mathematical structure.*

But if the universe is not a mathematical structure, then how could it pop into existence from nothingness? There seems to be no credible mechanism for an Aristotelian universe to come into being from nothingness (72). A conclusion would then inescapably have to be that the universe has always existed in some form (that form could be anything, which in turn seems to gainsay the assumption that absolute nothingness ever existed.)

2. Or, Big Bang can possibly happen under laws of physics we do not know.
3. It is possible that the laws of physics, if any, that were prevalent before or at the onset of our Big Bang, 14 billion years ago, were more or less the same as we know today (perhaps down to the value of some fundamental constants. A Big Bang can happen under our current laws of physics, and indeed, under a variety of different scenarios calling upon different laws.
4. There exist other possible scenarios for the births of individual universes, such as bouncing universes, and so forth (73).

In all cases, the bottom line is always that a new universe will suddenly Big-Bang into existence *because* if it did not, some mathematical law would be broken.

In other words, *we will know how to create a universe if we find a mathematical equation that would be violated if the universe did not form*: It's really as simple as that. The alternative would be that some form of the universe has always existed, and that time itself stretches infinitely backwards.

Here's how a universe can pop into being from nothing - just so that an applicable mathematical equation not be violated.

First, let's recall that time and energy, or equivalently to energy, mass (under Einstein's equation $e=mc^2$) are 'orthogonal' (as defined earlier.)

Combined with the discreteness of time, the effects of the orthogonality of time and mass can create universes out of nothing. The only requirement is that the matrix space-time begetting the new universe is already discrete, at least within the area whence the new universe arises.

In the quantum foam of so-called virtual objects and particles, the virtual objects that fleetingly inhabit it always stay 'under the radar' of perceivability and hence do not become part of our manifest, tangible, stable reality. This 'quantum vacuum' is a froth of seething virtuality where fleeting, ghostlike things continuously pop in and out of almost-existence. These things do not manifestly exist: hence the term 'virtual' as in virtual particles, virtual objects, virtual dimensions, even virtual time, etc., and

remain in their condition of virtual existence just briefly enough to not become real. However, crucially, they impact, or interfere with, the real world in a myriad of ways, sometimes even lending ghostlike properties to the real world, such as in the tunnel effect (74).

Energy can be borrowed, although for a very short time only, from the virtual objects that make up the vacuum's quantum foam. The statistical distribution of the energy levels available from virtual objects is not known. What is certain, however, is that on occasion spikes of high virtual energy can happen - any level of energy is in principle allowed, provided that the corresponding duration of existence of that energy remain under its authorized time threshold. In essence, the more energetic a virtual object, the less time it can exist.

Let's imagine that a particularly rare event occurs: a humongously big virtual object pops up within the quantum foam.

To create a universe out of the immaterial quantum foam, all we would need to do would be to make this virtual, rare, massive object manifest (i.e. make it instantly real) to wrest it, as it were, from under the cloak of invisibility and immateriality of its virtual existence. If we manage that, we will create a Big Bang, which would be nothing else than this massive virtual object instantly becoming real.

How can this happen? As it turns out, rather easily. Energy and time are orthogonal: When virtual things (particles, exotic objects, energy embodied as a virtual mass, etc...) appear, they may linger on about in the unreal limbo of their virtual existence for a duration of time only at most as long as Heisenberg's equation permits it.

Nothing in principle prevents a huge virtual mass from popping into *virtual* existence, even if it only happens very seldom. So let's imagine that once in a very long while a very massive virtual object, M, does pop into virtual existence - a mass which happens to be so huge that the maximum allowed span of time it is permitted by Heisenberg's equation to remain in virtual existence happens to be *smaller than the then-valid quantum of time*.

But M cannot remain in existence for a duration less than the quantum of time, because this quantum of time is incompressible.

Nor will reality allow a valid mathematical equation to be violated, which however looks exactly like it is about to happen here, because the maximum duration allowed for the virtual life of M by Heisenberg's equation turns out to be shorter than the quantum of time.

Put equivalently, the duration of time that would permit Heisenberg's equation to function properly would be smaller than the incompressible reigning quantum of time. In other words, a mathematical law is going to be violated.

This cannot happen.

The only possible way violation can be averted is if the mass becomes instantly real:

BANG

How actual reality takes over from that point on - with an inflation phase, say, or any other way - is out of the hands of the birthing mechanism. The mass is now in another world entirely than the ghostly virtual world whence it emerged. It has now actualized itself into manifest reality. Physical reality, with its laws and constraints, its sweat and tears, is now taking over.

This scenario is, by the way, not entirely neutral or transparent in terms of the virtual quantum foam it leaves behind. It is likely that it creates with it a trail of other, smaller universes, most of which will probably soon dissolve back into the vacuum, creating within it large-scale disturbances in the foam and frothing it up for a while. It also requires that the space time within the prior matrix universe be discrete, and rediscovers via a very different route and within the narrow case of a quantum fluctuation, Martin Bojowald's more general requirement of time itself existing prior to a Big Bang.

13 Bubbles of Time

As we saw in Chapter 10, one of the consequences of Bell's theorem, confirmed by experimental evidence (in experiments carried out by Alain Aspect, Nicolas Gisin, and many others), is that time across the universe distributes itself in distinct spatial 'zones' within which time ticks to the same clock - time bubbles with shapes vaguely reminiscent, perhaps, of the ever-changing and ever-moving oil blobs of a 70's style lava lamp. The objects or entities inhabiting these zones make up the separate variables of a valid *collective* wave function – which is how such bubbles of synchronous time create themselves in the first place (75). Whenever some change affects any one of the constituent variables, all the other variables react instantly so that the collective wave function seamlessly keeps being valid, irrespective of any spatial separation between the variables.

Now let's look at one of the consequences of the relativity of simultaneity. In the inimitable words of Paul Davies:

If reality is vested in the present, then you have the power to change this reality across the universe, back and forth in time, simply by walking around. But then, so does an Andromedan sentient green blob. If the blob oozes to the left and then to the right, the present moment on Earth, as judged by the blob, in its frame of reference, will lurch through huge changes back and forth in time.

There is only one rational conclusion from the relative nature of simultaneity: events in the past and future are every bit as real as events in the 'present': the distinction between past, present and future is bereft of meaning (76).

By tweaking distances and speeds, we can grow at will such separation to decades (77). So far, so good: nothing much new here.

But the description above of oozing to the left or to the right, or earlier of 'getting up and walking' is just too macroscopic and vague.

To appreciate this, let's act out the experiment that was touched upon in the Prologue: point out the forefinger of your right hand and move your right arm in the direction of the Andromeda galaxy in the constellation Cassiopeia, while you stretch out your *left* forefinger and simultaneously move your left forefinger towards any galaxy located in the diametrically opposed corner of the sky - say, the constellation Crux (*aka* the Southern Cross.)

Quite oddly, different parts of your body have now become separately simultaneous with different events, unfolding far away. These events are days apart from one another.

Let's make it a bit more puzzling. Start spinning on your heels, around your body's up/down axis. As you spin, one side of your brain moves closer to Andromeda while at the same time the other side of your brain moves towards the Southern Cross: you now appear to have become a split individuality in terms of which time bubble you inhabit.

But you are not: you happen to be whole, hale and sound. Your left brain is simultaneous with your right brain. At the very least, your two brain halves are not living days apart from each other. In a word, you are unitary. Yet as you spin, your left brain is simultaneous with events that are days apart from other events your right brain is simultaneous with.

There are only a few ways this apparent contradiction can be resolved: maybe your whole persona - who you are - is not distributed throughout the brain: your whole persona is contained in a space no bigger than the smallest quantum time cells we discovered earlier. Every time cell within your brain stays within its own determinate time. It never spreads out and simultaneity is always uniquely definable. But this seems absurd: the brain itself, or alternatively the minimum volume of space it needs to enable and perform the information processing that takes place within it, is vastly bigger than an elementary time cell.

As we saw earlier, Bell entanglement may exist within the brain: the various constituents and functional parts of the brain are instantly correlated (as are quite possibly all the other parts of your body, such as the fingertips of your spatially separate two hands): essentially because they are all participant elements in a single wave function, following the dictates of a valid Schrödinger equation, they operate in sync under a same time clock. When we spin, i.e. when we move our brain or body parts at different speeds towards different directions, it does not matter from the standpoint of what our governing time is: our brain's functional constituents all operate within the same clock time zone. A healthy brain has its own wave function, and all of its constituent parts are fully *entangled* within that wave function. A brain, as per Bell's theorem, inhabits its own same-time bubble.

But walking towards Andromeda (or spinning, thus alternatively nearing and receding from it) leads to a here-and-now simultaneity with that galaxy that ceaselessly shifts back and forth by about two whole days. Similarly, it's only a matter of calculation by what amount our simultaneity changes with respect to much closer places, such as for instance the next room in your house.

Indeed, if it were not for the instantaneous time enabled by Bell's theorem, the only possible simultaneity with our here-and-now would occur with places close enough such that the simultaneity shift would last less than a reigning *quantum of time*. If that quantum of time were, say, the Planck time we encountered earlier, then the distance corresponding to unique time compatible with any motion at usual walking or spinning speeds would be much less than the size of an atom (78). Therefore, the only way we can ever stay synchronous with any *thing* at all out there is if we are a participant in a collective wave function containing that thing as a participatory variable.

Many physicists conclude from the above that fundamentally, time cannot exist (see also 75). But is there an elephant in the room?

Let's recap where we are:

First, let's pick a person whose brain is self-coherent, and therefore operates wholly within its own simultaneous time, in other words within a 'Bell' time bubble. This person's wave function is coherent.

Second, because of relativistic effects, this person (79) can apparently have different areas of her otherwise unique-time-clock brain being *simultaneously simultaneous*, or simultaneous at the same time, with events and entities which are however separated between themselves by *days*.

It is the combination of the two points above that has led many Physicists to conclude, as we have seen, that the distinction between past, present, and future is bereft of meaning: you cannot be simultaneous at the same time with two events separated in time. Something has to yield. For a number of physicists, it is time itself that yields.

But this might not be the full explanation.

The elephant in the room is the way how and why things become entangled to begin with, i.e. become associated within a coherent common wave function.

Think of some piece of wood on Earth which may happen to be moving, buffeted by the wind, but which no one sees, no one perceives, no one cares about or knows about in any way. To that piece of wood, anything or anyone anywhere in Andromeda simply does not exist, does not come near any relationship or cognition or linkage of any conceivable kind. We cannot in any meaningful sense speak of correlation or simultaneity of this piece of wood with anything in Andromeda. There is zero correlation.

Unless some consciousness looks at that piece of wood and establishes a mental picture of its simultaneity with something there. Somewhere inside a mind, a link has been forged.

Likewise, in the previous picture, the person was sitting and thinking of Andromeda, or of something somewhere in Andromeda. That established a '*rappro*' of some kind, where none existed before. In the case of the wood, as in the case of the person, as in the case of the two correlated particles in Alain Aspect's and Nicolas Gisin's and all other experiments that confirmed Bell's theorem, *a consciousness was present* to establish some correlation, some *linkage* between the participatory elements - elements which otherwise would have been fully ignorant of each other (or of one another) - entities passing each others unawares like distant ships in the night, in disjointed and distinct Bell time bubbles.

A consciousness poured water into a teapot and thereby created a wave function associated with the full teapot, and then it interfered with that newly-minted wave function by watching it.

Consciousness could be seen as having *created*, either indirectly but instrumentally in the case of Alain Aspect's et al. labs, or directly, in the case of the seated thinking person, a new wave function; building on and coalescing hitherto separate individual wave functions. This new wave function evolved from existing

wave functions, such as the person's mind, and expanded to encompass more variables. Doing so, it partly *cohered* towards another wave function, such as that of some object on Andromed; it combined the thinking person on their chair on Earth, with the entity in Andromeda that they were thinking of. That person can now spin, move their fingers at speed towards opposite directions – a Bell time bubble binding them and the object of their thoughts in Andromeda has formed, and simultaneity has now set in. The person can spin and move different parts of their body and brain towards different azimuths and stay whole: the contradiction has now vanished.

But there is *no* qualitative difference whatsoever between a wave function relating to several variables, or one relating to only one variable. These wave functions are of the exact same essence. Indeed, underscoring their common nature, any wave function of a multi-variable, or multi-constituent system, can always be expressed by a mathematical expression that includes a product (in essence, a multiplication involving 'imaginary' numbers) of the erstwhile individual wave functions of its constituents (80) : whatever gives rise to a multi-component wave function must also give rise to a single-variable one.

Specifically, if a multi-variable wave function demands the intervention of a volition to exist, then so does a one-variable wave function: whatever gives rise to the former must also give rise to the latter. It follows that if the existence of multi-component wave functions requires the intervention of a consciousness, then *individual, one-constituent wave functions must also be created by a consciousness.*

Therefore the Big Bang itself, which created a materiality steered and governed by wave functions, *could not have happened without the existence of some prior consciousness* - i.e., some sentient being (81).

We could call this consciousness Tom, (for 'the original mind') or alternatively, because we do not know if there is only one Tom, OM for 'Original Mind(s)', and we'll analyze it further in Chapter 15.

Before we can do that, let's examine some possible objections.

A rather odd objection that was put forward was that the above *quote* proves the existence of God *unquote*. Apart from the odd and rather unscientific thought that if something actually proves something contrary to one's views, then it is an argument against the proof, it actually does nothing of the kind: the requisite pre-existing consciousness could be any consciousness in a pre-existing matrix universe whence our universe was born: say, a software engineer (in the 'stimulated reality scenarios' which we'll revisit shortly), or a lab assistant, or such (including in the case where our universe would have been born from a black hole; in the universe genesis by black holes scenario, not only our universe could have been created by a black hole from within an earlier universe, but our universe itself might also be continually spawning new universes. In that scenario, *our* consciousness would be enough to help create new universes), or any other consciousness. We will revisit these issues when we look at various multiverse scenarios (82). Beyond that, possible scenarios involve the possibility of the universe bootstrapping itself, owing to quirks in the topology of spacetime, as we shall see shortly.

The more interesting objections all boil down to the same objection: the use of math to underpin the whole argument. This constitutes, again, the inescapable kernel of the matter. At the very least, it seems that we can more readily comprehend time and the universe itself if it is a mathematical structure. There seem to be no ways however complex to understand the universe if the contrary Aristotelian view is right, if matter is the ultimate reality and all our math nothing but glorified bean-counting tools.

It's time we looked at the various multiverse scenarios.

14 Multiverse Scenarios

In keeping with the ‘principle of mediocrity’ (*aka* the Copernican principle), let us assume for the time being that there is nothing special about the universe we happen to inhabit, and that there are many other universes. If they exist, these universes are either fully or almost fully disjoint regions of a larger space-time, and hence we have little or no ability to observe or perceive their direct or indirect effects. As we saw earlier, there exist many possible ‘places’ where these universes could be located: some could be staggered within cracks opened up by the discreteness of space-time, and hence astonishingly nearby, others might be in totally separate, vastly distant regions. Some, as we will soon see, could be both elsewhere and elsewhen, tucked away in unexpected and exotic places.

Let’s first review two further mechanisms for the creation of new universes, which could be more productive than the huge virtual mass scenario envisioned earlier, because huge virtual masses could be just too rare to be able to generate many universes (*also see* the last paragraph of note 41). Better still, one of these mechanisms entails the unexpected resolution of an abiding problem of time in our universe.

One of these two alternative possible mechanisms is known as ‘eternal inflation’ and is similar to the Tryon scenario, except that it generalizes the productive effect of random quantum fluctuations to other parameters besides instant virtual masses. Its basic mechanism would be that various scalar fields will time and again happen to fluctuate up to a level where the energy of the quantum vacuum becomes punctually abnormally high. A region of space-time will then demonstrably begin swelling up if vacuum energy becomes its predominant energy; over, say, its matter content and/or its gravity profile. Such up-swellings can separate out and give rise to new distinct universes.

The other mechanism is the generation of new universes through black holes. We saw earlier that Penrose’s theorem predicts the formation of a singularity - a rip in space-time at the black hole. But looking more closely at how singularities may form, a group of physicists wondered whether we were missing a small elephant in the room.

This small elephant is that heavier matter particles, such as protons and neutrons (83), do have extra energy in the form of momentum, a factor that had been overlooked in the standard version of relativity. When they interact with one another, these particles create small amounts of a force called torsion. Too small to amount to anything much under normal circumstances, but becomes significant when matter density increases. When matter becomes so dense as to form a black hole, torsion alone becomes enough to stand in the way of the formation of black holes. At the same time, it generates a huge amount of extra energy which must somehow find an outlet. It soon finds it by creating matter in the form of matched pairs of particles of matter and antimatter. Because of random quantum effects, there will always be a small flickering amount of instantaneous imbalance between the instantaneous quantities

of matter and antimatter. To cut a long story short, such a small amount of imbalance can give rise to no less than a Big Bang which blows up within a separate space-time that it creates at the instant it bangs. That type of Big Bang comes complete with an early inflation phase, which physicists were earlier at pains to devise ad hoc theories to explain (84): under this scenario, inflation naturally happens owing to the huge repulsive forces born of the torsion force.

Nikodem Poplawski of Indiana University speculates that this scenario of universe formation by black holes may be creating new universes continuously, including from our very own universe, which would then become the parent universe to an ever-growing number of child universes: every time a supernova goes off somewhere in our universe, a new separate universe is born. He surmises that this scenario is testable, because some of the properties of the parent universe would leak through to the children.

This scenario would also solve one of the most abiding mysteries of time. One of the properties that would seep through is ... the apparent *arrow of time*, when seen at the scale of a whole universe, an arrow as of yet unexplainable any other way: all of the laws of physics are time invariant, which means that they work transparently and equally well with time going forward or backwards (85). As Nikodem Poplawski puts it, “the arrow of cosmic time of a universe is set by the time-asymmetric collapse of matter through the event horizon during its formation.” Seen from outside the black hole that gives rise to the new universe, the horizon’s formation and all the subsequent processes all occur after ... *infinite time*!

Anything that happens, from an outsider’s viewpoint, inside the barrier of the event horizon takes place after infinite time when measured by the outsider’s clock. Thus, all universes born from black holes are for ever *in the future* of the original universe containing the generating black hole. Likewise, if we were born from a black hole in a parent universe we are for ever in the future of that parent universe, which for us is stuck for ever in an infinite past. Child universes become unmoored from both their original parent universe and the black hole itself, and go on to create and lead their subsequent lives in whole new branches of space-time, inaccessible for ever from the parent universe.

Besides the manifold ways in which separate universes may be born and go on to populate a metaverse, what form or forms can a metaverse take?

According to Max Tegmark et al., there are broadly 4 distinct categories of possible multiverses, each next level up allowing for more diverse universes:

The Level 1 metaverse is a spatially infinite metaverse, housing universes which essentially feature laws of physics similar to our own. They may however have different initial conditions, boundary values and different values of the fundamental constants.

Level 2 is an elaboration on level 1 whereby universes with all kinds of weird laws of physics could exist, as opposed to the more pedestrian equivalents before.

Level 3 is a metaverse wherein all of the possible potentialities contained within all possible wave functions are all manifested in reality somewhere

Level 4 is the broadest possible metaverse, a weird, hard-to-conceptualize metaverse, where mathematical structures could be so oddly different from ours that we can't imagine them, yet they do happen somewhere or somewhen.

The idea of the possibility of a multiverse has been around for years but until recently had never much caught on. One of the reasons for this understandable reluctance has to be that the metaverse idea has come burdened with strange baggage, understandably widely perceived as unacceptable and far too weird.

Before we go on, we must visit this issue. There is an affirmation put forward by a number of scientists that a Level 1 multiverse would necessarily contain exact copies of all individuals, yourself and of everybody else, somewhere across or within the metaverse. The assertion is that a metaverse, from Level 1 upwards, would inevitably contain an infinity of exact copies of everybody on Earth, as well as an infinity of all manners of near copies. Some have taken the idea to the extreme. Colin Bruce avers, it is to be hoped apocryphally, that he would be ready to commit suicide without a second thought because he just knows that he'd keep living in an exact similar life somewhere else in the metaverse, and that hence suicide as we know it is factually impossible.

But must not science, in the words of Graham Farmelo, be beautiful?

The physicist Joao Magueijo spoke in his 2003 book 'Faster than the Speed of Light', of experiencing the pursuit of science as follows: "When we touch upon certain scientific realities, we physicists undergo adrenalin spikes far more intense than is achievable by any other experience on Earth. After such experiences, all other human activities - drinking, eating, and socializing with friends - become miserable and dull in comparison. Therein lies the reason why all true scientists are asocial, and tend to become veritable social suicides." Many other scientists, such as Murray Gell-Mann and others, have echoed these words.

And would not an endless metaverse, wherein an infinity of exact as well as near-exact copies of oneself in all conceivable shadings would hang around in identical and near-identical duplicate lives, be uncommonly *ugly*? Can a science that accommodates exact copies of yourself somewhere, leading exact and nearly exact copies of your life be deemed beautiful in any acceptable sense of the word? More to the point - what does the math say?

Calculations have been made: the first exact copy of yourself, the calculation goes, is located at some ten to the power ten to the power 29 meters away from you.

But it seems quite wrong. The mistake seems to come from dealing with infinities. At the risk of paraphrasing Richard Feynman who once famously said 'nobody understands quantum mechanics' - nobody quite understands infinities.

The calculation leading to the conclusion that exact copies of you somehow exist in a metaverse is based on the observation that if something, such as yourself, has

some probability to exist, however small (there is a non-zero probability that you exist in the universe, since you actually do exist), then that probability value multiplied by infinity - the infinity of space-time, of possible events, and indeed separately of both time and spatial extension within an infinite metaverse - yields infinity: ergo, there are infinitely many copies of yourself within the metaverse, and indeed of the world, conditions and environment you live in: QED, quod erat demonstrandum, as the saying goes.

But the non-zero probability that you exist (a probability equal to one, since you do actually exist) has emerged from an infinite pool of probabilities. The incalculable number of micro events and parameters which must come together to eventually yield *you* is accompanied at every step in the chain of events by randomness stemming from quantum fuzziness. Because the realized outcomes from randomness take their values from an infinite pool of possible outcomes, a layer of infinity exists at every step in the chain of events that eventually produces you.

Hence, the probability to ever produce you again you and your life environment is equal to infinity (representing the infinity of space and time and events in a metaverse) multiplied by the probability for you to emerge from an infinity of possibilities, to wit one divided by the infinity of possible outcomes of the collaborative chain that did eventually produce you once: we are left with infinity divided by infinity, which is an indeterminate number, which could take any value from zero to infinity. There is therefore no mathematical reason why you should ever be produced again within an infinite metaverse at any level, nor is there any reason why someone could not possibly exist again - the only way to assess the mathematical odds would be to try and assess the relative cardinalities of the competing infinities.

Let's illustrate this with a simpler, yet kindred, scenario. Say that you are going to draw the winning numbers of a lottery from a hyperbag containing a full infinity of real numbers. The absolute possibility of drawing any number, say 3345789873578071201, or 0.00234109, is not nil: the number exists somewhere within the hyperbag. Yet the probability of drawing that particular number is one divided by ... infinity. It's, in effect, zero. Yet that number was drawn.

(The full picture is actually slightly more complex, as follows: there are two kinds of numbers in the hyperbag: numbers which have a finite digit extension such as, say, 63946254456780177753405 or 2.99335, and numbers which feature an infinite digit extension, such as π or $\sqrt{2}$. Any number featuring infinite digit extension could be represented in the hyperbag by the formula that generates it, if that formula exists. Since there is demonstrably an infinity of numbers with finite digit extension (for instance, there is an infinity of prime numbers, which by definition are all finite digit extension numbers), and because including numbers with infinite random extension not representable or generable by a simple formula would give rise to a new category of issues, we'll simply leave out such numbers from the hyperbag. Their absence from the hyperbag does not invalidate the argument.)

In an infinite multiverse however, all events have either 100% or a nil odds of ever being *able* to exist, irrespective of whether they do.

This probability refers to the *possibility* that such events may exist, not to their existence per se. For instance, there is a 100% probability that any given person *can* possibly like a certain type of music if that person is not deaf, and a 0% possibility if he or she is deaf. Now the probability of the person *actually* liking the particular kind of music, rather than being equipped and able to like it, is less than one hundred percent: not everyone who could actually likes it.

A precise point for a switchover between probabilities of 100% and 0% cannot *in principle* be calculated for certain events, which invalidates the notion that such events exist. To put it another way, if there existed copies of yourself that could become slightly older than you, the impossibility in principle of setting an age cut-off point for all such copies would necessarily lead to the existence of copies of yourself reaching impossible ages.

Another possible type of metaverse would be made up of *simulated universes*. Although this scenario looks like some mad professor's mind figment, its premise is nevertheless sound. In a nutshell, any technical civilization just a tad more advanced than our own would have, in the words of John Barrow (86),

... the capacity to simulate universes in which entities could emerge and communicate with each other, because they would have computer power exceeding ours by a vast factor. Instead of merely simulating their weather or the formation of galaxies, like we do, they would be able to go further and watch the appearance of stars and planetary systems, and, building the laws of biochemistry into their simulations, the evolution of life and consciousness, all speeded up to occur on whatever alien-friendly timescale. Once this ability to simulate universes is achieved, fake universes would proliferate and soon greatly outnumber the real ones.

This is why physicists like Nick Bostrom and Brian Weatherson argue that a thinking being here and now is far more likely to be in a simulated reality than a real one. Could OM be a software engineer, or perhaps one of a multitude of bored alien teenagers playing a simulation game on his or her very advanced alien computer? We should eventually know: the physicist Martin Savage and his colleagues at the University of Washington say they have devised a sure-fire way whereby the hypothesis that we're living in a simulated Matrix can be tested and decided once and for all.

The notion of a metaverse is sometimes taken to mean a metaverse in the Everett sense, as per his previously cited thesis, the 'Many-Worlds Interpretation of Quantum Mechanics' but as this short and incomplete overview shows, there are many other ways that a multiverse can exist. In the simulated universe scenario, OM would be a software engineer or, indeed perhaps a bored alien teenager, but as soon as we are technically capable of carrying out Martin Savage's test we'll likely demonstrate that this is not who OM is (87).

It's time we looked for OM.

15 In Search of OM

From the twin consequences of Bell's theorem and relativity, we inferred in Chapter 13 that to resolve a conundrum in the physics of time we are led to postulate the prior presence of a consciousness before any physical reality can be actualized.

But before we can know who OM might be (OM for 'original mind' or 'minds'), we must begin by defining and apprehending what, generally speaking, a mind is. To begin with, if a mind and all of its thoughts were purely and exclusively an *emergent phenomenon* from the physicality of the brain, in other words a side effect arising from the brain's billions of material neurons and their connections, the argument would break down in most scenarios (with the possible exception of some 'circular time' scenarios.)

Let's therefore first look more in-depth at emergent phenomena and how they arise. Emergence in this context means the appearance of utterly new and wholly unpredictable properties and phenomena that follows the involvement or intervention of huge associated sizes or numbers. It leads to novel, utterly unforeseeable phenomena, and often in profound qualitative shifts which cannot *in principle* be anticipated and which show up - *emerge* - when some relevant associated metrics, numbers or characteristics become very high.

For instance, say that you have one dollar: you can only buy items priced up to the value of one dollar. Then start adding dollars into your kitty: the more money is added, the more novel possibilities emerge. Say that the million dollar mark is reached: emergence is the property that arises when one has *one million dollars* as opposed to *one million times a single dollar*. When equipped with merely a million times one single dollar, the most one could buy would be a million times cheap one-dollar (or less) items, such as, say, a million bubble gums. No emergence kicked in there. Emergence occurs when the dollars are allowed to pool together in great numbers, and new properties arise: a yacht, say, can now be bought rather than a great number of cheap items. Indeed, should you be given a million dollars with a stipulation that no emergence is allowed, you'd still be quite poor - constrained to one-dollar (or less) item purchases. Another example of emergence would be that of a viscous traffic jam, an emergent phenomenon arising from a large number of times the single phenomenon of one car being driven on a given stretch of road. In physics, odd quasiparticles emerge when vast collections of subatomic particles come together within constrained environments in space and time. These emergent quasiparticles typically have strong, measurable effects on the collective properties and behavior of the group of particles.

Emergence can occur both within material contexts and within abstract or mental domains, as long as they build on scales significant enough to enable the phenomenon to arise. Knowledge is one such area: a primary school student cannot begin to yet even dimly conceptualize the contents of, say, an MIT Ph.D.-level course

in engineering: the course builds on, and indeed *emerges from*, too many prior layers to be simply imaginable from a much deeper layer.

One of the most striking examples of emergence is found in biology, in the case of the *Dictyostelium discoideum*, aka the slime mold. When conditions allow it, the slime is made up of tens of thousands of independent, single-celled fungus spores. A change of conditions towards a harsher environment can cause the many spores to congregate and become a single entity - an emergent single, coherent slug-like multi-cellular *animal*, which only appears if there are enough spores. In that case, as in the case of the dollars, emergence profoundly shifted the very nature of reality: out of a vast collection of loose independent spores arose one animal. The examples are endless

When the relevant numbers however tend towards the *infinite*, then whole new categories and *qualities* of emergent phenomena are apt to appear: even in the rare (usually abstract) cases where emergence somehow did not manage to arise before, irrespective of how big the relevant numbers were. The mere onset of infinity typically triggers emergent phenomena, which typically lead to familiar concepts losing their erstwhile, well-established meanings (88).

In this context it is perhaps unsurprising that material reality itself is demonstrably entirely *an emergent phenomenon arising out of the vastness of the underlying quantum vacuum*.

In our material, solid reality, the presence of the vacuum is vast. Even if we viewed the particles that constitute matter, the neutrons and protons of atomic nuclei and their orbiting electrons, as solidly material; we'd still end up with solid matter being mostly made up of vacuum. Solid steel, for instance, is nothing but pure vacuum to the tune of about 99.999999999999% of the space it occupies. It all amounts to an overwhelming preponderance of vacuum everywhere and, perhaps inevitably, emergence arises. The solid, ordinary constituents of matter are wholly made up, in the words of physicist Stephen Battersby, of mere vacuum fluctuations; matter is entirely an emergent phenomenon from the sea of nothingness.

Here's how.

Matter is made up of (fields which give rise to) protons, neutrons, and electrons and a few more particles beside. Neutrons and protons, which together make up almost all the mass of ordinary matter, are in turn made up of quarks. A part of matter's observed mass arises out of the force that binds quarks together (the 'strong force'), another part arises from *virtual* quarks and antiquarks, and last and not least, a small part stems from all the other particles, first and foremost the electrons and the non-virtual quarks themselves, and a few more.

The role of a vacuum in producing the illusion of reality in the form of *neutrons* and *protons only* has been calculated by a team at the John von Neumann Institute for Computing in Jülich, Germany. Their result falls to within about two percentage points of total actual mass. As Battersby puts it, "most of mass arises from virtual quarks and gluons fizzing away in the quantum vacuum."

Then, putting the last brick in the edifice and taking care of the remaining 2% or so of observed mass, the Higgs boson, named after the physicist Peter Higgs, was finally experimentally ascertained years after its existence had been inferred from purely theoretical considerations. The Higgs *field* lends mass to electrons, individual quarks, a slew of other particles, and also creates further mass out of the quantum vacuum through virtual Higgs bosons. The upshot is that *all* of the mass of material reality emerges from the quantum vacuum - i.e., from nothingness, what we called a quantum vacuum, quantum froth, is sometimes therefore called pre-reality.

How does this apply to the mind, in other words to the wellspring of all thoughts? There are the usual two schools of thought on whence the mind, i.e. the mind-stuff of incorporeal consciousness and its attendant environment of thoughts, reflections, feelings, dreams, and general awareness originates.

The Aristotelian view holds that the mind is a side effect of the materiality of the brain, an emergent phenomenon arising from its 85 billion or so neurons and their respective ten thousand-odd neural connections each, and the more Platonic view that says the brain is at least in part a relay, a translator/conveyor of a source of thoughts somehow situated outside itself – much like the shows that play on a TV set with complex electronics do not emerge from the electronics but from a non-local source.

An argument is sometimes made that the brain cannot possibly be a relay of remotely-sourced thoughts, because, in the words of Sam Harris, ‘less brain would then mean less filtering and hence more thoughts’, and ‘brain damage however always leads to less thinking’. But there are those who point to the astonishing counter-example of the so-called ‘idiot savants’ - who suffer from extremely debilitating mental conditions and sometimes very low IQs, but are nevertheless capable of jaw-dropping mental feats such as instantly and correctly working out the results of complex operations which Ph.D. holders would need minutes to solve, or memorizing huge lists of numbers or vast swathes of the telephone book after a single sighting, or flawlessly playing back lengthy, complex classical music pieces after hearing them but once. In *every case* when the autistic condition can be and eventually is healed, and the brain brought back to normal or near-normal capabilities, the subject then irremediably loses whatever extraordinary abilities they possessed, as if some direct and privileged link to some more capable wellspring of abilities were cut off or dampened. Of course, these abilities could well arise fully locally: the bottom line is that we still do not know enough about how the brain works, despite great strides in understanding over the last few years, and the debate is far from settled. As the neuroscientist Daniel Eagleman puts it: “I’m not asserting that the brain is like a radio - I’m pointing out that it could be true. There is nothing in our current science that rules it out”.

But it may even turn out to be largely the wrong debate, because these two apparently starkly differing views really coalesce into one: since material reality is itself *entirely* an emergent phenomenon from vacuum fluctuations, it follows that

either the mind takes its source *indirectly* from pre-reality, in the former scenario of a mind emergent from the nuts and bolts of the brain, *or directly* from pre-reality in the latter, Platonic case. In both cases, the wellspring of thoughts and mind lies entirely in the selfsame immaterial pre-reality (although all of the constraints of materiality apply in the former case.)

Reams of literature and whole areas of specialization have been, and are, given over to the study of the mind. We will prefer here to tackle the subject by means of a seldom-used tool: its wave function. If we view the mind in terms of the brain's wave function, several unforeseen consequences emerge.

An interesting one is that a form of *telepathy is theoretically possible* for a brain governed by its wave function which subsumes the sub-wave functions of its data-bearing ion exchanges. As we saw earlier, quantum effects enable the brain to exchange and process information far more efficiently, with a much greater wealth of options as to how to deal with information, because the wave functions enable the brain to exchange information with any synapses within itself, and to build groups or ensembles of neurons firing cooperatively, irrespective of the location of these neurons. But nothing in principle stands in the way of such wave function-mediated information exchanges occurring between synapses located within *separate* brains.

Should they happen, such occurrences would be seen as telepathy at the macroscopic level. Depending on intensity, compatibility, and perhaps on the number of participatory neurons within a given wave functional event, this could translate itself as instances of 'soft' telepathy or as more intense experiences. Examples of soft telepathy seem to abound in ordinary life, and they can, at least statistically, be analyzed and apprehended. It is for instance what could be happening when two people in a relationship happen to often send each other cell phone text messages or phone each other at exactly the same time, after hours of mutual silence when apart. For couples who routinely experience many such occurrences, it would be interesting to analyze their frequency mathematically and determine, after due allowance is made for other factors, such as established routines and common habits and ways of thinking, whether the *expected* statistical likelihood of the routinely repeated phenomenon is perhaps less than observed.

As is consistent with a wave functional approach, telepathy would not even need a *human* brain to work: Lawrence Anthony, a no-nonsense, hard-nosed wild life specialist, gives astonishing examples of apparent cases of telepathy from animals in the wild (89). A few neuroscientists, such as Rajesh Rao and Giulio Ruffini, are pioneering experimental research in this area.

How does this relate to time? If wave function-enabled instant telepathy over vast *distances* is possible, then we must conclude that some form of wave function-enabled mind connection is also possible *over time* itself.

A wave function that can smoothly encompass both the past and the future has indeed potentially been demonstrated by *delayed choice experiments*, which we briefly encountered in the Prologue. These experiments have done much to attach the

notion of weirdness to quantum mechanics, and also led to the development of the Transactional Interpretation of Quantum Mechanics.

Delayed choice experiments were originally devised by the physicist John Wheeler in a bid to pinpoint the precise point in time when a photon makes a 'decision' to behave like either a wave or a particle: Wheeler's pioneering experiments involved one travelling photon of light. As mentioned earlier, the experimental set-up forces the photon to either travel through an opening A or an opening B, or both at the same time: if the photon travels through both openings, it behaves as a wave, much like water can flow through two sluices at the same time. If it travels through one opening only, then it behaves like a solid particle (photons can behave in both modes, which is known as the wave/particle duality of light.)

In an attempt to 'trick' the photon, either one of the gates A or B will be shut, or both will be left open, *after* the passage of the photon past the screen that contains both openings. Will the photon 'decide' to behave like a wave or like a particle, and when?

The decision to shut one of the gates or to leave both open is made on a verifiably purely *random* basis, and the outcome of that random decision *cannot* possibly be forecast at the time when the photon is going past the screen. Stunningly, the photon always already adopts either wave-like or particle-like characteristics in a manner consistent with the outcome of the open-or-shut decision (shut either gate, or leave them both open) which *still lies in the future* at the time when the photon 'decides' whether it will act as a wave or a particle.

On a horserace track, this would be the equivalent of opening either gate A or gate B for a horse to come out of. The decision to open either gate A or B would result from the heads-or-tails flip of a coin. In our experiment, both gates would be open, and at the start of the race the horse would gallop out of either A or B *before* the coin is tossed. We would then toss the coin - *after* the horse has left either gate A or B - and the toss would always confirm that the horse came out of the gate that we observed he came out of. In all experimental cases, the nature of the event conformed to the decision that was going to take place, randomly, in its future. Odd.

This leads to an extremely low but non-zero possibility that a human mind or group of correlated human minds, which evolved much later than the onset of the universe, could be OM. Someone or some group. Perhaps a tight-knit community of resonant, like minds at some time in our future, or past, or now. Indeed, there is a vanishingly small but non-zero possibility that OM is... someone like *you*!

If anything could ever bootstrap the universe by reaching backwards in time, then the prime candidate would have to be the most complex object in the known universe: the human brain. This would create the ultimate self-bootstrapping universe; sentient beings within an existing universe mind-connecting over time to an earlier time when the universe does not even exist, and thereby triggering the creation of the universe through an induced energy fluctuation creating a Big Bang (90).

This would also solve in one fell swoop an old and hotly debated mystery of the universe: the so-called *Anthropic Principle*.

In a nutshell, the Anthropic Principle arose from the observation that only a stunningly unlikely chain of coincidences led to the existence of our habitable

universe. The chain of improbable cosmological, chemical, and other coincidences that has led to the universe being habitable is broadly equivalent to winning some lottery jackpot a few score times in a row... This led, as we can imagine, to major puzzlement and to a number of attempts to explain it (91). One such attempt is the multiverse: there would be billions of universes out there, most of them barren and desolate. Bio-friendly universes would be exceedingly rare, but we quite inevitably just happen to, as we must, live in one. But if a sentient being can bootstrap a universe by backwards telepathy over time, then the mystery of the uncanny coincidence of scores of Jackpot wins in a row resolves itself at once.

As we shall see however, there exist many other valid candidates for who OM may be.

The mind is more of a slippery eel than we're normally aware. A well-known philosophical conundrum goes like this: if a dream is dreamt by a sleeping person who, upon waking up, has no memory whatsoever of that dream - did that dream exist? Is there any existence to that dream in any possible meaning of the word 'existence' (92)?

Here is a more intractable version of this old conundrum. David Darling, in his book 'Zen Physics', cites the effect of a certain sleeping drug which induces *retrograde amnesia* in its users. This drug will put the user to sleep within about two hours, but will totally sever the connection between short-term volatile memory storage and long-term memory storage within the brain. Upon waking up, the user will absolutely not remember what she did or anything that happened to her or around her in the hour before falling asleep. Such memories are gone for ever, and nothing can ever bring them back. Putting the user under memory-raising hypnosis would not work – it would be unable to unearth any memories from that hour from the subconscious. The memories are gone for ever, materially, bio-chemically, and any other way deleted from all of both the physical and quantum mechanical configurations of the brain, from whatever it is in the brain's chemistry that holds memories in storage. Now the question is: if the user committed a crime during the last sixty minutes before falling asleep (very clearly the person is guilty *at the time* when she commits the crime, and *until* she falls asleep), is the person who wakes up with no memory and no physical trace of the memory of that crime whatsoever still guilty? Your position as relates to still unresolved issues of science shall determine your answer. If you believe the brain is solely what creates mind, then you have no choice but to pronounce the person not guilty; under this view the mind that committed the crime is just not there, no longer there at all, the responsible chemicals have fully dissipated away and dissolved during the night's sleep. The person who wakes up is in a significant and material way to the case, *not* the person who fell asleep. If however you believe that mind and brain are related but however separate entities that exist independently of each other, then you have no choice either, but this time to return a guilty verdict.

Science is just at the beginning of exploring the mind's abilities. Explanations are elusive, for instance, the above-cited abilities of savants are not yet fully understood. Even otherwise ordinary people sometimes display uncanny abilities frequently enough that competitions showcasing such abilities are regularly laid on. As a case in point, some people can almost effortlessly and flawlessly remember tens of thousands of the pattern-less decimal figures of pi (93).

The possibilities for OM's identity are then as follows;

- §1 Someone like you, or any sentient being or group of sentient beings that has ever existed or will ever exist. Should this be the correct explanation, the vexing mystery of the Anthropic Principle would then be instantly solved. It does not explain however how these sentient beings came into existence, or if and how they existed for ever. Maybe the question of whether they existed for ever is moot, if time does not fundamentally exist and hence the phrase 'for ever' is meaningless.
- §2 God. This gives a different label to OM but does not explain anything - it shifts over, but does not solve in the slightest, the problem of understanding it all.
- §3 A laboratory assistant or a physicist who somehow created a black hole. Alternatively a black hole could have created itself independently but was able to do so only because a mother universe already existed, in which case there is still an original mind somewhere in a remote past.
- §4 A software engineer or a software user in the simulated universe scenario
- §5 Something else entirely

In all cases time has revealed itself as the vehicle whereby the universe bootstraps itself into being, and mind as the creator of time.

The only way forward at this stage has to be observation and experimental proof.

There is no shortage of *theories* that seemingly provide a '*eureka!*' moment, neatly appearing to explain at least some key element of the abiding mystery of what time is.

For instance,

It is Julian Barbour's neat explanation as to the true reason why time is an unobservable: "Time is an unobservable because it does not exist!"

It is Sean Carroll's hypothesized explanation for the arrow of time; in a wider metaverse, there is, statistically speaking, no arrow of time, no beginning of time, no overall flow of time. Individual universes may exhibit an arrow of time, which in some universes may go forward, in some others backwards: the apparent arrow happens statistically randomly and is determined on a case by case basis by the random initial conditions at the instant a new universe is created (by brane collisions in higher dimensional space.) Overall in the multiverse, time extends both backwards and forward to infinity, neatly cancelling out in the wider scheme of the metaverse.

It is Nikodem Poplawski's alternate explanation for the selfsame arrow of time: inherited properties seep through from a mother universe to child universes born of black holes within it and by doing so create an arrow of time.

It is Itzhak Bars who seemingly neatly solves an issue associated with the strong force in quantum chronodynamics by positing a second dimension of time.

It is the madman who keeps the vampires away with his clove of garlic.

It is the apparently neat resolution here of what Paul Davies called the ‘Goldilocks Enigma’ - the mystery of the mind-bogglingly small likelihood that a universe would be able to accommodate life as we know it. This conundrum would disappear instantly, because somehow we ourselves created the universe (94), and there may exist different self-contained, Möbius-strip like separate swirls of time in a wider metaverse...

... and many more.

And yet, none of these hypotheses are proven, at least as of yet. Martin Savage says all we need to test hypothesis §4 is enhanced computer power. Sean Carroll, Julian Barbour, and others are working away on trying and devising experimental proof for their hypotheses, although some hypotheses will surely turn out to be untestable even in principle.

So where are we? We are left with two elements which correlate with time and which, if we elucidate their roles, should provide answers: mind, and math (95).

To be meaningful, such elements must be independent of time: a legitimate question would then be whether time does not simply emerge from minds equipped with memory. As Julian Barbour puts it “The only evidence you have of last week is your memory - but memory comes from a stable structure of neurons in your brain *now*”. Would time objectively exist at all if we were all like the victims of *encephalitis lethargica* (52), forever trapped in an eternal present, not remembering anything that even happened a split second ago, and unable to envision a future? The evidence suggests that it actually would; matter decays within timeframes independent of our minds. A solid-matter proton is stable but will still decay with a half life of about ten to the power 34 years, almost certainly regardless of whether there are sentient beings about or not.

Can we test hypothesis §1 above?

Even if we were able to, we cannot simply go ahead and create a new universe - it just wouldn’t help. For one thing, if we could somehow mind-trigger a universe in the same space-time as ours we would not be able to hang around to observe our creation: we’d be swept away. Or, in a likelier scenario, we’d just create a new universe and not be aware of it - as Sean Carroll once said at in a previously quoted remark (97).

So we can only test this hypothesis indirectly.

One way to do so would be to test whether we can create anything backwards in time. If we can, then the issue becomes quantitative rather than qualitative: all we then need to do is provide enough punctual energy to a pre-existing quantum vacuum environment to create big enough a fluctuation so that a universe could be born from it – or create a fleeting bit of quantum vacuum to begin with and then a fluctuation within it. We would need to devise a delayed choice experiment that does not content itself with making a choice between two alternatives, but that actually creates something in the past, no matter how fleetingly or ephemerally.

A Tentative Answer

Looking back where we have arrived, the argument can be broadly summed up as follows:

Despite increasingly exotic attempts, we keep hitting a brick wall striving to understand a number of phenomena from a purely 'physical' or material angle. Bell's inequality, the Big Bang(s), $E=mc^2$, delayed choice experiments, and so on, all so far elude a purely physical explanation. Yet, should we view the universe as ultimately a simple mathematical structure, then everything falls into place: no other explanation is required than that of the math saying so. Physicality then becomes a side effect arising out of the underlying math structure (this physicality may ultimately be volatile and/or unstable.)

A number of contemporary physicists espouse that view, whereas others reject it.

Under that view, materiality is preceded and mediated by wave functions (the prior existence of a wave function is what brings about physical reality). The evolution of wave functions (through coherence and decoherence) in turn governs the evolution of materiality.

The mind itself is governed by its own wave function(s), which also leads to novel but cogent interpretations of mental phenomena (such as the interpretation of e.g. Dr Mark Salter's observations on multiple personalities within the same body).

To be able to begin existing, a wave function binding up several hitherto separate items (such as objects or particles) requires the prior existence, or the prior establishment of, a correlation between these items. Intervention of an external agent is needed to establish this correlation when it does not exist prior. This external prior agent compellingly turns out to be some volition - some mindful agent.

There is no qualitative, essential, or fundamental difference between a one-variable wave function or a multi-variable one; if a multi variable wave function demands the intervention of a volition to exist, then so does a one variable wave function.

Time itself remains an abiding conundrum, first and foremost because it is demonstrably non-observable, but also because it is provably capable of being not linear within certain environments and/or conditions.

A sane human mind, the most complex object in the known universe, is coherent with itself. The brain has been convincingly called the 'ultimate quantum machine' and indeed, quantum effects stemming from the interplay of a brain with materiality are observable in the lab (Quantum Zeno effect, etc.). Yet, a unique coherent mind / brain can be shown to live simultaneously in a spectrum of starkly different time zones if relativistic simultaneity applies without further ado.

A straightforward way to solve this seeming contradiction that of a fully coherent mind being apparently time-decohered, is to posit the existence of self-contained 'bubbles of time' within space-time – i.e. strands of time within which time ticks to a same coherent clock. These bubbles (or strands) of time may take on any shape within

space time (of whatever signature) and are closed; they encompass each a definite, closed 'zone', however not necessarily contiguous.

The existence of such time bubbles would also explain Bell's inequality: in one fell swoop, coherent and correlated items (in the meaning of the Schrödinger relationship, that is to say items bound up within a valid wave function) are seen to inhabit the same zones of coherent time and therefore can react instantly and coherently to changes affecting, or risking to affect, their collective wave function (for as long as these items are still and remain correlated and coherent).

This again points to the existence of separate 'strands of time' co-existing alongside one another within space-time (irrespective of the signature of that space-time). These strands of time may take on any shape and some of these strands may happen to be broadly circular, thus forming isolated closed-loop time-like structures within space-time. This hypothesis is testable.

There could thus exist dynamic bubbles (or 'eddies') of time of various shapes within a wider space-time within which items including whole universes could be trapped. Some of those eddies would lie in the past of others, some in their future. Whenever black holes are involved, some could lie beyond their infinite future, and some before any point in their past.

This seems to point to Time itself not being a fundamental feature of the universe. Some volition or mind(s), something called 'original mind' for lack of a better phrase, which could take very different forms, is more fundamental.

End Notes

1. Provided the star is far enough, such as Andromeda at a distance of some 2.5 million light years. The exact values depend on distance (the time shift would be less than a day for nearer stars and more for ones farther away) and on speed of walking, taken here to be about just over 3 miles, or 5 kilometers, an hour.
2. Without ever quite reaching it, because the mass of matter rises with increasing speed, and any mass would become infinite at c . The only objects that can travel at c are therefore massless (such as photons).

3. For an interesting analysis of implicit assumptions, see e.g. Dieter Zeh, 'Physik ohne Realität', 2011.

As a further illustration: in quantum mechanics (a branch of physics which we will look at in some detail) there is something known by the somewhat unwieldy phrase of *counterfactual definiteness*, which plays a key role in some of its interpretations. Adopting counterfactual definiteness (CFD) means that we take for granted that we have the right to speak of the possible expected outcomes of measurements that have not (yet) been conducted. But it might just not be legitimate to do so, and at times this assumption is simply plain wrong. The Wikipedia entry describes CFD by means of a brilliant everyday analogy: Say that we are trying to measure the positions and the momentums of some particles in a microscopic system. To use a macroscopic analogy, an interpretation of quantum mechanics which would not adopt CFD would look at measuring the *position* as being equivalent to asking where in a room a person is standing, while measuring the *momentum* would be akin to asking if the person's lap is empty or has something on it. If the person has been made to stand, then that person has no lap and neither of the statements "the person's lap is empty" and "there is something on the person's lap" can be true or false: they just do not apply. Any calculation simultaneously based on values where the person is standing at some place in the room *and* has a lap as if sitting would then be utterly meaningless.

4. Irrespective of the ongoing debate as to the possible limits of applicability of quantum computing. See e.g. Michel Dyakonov 2013, Scott Aaronson, 2013.
5. In a somewhat modern rendition, the original being 'O Time, suspend thy flight!', a phrase which begs the question of whether time 'flies'. We'll look at this very issue later on in the main text.
6. There are those who would say that the past can be altered, under a number of different scenarios. In Quantum Physics, especially under the specific interpretation of how wave functions come into existence – called the Transactional Interpretation of Quantum Mechanics (TIQM) (*see later in the main text*) – there are some narrow ways whereby micro-events in the past could possibly be altered, but it remains highly speculative. In essence, the TIQM says that a wave function is constituted by a merging or interference of a wave from the future (forward wave) with a wave from the past (backward wave), and that

this merging continuously weaves the present. The process of the merging of the two waves could conceivably slightly alter both the forward and backward waves in an ongoing loop, thus modifying the past.

Another approach draws from a specific interpretation of the many-universe (or multiverse) view of reality. Under that view, although every universe evolves under its own unique progression in time, *aka* its timeline, sentient beings might be able to hop from one universe to another. By doing so, they would acquire a brand-new past, different from their past in a previous universe.

Another, more widespread, view is that time does not exist. Even here, there are slightly different ways in which time may not exist - different modes of non-existence. As an example, Julian Barbour, in his book 'The End of Time', argues for the non-existence of time. Barbour's argument is that time is made up of a series of discrete 'nows' - every 'now' being whole and self-sufficient on its own, the 'nows' being similar to numbers: it cannot be said that, for instance, 3 is before 5 or that 6 lies in the past of 7. This view however seems to redefine rather than abolish time, in a manner that would be consistent and compatible with a number of other views, such as time as an emergent property (*see further on in the main text*). His further argument in favor of a 'block universe' where the past and the future pre-exist in a higher dimensional hyperspace may seem to clash with the indeterminate possible futures that would inevitably arise from Heisenberg's Uncertainty principle, at least within the context of a single, unique universe. To try to counter this, Barbour argues against indeterminacy and that the next 'now' that we experience is one of several potentialities, and that statistically we will tend to experience the mathematically most probable 'nows' (an approach related to the Many Worlds interpretation of Quantum mechanics). Apart from several inherent contextual difficulties, it could be argued that far from describing the non-existence of time, this scenario offers a valid possible *definition* of what time actually is.

For his part, the physicist Paul Davies draws the following conclusion from the odd results of Einsteinian simultaneity: "There is only one rational conclusion from the relative nature of simultaneity: events in the past and future are every bit as real as events in the 'present'. The distinction between past, present and future is bereft of meaning (Paul Davies, 'About Time', pp. 70-71-72. This will be examined further on in the main text). Similar views have also been taken by many others, including Einstein, who called the distinction between past, present, and future a 'stubbornly persistent illusion', by the playwright T.S. Eliot, and many others. However, as we shall see in the main text, other considerations force us to admit that there *is* something that we must call time, and that trying to escape the contradictions of time by denying its existence does not quite work. We will find time again - where we were not looking.

7. At least in a single universe. Some versions of a multi-universe (or multiverse) are fully deterministic, but other issues then crop up which makes clear-cut

deterministic scenarios moot. The issue will be revisited later on in the main text.

8. There are several variations to the ‘block universe’ view. One is the Growing Block universe, according to which both the past and the present are real, but the future is not. Under this scenario, the universe continuously comes into being within a thin slice of present time, which makes the universe continually grow. *Presentism* is yet another variation, under which only the present exists.
9. David Hilbert, keynote speech, Joint Congress of Pure and Applied Mathematics, cited by George Gamow.
10. A further question has to do with any possible built-in, inherent limitations of mathematics itself. To wit, are there areas where mathematics itself proves that it cannot answer some mathematical question, and if yes, what does it say within the context of the use of mathematics to answer real-life questions?
There are several categories of such problems, most of which are problems in applied mathematics and computability, *not* problems in pure mathematics. Examples include so-called undecidability issues, where a set mathematical question cannot be answered, such as the halting problem and problems reducing to the halting problem, whereby it cannot be determined whether a given computer program will eventually halt or go into an endless loop instead; Richardson’s theorem, which proves that if a mathematical expression includes certain oscillating functions, then no algorithm can ever be written that determines whether this expression can ever equal zero, or the so-called Word problem (in essence, if you have one set of elements (‘words’) that you label or index differently by means of two separate sets of labels (or ‘indices’), then there is no way to know whether two elements indexed differently are in fact the same element or not); the Collatz conjecture, and many more.
Contrary to problems in applied math, problems in pure math tend to typically arise either from our inability to solve them rather than from inherent limitations; or alternatively they may reflect a deeper, physical insolubility (such as the impossibility *in principle* to know, under certain circumstances, the values of certain physical attributes, an impossibility faithfully reflected in the mathematical description of these attributes, as we shall see in the main text.)
11. Shing Tung Yau (2010) describes how abstract geometry can give rise to material universes. We will encounter other ways in which abstract mathematical realities seem able to precipitate themselves into material reality further on in the main text.
12. Apart from a non-relevant small detonator designed to bring two sub-critical masses together into a single critical mass.
13. As it happens for a heavy metal, of which only a small portion is turned into energy. In the sun, at the other end of the scale of the masses of chemical elements used in nuclear reactions, the lightest element hydrogen fuses into helium (mostly), and by doing so sheds a bit of mass which turns into energy.

14. Einstein's unique contribution was emphatically *not* the development of the equations leading to $E=mc^2$ (which was already old albeit not well-known news by the time Einstein got around to it), it had been already worked out by others before him. His insight was to understand that the residual $E=mc^2$ term, which other physicists had dismissed without a second thought as a mere mathematical artefact, had in fact a physical, material sense.
For a simple and elegant derivation of $E = mc^2$, see Charles Stevens, 1995 "The Six Core Theories of Modern Physics".
15. Another type of field is the so-called 'vector' field, with a vector (i.e. a set of numbers plus a direction, indicated by angles, or 'direction cosines'), rather than a mere number being associated with every point.
16. The expression 'calculate and shut up' became current in the United States during the fifties and sixties to describe what was expected of physicists, and how physicists were supposed to conduct themselves. It was by then well-recognized that the math and the physics worked and led to tangible and useable results, but any ultimate explanation as to *why* remained elusive. Any discussions as to the deeper reasons why the physics worked were strongly discouraged, since they were deemed unproductive and conducive to unwanted arguments within teams. For a wonderful narrative on this period, see David Kaiser's 'How the Hippies Saved Physics' (2011).
17. There is no Nobel Prize for mathematics, and the 'The Fields' medal fills that void. It is awarded with a different frequency and different rules than the Nobel prizes.
18. Michael Monastyrsky, in his 1996 review of the themes which lead to being awarded the Fields medal: 'Modern Mathematics in the Light of the Fields Medals', makes the point several times, see in particular p. 102
19. ResearchGate forum at researchgate.net, 2013
20. Huw Price, in 'Time's Arrow and Archimedes's Point', provides an exhaustive review of the attempted 'physical' explanations for Bell's theorem.
21. The term 'hidden variables' has been historically used to mean different things. Traditionally, the term refers to the possibility that something defies explanation because other, overlooked and/or unseen phenomena are at play. Here, 'hidden variables' is meant in this traditional sense. On occasion the phrase 'hidden variables' refers instead to the hidden *influence* of well-understood other variables, such as the influence of the rest of the universe.
22. A BBC series in 10 parts called 'Dangerous Knowledge' looks at how some scientists were driven to near-insanity by their bid to understand infinity, see: <http://www.dnatube.com/video/6065/Dangerous-Knowledge-BBC-Part-110>
Straightforward human intuition can easily mislead when *finite* but *large* numbers are involved. I remember teaching a supply chemistry workshop at the University of Melbourne once, and to illustrate how simple common sense can

ill prepare us to deal with large numbers and/or infinities, I gave the following example (first thought up by Enrico Fermi):

The Roman Emperor Julius Caesar was assassinated some 2,000 years ago in a conspiracy involving his son, Brutus. He is reported to have sighed '*et tu, Brute*' ("you too, Brutus my son?") with his dying breath.

Now here's a question - what is the material and mathematical probability that you are right now, this very instant, breathing in or out at least one of the molecules of air which flowed through Julius Caesar's vocal cords when he spoke his dying words?

A simple calculation shows that the likelihood that any one in that class were then breathing, or for that matter that *you* are right now breathing, one of these molecules, is about 99%

Rather bafflingly, when I finished demonstrating the math, one of the students raised her hand and said: "You see, this just goes to show that science is really nonsense. It's some kind of superstition." She somewhat bafflingly chose to trust her (flawed) instincts rather than incontrovertible math.

23. Albeit not necessarily 'far between', since they tend to sometimes bunch up. For instance, the largest two bunched 'paired' prime numbers discovered as of this writing are (4,648,619,711,505 times 2 to the power sixty thousand) *minus* one, and (4,648,619,711,505 times 2 to the power sixty thousand) *plus* one.
24. The Aleph numbers are sometimes called 'transfinite' numbers, to indicate that although they are *infinite* - non-finite, or endless - they are however somehow not quite yet 'infinitely infinite' (language itself breaks down in its bid to properly describe such concepts).

An immediately unavoidable question arises as to whether the Aleph series of numbers itself grows indefinitely towards ever higher-numbered alephs; do Aleph three, 4, 5 which could be denoted $^3\aleph$, etc. exist? Cantor reckons and calculates that the answer is yes, as follows: If a *set* of n elements is defined as the group of n elements - for instance the set of the three numbers 1, 2 and 3 is the group (1,2,3) - and the unordered *subsets* are any group of elements from a set less than the set itself, for instance all the subsets of (1,2,3) are (1), (2), (3), (1,2) (1,3) and (2,3) (*unordered, so that e.g. (1,2) and (2,1) are one and the same and therefore counted only once*), then if we denote by A a set with a transfinite number of elements, and by B the set of all the subsets that can be built from the elements of A , then Cantor demonstrates in a still controversial proof that the cardinality of B is bigger than that of A . If the proof is correct, it proves that there is an infinity of alephs (or transfinite numbers) with increasing cardinality - an infinite hierarchy of infinities. Most mathematicians view Cantor's proof as correct, a few hold-outs are still unconvinced.

25. A general word about scales is probably appropriate here. Quantum mechanics - *aka* quantum physics - is sometimes said to be exclusively applicable at very small scales: nothing could be further from the truth. Direct effects from quantum mechanics have immediate material consequences at macroscopic scales. Whole branches of industry use the macro, everyday-scale effects of quantum mechanics - computers, DVD players, and so on. The brain itself uses quantum effects to boost its power (Henry Stapp, Evan Harris Walker, Roger Penrose, et al.). Quantum effects, however, become less directly perceptible at larger scales, both because typically the values of all quanta (of energy, length, time, etc.), are extremely small, and because macroscopic scales invariably involve huge numbers of atoms and particles leading to the predominance of statistical effects. These effects hide the essentially quantic nature of behavior at the individual component level. There is, however, no borderline scale beyond which quantum effects cease to operate, and the indirect effects of quantum physics are very often the key to understanding large-scale behaviors. At astronomical scales, quantum cosmology provides powerful explanations of how the universe evolved, how its current large-scale structure came into being because of early-universe quantum effects, and so on.
26. Technically, the disappearance and emergence of an electron at discrete locations in space is best explained by abstract mathematical equations: so-called creation and annihilation “mathematical operators” acting within the associated field.
27. An even more modern interpretation championed by Dieter Zeh et al. entirely does away with particles, fields, and quantum jumps, at least as they are traditionally understood, to replace them at their fundamental level by the effects of something called coherence and decoherence. We will revisit the issue, and this interpretation reinforces the view of the preponderance of mathematics over more ‘physical’ or material attempted interpretations of reality.
28. In particular, a theory called ‘Loop quantum gravity’.
29. It does store the memory of that event however by gaining a bit of mass. The extra mass however does not contain information that could be acted upon to, for instance, impart a direction.
30. Unsurprisingly, there are ongoing debates among physicists as to the *ontology* - the full meaning and role - of wave functions. Opinions range from so-called wave function realism, culminating in its logical consequence wave function *monism*, which holds that wave functions are ultimately the *only* reality (a view taken by physicists such as Wayne Myrvold, Jonathan Schaffer, et al. and, inevitably, by most Platonists), to attempt to prove that quantum physics and wave functions cannot fully describe *material* reality on their own (should areas of material reality be found which would not be explainable by quantum mechanics, new theoretical constructs beside quantum physics would then become indispensable - David Bohm has championed this approach), all the way to (at the other end of the spectrum) unsupported denials of the role of wave func-

tions beyond the narrow confines of particle physics. But since it is incontrovertible that wave functions govern all of the smallest constituents of matter, it stands to reason that they, at the very least, also play a role in all of matter itself and its attributes. There is no definable size or value threshold of any physical property where quantum physics ceases to be valid – its immediately observable effects, though, do become gradually subsumed into statistical effects at larger scales.

There exist many other cases where some effect becomes small or hidden at larger associated numbers or larger scales: for instance, radioactivity at any individual radioactive atom level is fully governed by quantum effects; the behavior of a large collection of such atoms, however, becomes quickly governed by statistical laws, which is why there is such a thing as the *half-life* of a radioactive element (*see also note 41*). Another example would be gravity: there is no distance at which gravity ceases to exert its pull, but its effects dwindle with distance. You are subjected to the gravity pulls of, say, Betelgeuse and Rigel and for that matter of every other object in space and deep space, but their effects are negligible because they are so far away.

What everybody agrees on, and which is corroborated beyond all doubt by experiments, is that wave functions govern particles, molecules, and assemblies of molecules, *aka* objects or *things* (what the physicist John Bell calls *be-ables*, i.e. entities or things that just can or do exist somewhere or somewhen (things that exist in ordinary four-dimensional space-time he in turn calls *local be-ables*).

An even cursory trawl through physics forums will yield up a number of papers in favor of wave function monism, as well as a number of papers which explore possible ways to avoid monism or even realism. The resultant weight of the arguments seems to squarely favor the view that wave functions ultimately shape all of reality, independently of course of whether we are psychologically ready to entertain or accept it. The question of the wave function of the universe itself is addressed later on in the main text, *see also note 90*.

31. There is an ongoing controversy as to whether the Quantum Zeno effect can yield measurable macroscopic effects. Whereas the QZE is used here as a handy way to illustrate how a wave function can attach to a macroscopic object, the question is generally interesting. At the core, the reasons why measurable quantum effects can be seen to disappear at macroscopic level are either because statistical effects become preponderant, thus masking individual quantum effects, or because quantum decoherence from the measuring apparatus has set in.

The QZE would not be valid at collective teapot wave-function level if, instead of a collective wave function of the macroscopic system, the individual and separate wave functions governing the individual water molecules represented the macroscopic teapot: i.e., a huge number of wave functions governing individual molecules instead of their ensemble. Then the effect would become subsumed and hidden by statistical effects, but the water in the teapot would lose its collectively

concordant behavior pattern. This illustrates the hierarchical structure of wave functions.

In the absence of decoherence the QZE could occur with the wave function of any system provided that the behavior of that wave function has not been lost through some mechanism to statistical effects.

Quantum effects abide everywhere in the macroscopic world - for instance, if a person's wave function is denoted by Ψ , calculating the corresponding integral denoted by $\int \Psi^* \Psi d\sigma$ would yield up the probability of presence in space of that person, clearly delineating that person's body boundaries (the expression of this Ψ is so mathematically complicated that there is however no hope that it could ever be calculated. See also note (33).

32. Among the more common interpretations of quantum mechanics are: Max Born's ensemble interpretation, the Copenhagen interpretation, the Louis de Broglie – David Bohm theory, the John von Neumann interpretation, George David Birkhoff's quantum logic, Hugh Everett's many-worlds interpretation, Karl Popper's interpretation, Edward Nelson's stochastic interpretation, the many-minds theory, the consistent histories view (Robert Griffiths et al.), objective collapse theories (Giancarlo Ghirardi, Roger Penrose), the transactional interpretation, and the relational interpretation (Carlo Rovelli). These interpretations are not necessarily wholly mutually exclusive and some interpretations do overlap. Among the less widespread, and sometimes weirder interpretations, are the Francesco Calogero conjecture, the semiotic interpretation, the Alfred Landé view, the "prowave" (for propagating wave) interpretation, various time-symmetric theories, the Pondicherry interpretation, various shadings of quantum mysticism, the so-called London ticker tape interpretation, sundry theories of incomplete measurements, the Montevideo interpretation, quantum bayesianism, the synchronized chaos interpretation, the Vaxjo interpretation, and various dimensional theories.
33. Technically, the mathematical expression of that probability involves mathematical objects called integrals, symbolized by \int . An integral is simply a sum, under certain conditions, of infinitely many infinitely small quantities.
34. The informative power of wave functions goes even deeper: quoting from the main text, *if the size of the universe itself is used to set the boundary conditions of the calculation, then the calculation always yields one, because there is a one in one chance, a one hundred per cent likelihood, that we'll find an object within the universe if that object exists: an existing object has got to be somewhere in the universe.*

There is however an interesting twist to this observation, as follows: the math shows that the probability calculations of the position of something somewhere must make use of wave functions of that something, no matter how complicated. The probability calculation always contains a multiplicative factor featuring a squared trigonometric function, such as a squared *sine* function, within an integral (where 'squared' means multiplied by itself). If we use *infinities* for

the boundary conditions of the integral in the calculation which describes and calculates the probability of location of that object (therefore within an infinite universe) - then the result of such a calculation is *undetermined*: it takes no value at all, the calculation cannot be carried out and completed (it's easy to see why: the squared sine of any quantity (x) takes on a value between 0 and 1 for any *finite* x , however small or gigantic, but cannot take any value, and is thus indeterminate, when x becomes infinite.) This can be interpreted by saying that the question of the probability of presence of an object within an infinite universe is inapplicable - there is no number, not 0, nor 1, nor any intermediary value that expresses the probability of presence of anything within an infinite universe, i.e., *there is no such probability*. It does not mean that the object would somehow evaporate within an infinite universe: if that were the case, then the probability calculation would simply yield naught. This seems to be saying that either *simple* spatially infinite universes cannot exist, and it is nonsense to try to calculate the likelihood of presence of anything within such universes, or alternatively if they exist they cannot contain material objects.

It does not say, however, that universes cannot exist within a higher dimensional matrix - it only says that if such higher dimensional mother universes exist, and contain bubble universes, then these universes cannot be simply correlated, and therefore the bubble universes remain totally separate and independent of each other and of the mother universe. Indeed, as we'll see, if a mother universe gives rise to child universes via certain scenarios, then these child universes are time-wise forever beyond even the infinite future of the mother universe.

It does not say either that the metaverse, if it exists, cannot be infinite; as we will see in the chapter on Gödel Universes, there are many ways that infinity can be accommodated, even if its constituent individual universes could not be spatially infinite.

35. The exact mathematical expressions of any but the simplest wave functions (corresponding to the simplest physical cases, such as free electrons, or the hydrogen atom) are extremely complex and, in the current state of our mathematical ability, mostly impossible to explicitly work out and formulate.
36. In 2014, a widely reported remark by Stephen Hawking was misinterpreted as meaning that he'd said that 'black holes do not exist'. What Stephen Hawking said was that they did not exist in the way he had hitherto envisioned them. The existence of a number of black holes in the universe has been reliably ascertained.
37. See e.g. books by Evan Harris Walker, Roger Penrose, David Hodgson, Michael Lockwood, Henry Stapp, Werner Loewenstein. Many other books and research papers at various levels have been published on this theme.
38. See e.g. Martha Stout, 'The Myth of Sanity' (2001).
39. Of course, some attributes are not orthogonal, and hence can be known simultaneously with any arbitrary level of precision. For instance, the color and the

location of something are not orthogonal properties (although for entirely other reasons, color may happen to depend on location in certain circumstances.)

40. It's actually even worse than that; it would be, to begin with, impossible to have a infinitely accurate snapshot of the momentums and locations of everything in the universe at any instant in time, because speeds and locations are orthogonal.
41. The tunnel effect in physics is one such indirect effect, a phenomenon that can even cause the onset of certain cancers. At a macroscopic scale, the tunnel effect would be the equivalent of a football being kicked into a brick wall, and somehow sailing through to the other side of the wall. To be able to occur, what happens is that a *real* particle - say an electron - 'borrows' energy from one or several *virtual* particle(s) and relinquishes the borrowed energy back to the virtual particle(s) at once after use quickly enough so that this energy loan remains virtual and under the 'Heisenberg radar'. This enables the electron to temporarily overcome energy barriers (the microscopic equivalent to the wall) which would otherwise be insurmountable.

Another well-known effect is the so-called Casimir effect, whereby a measurable force is created seemingly out of nowhere, but is generated when lopsidedness is deliberately engineered in the distribution of virtual particles around two objects.

Another such effect is radioactive decay. Whereas the *statistics* of radioactive decay are well known, and give rise to the half-life value of any given radioactive element, it is impossible to pinpoint accurately when the decay of any one particular molecule within a radioactive material will take place; it happens spontaneously at some apparently random time because an atom of a radioactive element must borrow energy from nearby virtual particles to be able to decay. For instance, one particular isotope of germanium has a half-life of some 1800,000,000,000,000,000,000 years, whereas, an isotope of, say, ruthenium has a half-life of one year, carbon-11 has a half-life of twenty minutes, and carbon-15 of about 2 seconds. Since decay occurs from resonance between attributes of virtual particles (of unknown statistical distribution or frequencies) with the well-known attributes of these particular isotopes, the resonant attributes of the virtual particles together with their frequencies could be inferred.

42. In the mathematical expression of any time quantum in the 'emergent time' scenario, there is a factor including a denominator containing the number of possible separate events within the universe. With that number set at infinity, its presence in a denominator ensures that the resulting value for the time quantum becomes nil.
43. Planck time, about ten to the minus 44 seconds, is defined by the time it takes for light to travel the 'Planck length'. The Planck length is defined as the theoretically smallest distance that can be measured with any theoretically ideal measuring apparatus. At shorter lengths, quantum effects predominate and we are firmly within the domain of quantum foam, where palpable reality is replaced

by quantum evanescence, with its cohorts of virtual objects putting in fleeting and 'ghostlike' appearances.

44. The word signature here is used to mean the number of space dimensions and of time dimensions: For instance, a space-time like ours with 3 spatial dimensions and one of time, would be said to have a signature of 3 and 1, denoted by (3, 1) or (+++ -) For a non-specialist high-level discussion of space-time with more than one dimension of time, see for instance Paul Davies's "About Time".

There is no theoretical obstacle to the existence of universes with different signatures than our own, however calculations show that some of these universes could be unstable, others could be inhabitable, and so on.

In particular, there is no *theoretical* reason why we should limit ourselves to 2 dimensions of time. Practically however, there is. Calculations show that most higher dimensional universes are unstable. Our type of universe, with a signature of (3, 1), is calculably stable. Most other Universes are either mathematically incalculable and hence, on the basis of our current mathematical abilities, unknowable, or they are calculable and turn out to be unstable (except for the (1, 2) and (2, 1), which are Universe types far too primitive and simple to be interesting). A (1, 3) universe is calculable – the only thing that it could contain would be a *tachyon broth* - a soup of superluminal photons.

Whereas mathematically modelling the dimensionality of space-time is easy to do on paper, what we learn from it is in terms of the physical consequences of extra dimensions is that not everything is allowed - there is always, as it were, a piper to be paid. For instance a new dimensionality, designed to solve a given, still-open issue, will typically solve that issue but will often *un-solve* some other issues that had already been resolved prior; this makes the very exercise of mathematically modelling reality a lengthy and somewhat frustrating exercise. Mathematical sleights can thus be self-defeating – they can plug a gap somewhere in some modelling edifice we are trying to build but thereby open up a new gap somewhere else. It is the ultimate reality check of nature letting us know that we haven't figured it out totally yet.

As an example, let us look at the so-called Kaluza-Klein space, named after the mathematician Theodor Kaluza and the physicist Oskar Klein; a specific kind of higher-dimensional space. Kaluza-Klein theory extends vacuum to 5 dimensions so as to contain enough degrees of freedom to be able to accommodate the properties of electromagnetism.

The extra dimensions neatly resolve the capacity of vacuum to convey electromagnetism - but immediately generate a new problem; the simple Kaluza-Klein model cannot describe nor account for the known interactions between the weak force and electromagnetism (the weak force binds particles made up of quarks, such as nuclei's heavy constituents, with lighter particles, such as electrons). Therefore, we have no choice but to add complexity to the mathematical formulation of the Kaluza Klein model to account for the observed

interactions. By doing so, however, we create yet again another new issue. Whereas the earlier, simpler mathematical formulation seamlessly accounted for so-called chiral fermions, we have now irreparably damaged the mathematical framework capable of accommodating them (chiral fermions are a category of particles whose spin value is an odd multiple of $\frac{1}{2}$ - such as electrons, protons, and neutrons.)

Extra *time* dimensions started to regularly appear in the scientific literature in the '80s. Physicists soon began trying out all kinds of mathematical constructs involving models of reality with different signatures, such as (10, 2) and others. Most of the pioneers of the use of a second *time* dimension in such models, Cumrun Vafa, John Barrow, John Schwarz, Edward Witten, Paul Davies, Andy Strominger, and many others tended to consider that this extra dimension was but an expedient mathematical trick without necessarily much meaning or underlying physical reality. Indeed, a sometimes useful trick in solving certain quantum mechanical calculations consists in shifting a space dimension over into a time dimension during the course of the calculations, even if only temporarily and changing it back to a space dimension at the end.

45. This scenario was first put forward by Tryon. We'll look more in depth at this quantum fluctuation scenario a bit further on in the main text.
46. The difference between numbers in this field depend upon local conditions such as gravity, space topology, and so on. Differences between points can take any value, from large values between points spatially far apart, to exactly zero.
47. Schrödinger's equation describes the behavior and time-like evolution of coherently correlated objects.
48. The Pauli exclusion principle, named after the Austrian physicist Wolfgang Pauli, forbids certain types of particles (fermions, which include electrons), from finding themselves in a same quantum state *at the same time*. This is the fundamental reason why electrons must arrange themselves in different orbits around a nucleus.
49. In other words universes with signatures (N, 2) or (N, $X > 2$), where N is the spatial dimensionality and X is equal to or greater than 2, the time dimensionality.
50. Any dimension could be either continuous or discrete. Note (43) above examines whether universes with more than one dimension of time would be stable enough to host life as we know it, or whether they could exist in the first place.
51. For further examples and an exhaustive discussion see also David Eagleman, 2012
52. All of the above occurs when brains are normally healthy, when their capabilities for retention of memory are fully operational. When the ability to memorize is cut out, the perception of time inevitably vanishes into thin air. In his book 'Awakenings', Oliver Sacks describes what befell some of the people who fell victim to the epidemic of *encephalitis lethargica* that wreaked havoc on the planet in the 1920s; for some of them, time seemed to utterly disappear. Despite being awake and about, these patients lost all notion of passing time and although clearly

alive seemed to have tranced out in frozen time. Decades later, some of the patients recovered, with their last living memories hearkening straight back to the world shortly after the First World War. Although now in the very different world of the sixties, these patients segued seamlessly, with no perceived discontinuity whatsoever, into a world 40 odd years apart from their immediately prior memories, which led to deep puzzlement and confusion on their part: how could they instantly have been transported to what was, quite obviously, a world some 40 odd years into the future? Rather similarly, William Langston and Jon Palfreman describe in their book 'The Case of the Frozen Addicts' the case of drug users who destroyed their memory centers through using bad drugs and thereby lost their notion of time. The myriad ways a *healthy* brain interprets, rather than faithfully relays, external reality is described in a number of fascinating reports, such as by David Eagleman (2011), and in other works.

53. In technical terms, any wave function, let's call it ψ , always contains both real-numbered and 'imaginary-numbered' constituents. If we call the real-numbered constituents a , and the imaginary-numbered constituents b times i (with i being the usual imaginary number i , equal to $\sqrt{-1}$), we then have $\psi = a + bi$, *aka* $a + bi$. Let's define ψ^* as being equal to a *minus* bi , or $(a - bi)$. ψ^* is called the 'complex conjugate' of ψ . The probability of finding the associated item (governed by ψ) within any area in space-time is then given by $\int \psi \psi^* d\sigma$, within set calculation (or 'integration') boundaries denoting that particular area in space-time.
54. Should there be several dimensions of time then other presents, pasts, and futures could also populate identical spatial locations.
55. The well-known US author Stephen King uses this scenario as a plot device in two 1990 novellas, 'The Library Policeman' and 'The Langoliers'. Other sources and authors have mentioned allegedly real such local 'time warp' incidents happening spontaneously, whereby a protagonist is said to slip back or forward in time without changing their spatial location. See for instance the oft-cited Moberly-Jourdain Versailles incident at http://en.wikipedia.org/wiki/Moberly-Jourdain_incident. A casual Web search throws off several sites given over to such tales of alleged slips in time.

For all their apocryphal character, these tales help to illustrate a very real but hard to apprehend feature of time as a dimension, as follows:

55.1- The Earth continuously moves through space at a speed of some 160 miles per second.

Neglecting for the sake of this calculation any speed due to the expansion of space itself, and further neglecting smaller motions such as the 'wobble' around its axis, the Earth moves in 6 different ways: its spin, its orbit around the sun, through space along with the rest of the solar system (roughly towards the star Lambda Herculis, at 12 miles per second), cyclically up and down perpendicularly to the Milky Way's median plane, and last but not least, it orbits along with the solar system at some 125 miles per second the center of the Milky way.

55.2- Nevertheless, in the above-cited tales, the ‘crack in time’ experienced by the protagonists hurls them into a past, or a future, at the very geographical spot or location where they happened to be just before - even though in terms of *where in space this very spot was in the past* is vastly different to what it is now, due to the Earth’s motion through space.

This scenario is nevertheless correct: the protagonists are only moving backwards or forward along a time axis, but are staying put, in terms of space dimensions, during the time-slip:

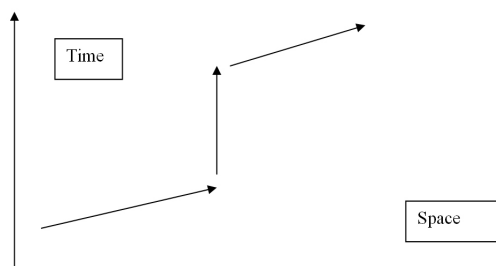


Figure 10.1: Indivisible spacetime: if spacelike parallel universes exist, then so do purely timelike ones.

The Earth moves through space along the horizontal ‘Space’ axis. If a time slip towards the past or the future is experienced, it occurs purely along the Time axis. Therefore the apocryphal tale of experiencing, say, a two-hundred year slip into the past in the gardens of Versailles would indeed happen in the *current* location of Versailles in space, rather than where Versailles actually *was* in space two hundred years ago.

56. Or, say, within the context of a ‘block universe’.
57. The words ‘metaverse’ and ‘multiverse’ are sometimes used with different meanings, but are used here interchangeably throughout. Possible different kinds of metaverses are usually classified into four main categories, which will be covered further on in the main text. Metaverses can accommodate different universes in a variety of ways, both infinitely far from our own (including far away in *time*), and extremely nearby; such as, up to aleph-one parallel universes could be located within the gaps opened up by the quantization of space-time, leading to the possibility of universes interlocked or staggered within the weft of quantized space-time.
58. Despite the overwhelming evidence in favor of the theory that the Big Bang started our universe, there is no smoking gun evidence that the wider universe is spatially finite. If infinite, we are inside a bubble, a subset of space formed by a Big Bang which occurred within a pre-existing universe. Seen from the pre-existing, ‘parent’ universe, our Universe would probably very much look like a black hole. Some cosmologists, such as *Nikodem Poplawski - a theoretical physicist at Indiana University*, argue that viewing our Universe as a black hole solves in one go

a number of issues that still bedevil our understanding of the universe. We'll revisit the issue a bit further on.

59. Bernard Carr collates in his fascinating volume 'Universe or Multiverse?' twenty-eight contributions to the question by a number of well-known physicists, addressing the issue from a variety of angles. Separately, John Barrow, Paul Davies, John Gribbin, Brian Greene, Roger Penrose and others have also weighed in with book-length arguments.
60. Ockham's razor, sometimes spelt Occam's razor, is only a general guideline (and a good one at that), but emphatically not a theorem. In essence, it states that when we face several possible interpretations of a phenomenon, the interpretation that most likely is the proper one is the simplest one, the one that gibes the most with common sense, simplicity, and lack of unnecessary or overly involved baggage. It is relatively easy, however, to engineer situations where Ockham's razor woefully fails, and indeed it is routinely falsified, sometimes spectacularly so. In 'A Universe from Nothing', Lawrence Krauss fascinatingly demonstrates that, if they are around then, cosmologists of the far future applying impeccable science and Ockham's razor would inescapably draw all the wrong conclusions about the birth and genesis of the universe, because by then they'll be unable to observe a number of essential features of the universe, such as any erstwhile neighboring galaxies which will have by then firmly drifted out of sight, or to perceive, let alone measure, things like the residual cosmic radiation background, or dark energy. Even if some of these cosmologists somehow stumbled upon the right, seemingly far-out ideas, applying Ockham's razor rules would firmly relegate the correct scenario and their proponents to the kook fringe.
61. The Copernican principle basically says that there is nothing special about the situation and universe we find ourselves in, and that to believe that we somehow find ourselves in a special or unique position (akin to a medieval view that the Earth was the center of the universe), is statistically unwarranted and hence most likely a delusional form of exceptionalism. Under the Copernican view, our universe is but an unexceptional universe among many, all of which born and evolved in a variety of ways and circumstances.
62. Advocates of the lone universe view have tried to use Ockham's razor to dismiss out of hand the possibility of a multiverse. For instance, in his book '*The Human Touch*' Michael Frayn uses Ockham's razor to make short shrift of the excess and 'unnecessary' baggage that various metaverse scenarios seem to lead to. Yet, Max Tegmark turns the argument rather spectacularly on its head and uses Ockham's razor to *promote* the multiverse view. The gist of his argument is as follows:

Because of something called the '*algorithmic information content*' (AIC), it turns out that a whole collection of elements is often much simpler to describe or otherwise apprehend than any arbitrary single individual element of that collection. This perhaps counter-intuitive result is actually easy to demonstrate, as follows.

A coarse approximate measure of the ‘algorithmic information content’ of anything is given by the *required computational resources* that would be needed to specify that something - broadly, the length of the shortest computer program that would be required to run a true mathematical modelling of that something. (The minimum computational resources required to generate the requisite information capable of fully defining that something is sometimes called the *Kolmogorov complexity* of that something.)

Now, if we take ordinary real numbers as an example, a computer program generating all of the real numbers is much shorter (in fact quite trivial) than a computer program that would generate even a single, arbitrarily very long real number.

Likewise, the properties and characteristics of a multiverse may naturally arise from broad general principles, whereas in the case of a single universe, such properties would have to be individually selected by some compelling mechanism, adding a further layer of complexity to reality. To be fully understood, a single universe would thus require more analysis and theoretical justification. Hence, far from favoring a lone, single universe with individual laws of physics and somehow unique fundamental constants (such as the charge of the electron, etc.), Ockam’s razor in fact militates for a multiverse-based picture of reality, able to accommodate many different modes of reality distributed among many universes.

The way this analysis begins from the selfsame parameters and yet lead to diametrically opposed views, shows yet again that truth, like beauty, is often in the eye of the beholder.

63. A rather widespread objection that tends to for ever crop up in different guises says that, at its core, this universe is all we’ve got, period. It is an argument sometimes heard from communities with an ulterior agenda which may not spring from scientific considerations, such as from creationist and other more or less kindred communities.
64. It is easier to visualize higher dimensions by reducing them to lower numbers. In spatial terms, it is hard to visualize how, say, a fourth or fifth dimension can be both present throughout 3-D space and small (most extra dimension are probably tiny and ‘curled up’) However, if we consider a very thin sheet of paper, representing a 2-D universe, then we can visualize the thickness of the sheet as its extra third dimension, both very tiny and omnipresent.
65. Hugh Everett was a student under Archibald Wheeler, an eminent Physicist who was awarded the Wolf Prize, one of the highest distinctions in Physics. The ‘Many-Worlds Interpretation of Quantum Mechanics’ was Everett’s Ph.D. thesis.
66. The mechanism of the collapse of large supernovae is described at length in a number of publications see e.g. Paul Davies’s ‘The Edge of Infinity’, Chapter 4, for a solid general level discussion.

67. The Mercator projection is the usual 2-D rendition of the 3-D globe. The huge distortions brought about by the projection are obvious; for instance Greenland appears much bigger than Australia, although its surface area is actually about one-fourth that of Australia. The North and South poles of the Earth, far from being pointlike as they are in reality, now appear as the full-length top and bottom edges of the rectangular map.
68. As always, many different interpretations exist. For instance, under the transactional interpretation of quantum mechanics, the stability of manifest reality does not arise from the stabilizing effect of parallel universes, but from the interference of the future with the past which generates, at every instant, the weft and weave of present reality.
69. Technically, the standard models of the Big Bang are the Friedmann-Robertson-Walker (FRW) solutions of the gravitational field equations of general relativity, which can describe both open and closed universes. All FRW universes have a singularity at the origin of time - the Big Bang.
70. See <http://www.math.columbia.edu/~woit/wordpress/?p=699>
71. A fundamental constant of nature is any number that arises naturally and typically recurs in many applications and calculations. In mathematics, the ratio π of a circle's circumference to its diameter, or the base of the natural logarithms e , are fundamental constants.

In physics, such numbers as the mass of the neutron or the charge of the electron are fundamental.

There may be very different reasons why nature's constants take on the values they do. Either there is a fundamental, environment-independent reason why their values are what they are, in which case the observed values are the only possible ones, on grounds that are not yet understood but which we should succeed in working out some day. Or alternatively, our universe is the result of a quasi Darwinian-like evolution, and these values *evolved* to what they are. Calculations show that any universe born with constant values slightly different from those we know would be unstable, and in most cases would vanish again fast. Only a universe with the constants we know would stay in existence long enough for life, and indeed readers and physicists, to appear in it. For every such rare life-friendly universe, many other dead universes would exist or have existed.

Many different attempts to work out directly and independently the values of nature's constants have been attempted, with little success so far.

As a case in point, Ernst Sternglass published a few years ago a scenario leading to values of nature's constants. His theory has however two probably insurmountable flaws: First, it is closely predicated on the great physicist Georges Lemaitre's "Primeval Atom" theory, a still immature forerunner of what has since become the modern Big Bang theory. Second and most questionable, Sternglass's theory involves precisely 270 evolutionary steps from the posited primeval atom: although the theory seems to explain all of the numerical values of the constants of nature, it does so at the cost of creating one arbitrary number: 270 steps. The theory cannot

explain that new number: A familiar domino effect rears its head, whereby an attempted explanation semantically shifts a problem sideways but does not solve it: there is no essential or qualitative difference between wondering why the electron charge is what it is or why there are 270 evolutionary steps from some starting point. There is no satisfactory explanation either for the primeval atom. Thus, Sternglass's theory does not qualify as 'beautiful', in the meaning of that word when used by physicists: it lacks a *eureka!* quality, the 'ring of truth' which would make it readily acceptable by the wider physics community. A compelling theory looks and feels natural, is 'free-flowing', and does not contain features that look unexplainable, too ad hoc or artificial, such as unexplained numbers, overly and/or groundlessly convoluted mechanisms, and so on. Most attempts to work out the values of nature's constants have so far foundered on issues exemplified by Sternglass's approach. For a good exposition of 'beauty' in physical theory, see 'It Must Be Beautiful', by Graham Farmelo.

72. Of course, it could be God or a godhead. But, as Paul Davies puts it, *'Merely declaring 'God did it!' tells us nothing at all. An old-fashioned cosmic designer is a content-poor explanation, and only kicks the questions upstairs.'* Moreover, a belief in some godhead is logically totally incompatible with a purely Aristotelian approach.
73. For a general-level exposition of various scenarios see e.g. 'Endless Universe: Beyond the Big Bang', by Paul Steinhardt and Neil Turok, 2007, 'Cycles of Time', by Roger Penrose, and also works by Alex Vilenkin, Joseph Silk, Martin Bojowald et al.
74. Incidentally, the tunnel effect is responsible for causing the onset of certain cancers. Some cancers are caused by the 'scrambling' of cells within the body, which happens when the cells are haphazardly flung into new random positions and/or orientations by the indirect effect of spikes of energy passing through tissues. Cells can change their electrical polarity changes from their normal neutral status whenever cosmic rays kick a few electrons out of their place. On their own, cosmic rays would seldom have enough energy to displace electrons, but thanks to the tunnel effect, they can become instantaneously more energetic than they are, with sometimes disastrous consequences. An electron within a cell can thus become displaced and the cell (now lacking an electron, flicked out of place by the cosmic ray) shifts into a new position owing to the new environment of electrical charges around it. An ionized cell is now repulsed by other (positively charged) ionized cells and electrically attracted to these other cells which have absorbed randomly displaced (electrically negatively charged) electrons. Such cells become all scrambled up and may become a starting point for the onset of certain cancers.
75. These synchronous time bubbles can dissolve if the entangled constituents of the wave function drift apart through the process of decoherence, whereby the various constituent elements within the wave functions start correlating with other outside entities and drift away, *disassociating* themselves from their earlier associations. The universe is thus host to an ever changing configuration of co-existing, separate same-time bubbles.

1. Is a circular argument (time before the BB is nonsense because time before the BB is nonsense)
 2. Is invalid under a number of scenarios (bouncing universes, brane universes, Black Hole genesis, loop quantum gravity, and so on)
 3. Last but not least, at no time was time used as a pre-Big Bang variable in the calculation!
83. Technically, particles with half-integer spin (so-called *fermions*). The full theory is known as the Einstein-Cartan-Kibble-Sciama theory of gravity.
84. Many of the *other* scenarios proposed so far for the births of universes seem to routinely involve with unwieldy baggage not easily disposed of nor explained. At every step of many attempted explanations, new hurdles keep cropping up, so that ever new theories or massive tweaks in existing theories are called for. In the traditional explanation of what happens immediately after the Big Bang, the attempt to reconcile Einstein's relativity with the observed huge rate of expansion of the split-second new universe led to discrepancies. Therefore, a new idea was introduced, that of inflation (Alan Guth). Since relativity does not account for inflation, a new theory is invoked to explain it, which in turn won't explain other features of the universe - such as the value of nature's constants, and so on.
85. Attempts have been made to relate the perceived arrow of time with the growth of entropy. However, cognitive bias seems to invalidate most of these arguments, as Dieter Zeh and others have convincingly shown. At its heart, entropy is a measure of the 'disorder' of a system - a tidy, well-ordered child's room has low entropy, whereas the same room when messy has high entropy. Since there is a natural tendency for, say, the room to become messy, its entropy has a tendency to naturally increase. The *direction* of the change of entropy towards increasing, and never towards decreasing, merely reflects the fact that there are many more ways for the room to be messy than for it to be tidy. If the child is careless and does not deliberately undertake to tidy the room (thus willingly decreasing entropy), the room will never naturally gravitate towards tidiness. It's a purely statistical phenomenon - unrelated to any possible fundamental or inherent arrow of time in nature.

This is quite general: entropy has a natural tendency to grow everywhere. The same holds for all systems whose constituent elements may take on different configurations. Constituent elements may be, say, engine parts (there are very many ways to assemble an engine wrongly but only one way to put it together right), or molecules. For instance, put a drop of ink within a glass of water. The ink blobs will slowly dilute and soon color all the water in the glass. There are far more ways, statistically, for the molecules of ink to be distributed more or less homogeneously within the water than there are for these molecules to clump together. Hence, the tendency will be for the ink to become broadly homogeneously diluted throughout the water, rather than remain in distinct blobs

of ink. This has nothing to do with the arrow of time, only with the statistically immensely many more ways the ink molecules can be distributed throughout the water (diluted), in comparison with the much fewer ways it can stay undiluted. Contrary to appearances, dilution is not fundamentally irreversible at all: any given distribution of the ink molecules in the water is every bit as probable as any other configuration. Any given precise *diluted* configuration of the ink molecules has the same probability of appearing that any ‘undiluted’ configuration. Since immensely more configurations lead to the macroscopic state of dilution than to the macroscopic appearance of undiluted blobs, the probability of the appearance of dilution is immensely higher than the likelihood we’ll see blobs of ink.

86. John Barrow, ‘The Book of Universes’, 2011
87. Martin Savage’s idea is predicated on the fact that high-energy cosmic rays could not travel along the edges of a computer generated numerical lattice in any conceivable digital computer model, but would travel diagonally, and neither would they interact evenly in all directions the way true cosmic rays would be expected to do. To test the hypothesis however, we need far more computing power than is currently available. See <http://arxiv.org/abs/1210.1847>
88. A simple illustration and proof of this phenomenon is provided by, for instance, the basic mathematical series of additions and subtractions called Grandi’s series.

Grandi’s series is the simple, endlessly repeated sum of paired ones and minus one: +1 and -1.

If we add up a million *matched* pairs of 1 and -1, we shall unsurprisingly and reliably get an end value of zero: $1-1+1-1+1-1 \dots = 0$. If instead of a million times we repeat this addition a trillion times, or a trillion trillion times, or a googol times, or a googol times squared, we will still always get zero.

But the situation changes the instant we shift over into infinity:

Let us call G (for ‘Grandi’) the infinite sum of paired (+1) and (-1):

$G = 1-1+1-1+1-1 \dots \text{ad infinitum}$.

G is equal to $(1 - 1) + (1 - 1) + \dots = 0$, but it is also obviously equal to: $1 + (-1 + 1) + (-1 + 1) + \dots = 1+0 = 1$, and since we can obviously also write that $G = 1 - (1 + 1 - 1 + \dots)$, we therefore also have $G = 1-G$, which now yields $G = 0.5$

We can keep on manipulating this infinite sum G and end up with all kinds of seemingly legitimate values: the onset of a simple infinity has destroyed the straightforward, intuitive value of zero for the sum of matched pairs of one’s and minus one’s, and replaced it with indeterminacy.

A further illustration involves what becomes of the simple arithmetic operations of multiplication, addition, subtraction, and division, which all become something

profoundly different when applied to infinities: for example, multiply any number no matter how large by zero, and the result of this multiplication firmly remains zero. Zero multiplied by a trillion zillions firmly remains equal to zero. But multiply zero by infinity, and the result may now take on any value between zero and infinity: the result has become indeterminate.

89. Lawrence Anthony, 'The Elephant Whisperer', 2009

90. There are several, ultimately equivalent scenarios how this could work. One is that a single consciousness's wave function would happen to link up backwards in time and enable the Big Bang by generating a wave function spike triggering the event. Another would be if there is such a thing as the wave function of no less than the whole of humankind. Since there are only six degrees of separation between any two people on Earth, then a collective wave function likely exists, although it would be 'weak' - for lack of a better word. By weak is meant a wave function sitting high up in a hierarchy of wave functions, with some of its elements being wave functions themselves. This would lead to a form of 'weakness' or looseness, inasmuch as any change affecting one of the constituent wave functions can be reacted to in a wide variety of different ways by the other constituent wave functions, unlike the 'strong', unique way whereby a particle within a two particle wave function *must* react to a change affecting the other particle, or the narrowly limited ways a particle in a few-particle wave function would have to react to a change affecting one of the particles.

This wave function would have encompassed over time all of the humans who ever existed, although it would probably decohere from those who pass away (unless one assumes survival of some of the mind after physical death). Speculating here for a minute, this wave function could have at one time encompassed pre-humans and other historical life forms, and have included enough correlated physical elements to create an uninterrupted backwards linkage all the way to the Big Bang. *Indeed, it could be the wave function of the universe itself, wherein all of our individual wave functions are subsumed.*

The very concept of a wave function of the *whole universe* is still hotly debated, with strong supporters on both sides of the issue - both the view that it exists (which derives seamlessly from adopting wave function realism, or even monism. Jonathan Schaffer sums up the relevant argument of monism thus: "*Physically, there is good evidence that the cosmos forms an entangled system and good reason to treat entangled systems as irreducible wholes*"), and the contrary view of others who do not admit its existence (Ray Streater et al.) The view taken in this work, as the reader has seen, is of a hierarchy of wave functions expressing material reality: at bottom, there provably exists a wave function for a single particle; then there provably exists a wave function for an atom; there provably exists a wave function for a molecule; there provably exists a wave function for an object made up of molecules ... and so on all the way up. Wave functions can encompass other wave functions as their constituent variables, which provides for a linkage mechanism between all of reality. This linkage can be strong or weak or even nil - depending on the strength of the correlation and on its corresponding mathematical rendition (irrespective of the fact that we are unable to calculate this mathematical rendition).

Yet another equivalent way this could work is if there exists a wave function of the whole biosphere - a wave function not limited to humankind but whose participatory variables include your pet's wave function, along with those of all living entities on Earth. Under this scenario, this wave function would create the necessary conditions leading to the universe actualizing itself in a Big Bang.

91. There are two main flavors of the Anthropic Principle (AP), the so-called weak AP, and the strong AP. In essence, the weak AP would permit a vast multiverse of other, barren universes: whatever its cause, we just happen to live in a bio-friendly universe, as we must - because we are simply not able to live anywhere else. The strong AP is more compatible with the view that there is a single universe. It says that there must be reasons, not quite elucidated yet, why that universe had no choice but to take on the bio-friendly characteristics it assumed, irrespective of how unlikely they may appear to us. The Anthropic Principle is treated at popular science level in a number of publications, see e.g. 'The Anthropic Cosmological Principle' by John Barrow, Frank Tipler, & John Wheeler (1988), or Paul Davies's excellent 'The Goldilocks Enigma' (also titled 'Jackpot' in its US edition.)
92. There might now exist an answer to this conundrum, which goes like this: in a multiverse, the answer is yes (that the never-remembered dream exists in some meaningful way), because the dream may have also unfolded in a parallel universe, and left some trace or even gone on to a form of existence there. In a single universe, the answer is no.
93. See at <http://www.pi-world-ranking-list.com>. The current world champion, Chao Lu, flawlessly reeled off more than 67,890 decimal digits of π over the course of some 24 uninterrupted hours before begging off.
Sometimes people who report the most extraordinary feats or tricks played by their minds become the butt of attacks caviling about some point or another. The critics, however, seem to be missing the wider point, which is that such extraordinary feats are *possible* in the first place. The catch-all explanation that our mind is exceptional or perhaps even infinite seems to be mere labeling rather than explanatory. Even if, notwithstanding the Bekenstein bound and other possible limitations, our minds were infinite in some definable way, the question would remain how even infinite minds could achieve certain things; to give a simple analogy, regardless of how infinite the set of natural numbers is, it does *not* and cannot contain the number one half. The question of whether an infinite mind would necessarily be able to do any conceivable thing is moot and probably deserves further exploration.
94. Om's existence is compatible with both a lone universe and a multiverse, i.e. this scenario is neutral in the universe vs. multiverse debate.
95. If we adopt the view of a platonic universe where, to use Max Tegmark's phrase, we are 'self aware mathematical structures', *math* can then be conflated into

mind; then all that is left is 'mind and time together weave our reality into existence'. They do so, of course, by means of wave functions.

96. Sean Carroll's remark is, however, fully legitimate, because the newly formed universe could come into existence into staggered interstitial space or alternatively in a newly formed black hole - beyond infinite time when seen from the room, left behind in the mother universe.

Further Reading

A brief selection of related books

(Books which may require some mathematical background are preceded by an asterisk)

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