7

Time and the Visual Imagination

From Physics to Philosophy

Jenann Ismael

The visual imagination is one of our most powerful tools in helping us think through abstract problems in physics and it plays an especially prominent role in spacetime physics, but it is also behind some of the most trenchant misunderstandings about what physics tells us about the nature of time. This chapter is about the images of time coming out of physics and the philosophical confusions to which they give rise.

It is not a new idea that philosophical problems can have their roots in mental pictures. This is a theme in Wittgenstein's later philosophy. I am interested here both to make the confusion explicit and to explain the powerful grip it has on the imagination.

1. The History of Spacetime Theories

Physics in its modern form began with Newton. The time of Newton's physics was very close to the familiar time of everyday sense. Newton's Universe was a three-dimensional space containing material objects and the History of the Universe was a dynamic process that unfolded in time. God, looking at the Universe from the outside would see the Universe coming into being one stage at a time.

A new vision of time took shape with relativity. The new vision presented space and time together as a four-dimensional manifold of events. There remain differences between the spatial and temporal dimensions, but these are quite subtle. Formally, the spatial and temporal dimensions look alike. Just as there is no ontological difference between here and there, in the relativistic Universe, there is no ontological difference between past, present, and future.

Jenann Ismael, *Time and the Visual Imagination: From Physics to Philosophy* In: *Oxford Studies in Philosophy of Mind Volume 2*. Edited by: Uriah Kriegel, Oxford University Press.
DOI: 10.1093/oso/9780192856685.003.0007

The difference between the familiar time of everyday sense and time as it appears in the relativistic image of the Universe echoes an ancient philosophical debate between the Heraclitian and Parmenidean conceptions of the Universe, which has been one of the most persistent debates in philosophy about the nature of time. You may know Heraclitus from the famous dictum 'all is flux'. For Heraclitus the fundamental character of reality is *change* itself.

Here's Heraclitus:

> Everything flows and nothing abides; everything gives way and nothing stays fixed.
>
> You cannot step twice into the same river, for other waters and yet others, go flowing on.[1]
>
> Transience is basic, and the present is primary. Those things which exist now do not abide. They slip into the past and non-existence, devoured by time, as all experience attests.

The opposing view comes from Parmenides. For Parmenides, there is no change. He writes:

> Change is an illusion. The Universe itself is constant, unchanging and eternal.
>
> What Is has no beginning and never will be destroyed: it is whole, still, and without end. It neither was nor will be, it simply is—now, altogether, one, continuous.

To most in the physics community, relativity seemed a vindication of the Parmenidean conception. It became customary to say that the passage of time is simply an illusion. Einstein himself used the vocabulary of illusion on several occasions, most famously in a condolence letter to Besso's widow, where he wrote: "In quitting this strange world he has once again preceded me by just a little. That doesn't mean anything. For we convinced physicists the distinction between past, present, and future is only an illusion, however persistent."[2]

[1] The passages and translations of Heraclitus and Parmenides come from Wheelwright (1960).
[2] Isaacson (2007), P. 57.

In the philosophical community, relativity revived the ancient debate between the two competing visions. There are what are called the Block Universe enthusiasts (the name comes from the idea that the Universe is a four-dimensional block of events) who ally themselves with physics, on one side, and the defenders of Becoming, on the other. Defenders of Becoming hold that the Universe is open-ended and on-going, that its future is not fixed by its past, and that it is always in the process of coming into being.

Block Universe enthusiasts insist that there is no Becoming. There is, rather, a four-dimensional Block or manifold that comes into view in stages for people whose lives are embedded in it. Friends of Becoming insist that the four-dimensional relativistic image of time heralds the disappearance of everything that we think of as essential to time.[3]

2. The Roles Visualization Plays

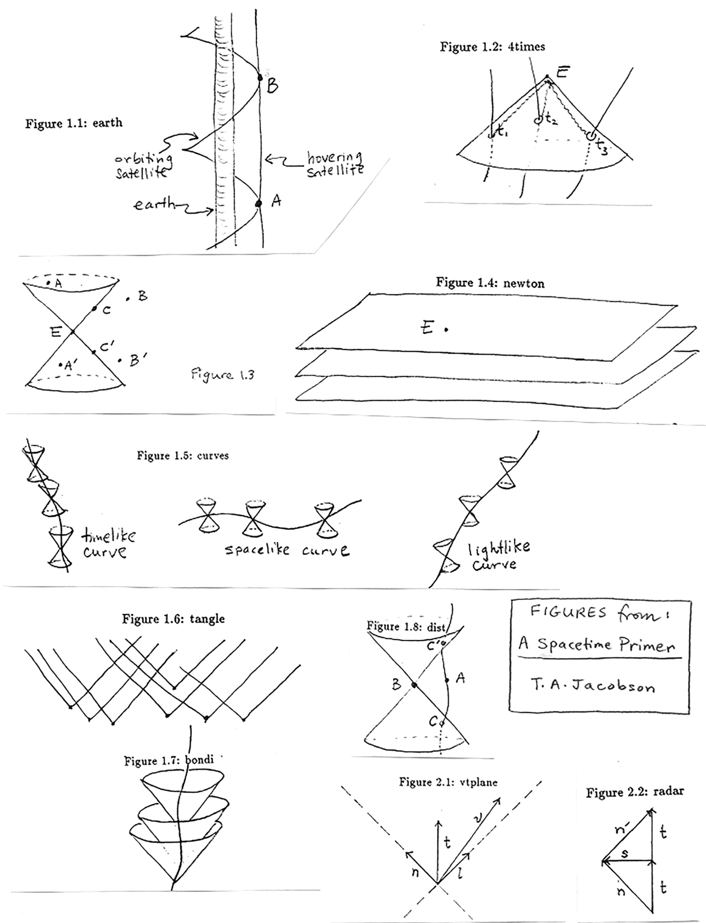
I will be talking about the four-dimensional image of time at the center of this controversy, but it will be useful to begin by saying something about the role of visual representations in physics generally.[4] Physics is all about patterns. The patterns that turn out to be the most important are difficult to unearth and not immediately visible. They are complex, distributed, higher order regularities buried in the phenomena in a manner that requires complicated mathematical analysis to expose. Once they are discovered, however, we tend to represent them in ways that render them visible, creating diagrams, images, and representations that reveal them. We do that for ourselves, and in conveying the content of science to others.

Visualizing plays an especially heavy role in the parts of physics that are concerned with space and time. Questions about the structure of space and time come into physics by way of their connection to motion. The geometry of space and time affects the observable movements of material objects. And because the physics of space and time is all about geometry, it is particularly amenable to pictorial representation. We give people all kinds of

[3] For an overview of the debate and an excellent bibliography, Emery, Markosian, and Sullivan (2020) Steven Savitt (2017).

[4] I focus on visualization because that is the case about which I can speak informatively. There are questions, to which I wish I knew the answers, about what the spatial imagination is like for blind people. Spatial thinking is not necessarily visual. Non-sighted people have spatial concepts. Their motor and tactual experience is as spatial as our own. I wouldn't want to speculate about extending these ideas. See Schmidt et al. (2013).

tools for visualizing motion and space. If you go to a science museum, or open up a YouTube video on relativity, you'll be shown images of how the world would look if you were travelling on a beam of light. You will be told that in general relativity matter curves spacetime and shown images of iron balls on rubber sheets, often set in motion to see the way that movements of matter 'change the shape of space'. In cosmology, people love full color digital representations of the beautiful global geometries that provide solutions to the field equations. And it's not just public relations (popularizing science for the non-professional). Diagrams are indispensable in learning relativity. Flip through any physics textbook on spacetime theories



AQ1 **Figure 7.1** Teaching notes from a primer on relativity
Source: © Theodore Jacobson. Reproduced with permission.

and you will find as many diagrams as equations. Nobody that has a passing acquaintance with Special Relativity would fail to recognize ~~them~~.

Visual representations do several things:

- They carry the content of the theory. What you learn when you learn the theory is what it says about the geometry of spacetime, and that is what is depicted in these diagrams.
- They guide the imagination in computation. When thinking through a problem one will often work it out by casting it visually. Quite generally, understanding how to carry out inferences in special relativity involves, in large part, learning to manipulate light cone diagrams.

People who aren't physicists commonly picture what thinking through a problem in physics looks like as something like Figure 7.2.

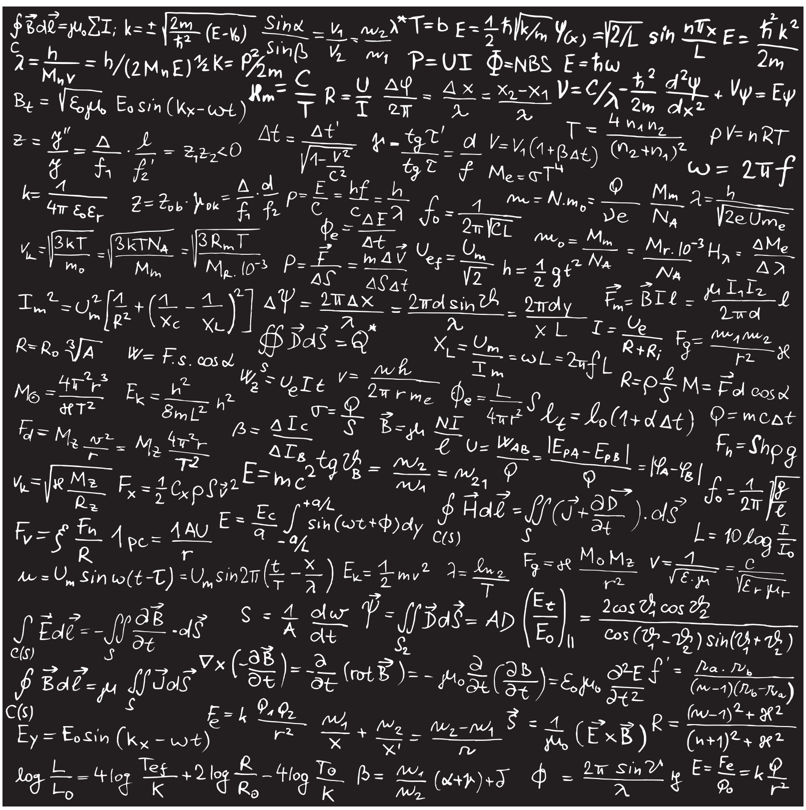


Figure 7.2 A non-physicist's view of a physics problem
Source: © Shutterstock/EtiAmmos.

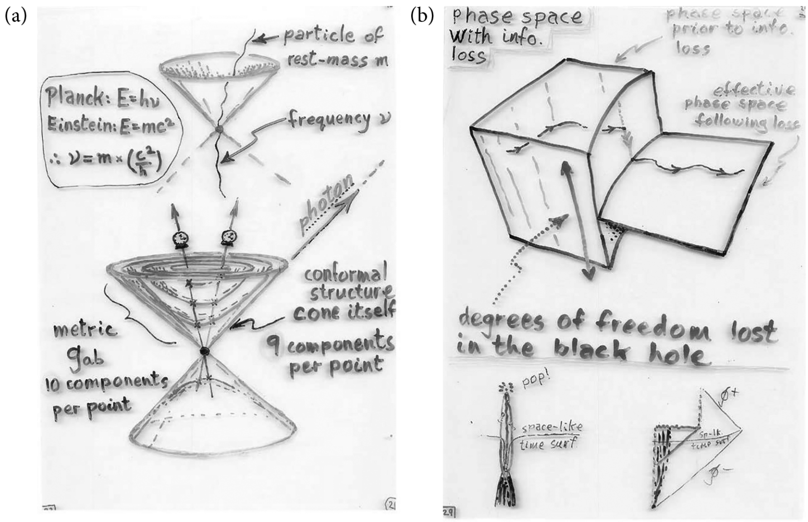


Figure 7.3 A physicist's view of a physics problem
Source: Penrose (2014).

In spacetime physics, more often, it looks like Figures 7.3a and 7.3b.[5]

3. Why Visualization Helps; the Power of Images

The reason that images are so powerful has to do with the way that our brains work. We are really good at *seeing* patterns. Our visual processing systems are made to detect spatial patterns. If you are shown images like those in Figures 7.4a and 7.4b, the pattern is visible to you without any conscious inference: it is available on inspection.

You see it as immediately and directly as you see the color or the shape. Apprehension of the pattern is a *perceptual* phenomenon: it is a part of the processing of sensory information that requires no cognitive effort on your part. For evolutionary reasons, it is important to be able to detect spatial regularities and we evolved to be very good at it. Physics, however, takes its

[5] The reason for this is in part that the order of explanation goes from the geometry to the mechanics. You understand why the numbers come out the way they do in measurements of distance and for observers on different trajectories if you understand the geometry of the space in which those measurements are performed. That is what is meant by saying that space contraction and time dilation (those old familiar oddities of Special Relativity) are kinematic rather than dynamical effects.

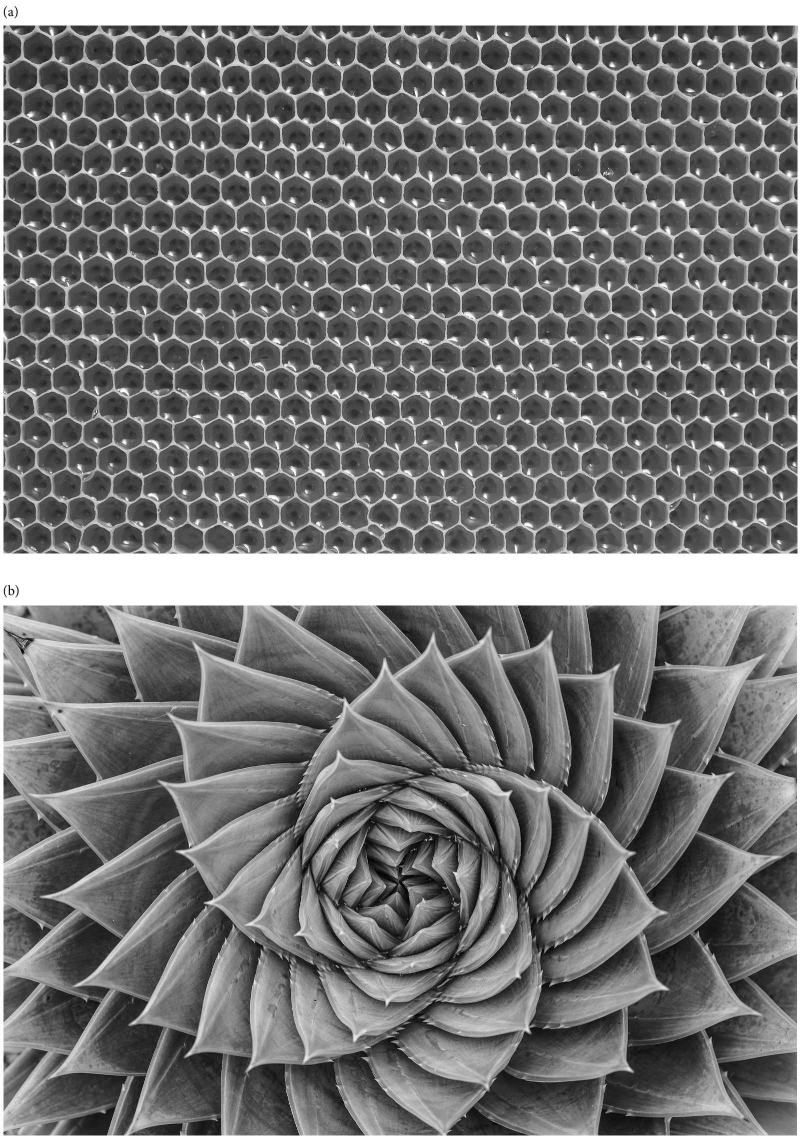


Figure 7.4 Patterns that are clear to see
Source: © Shutterstock/kosolovskyy and Shutterstock/Paggi Eleanor.

regularities where it finds them and the sorts of regularities that turn out to be important for physics—regularities that are inductively powerful and that get embodied in scientific laws—are abstract, higher order regularities that don't have this kind of perceptual immediacy. They are often regularities in motion (patterns in temporal development) so they are distributed across time and they tend to relate measurable quantities (things like force or velocity or charge) that take some analysis to discern. What visual representations do is render these abstract higher order regularities in a form that we can simply see. They transform a complex and higher order similarity into something that the biological brain recognizes effortlessly, something that reveals itself on inspection.

Consider, for example, Newton's recognition that the motion of a cannonball as it is released from a canon and a planet going around the sun are actually instances of the same type of motion. This was a very deep physical insight. Superficially, a cannonball and a planet are very different kinds of system. One wouldn't expect that they should be any more alike in their behavior than a marigold and a mole rat. For almost 2000 years before Newton, the dominant physics presumed that planets were made of different stuff from cannonballs and were obeying different laws. The manifest regularity and symmetry of planetary motion, in contrast to the unruly behavior of earthbound objects, made this a very natural presumption.

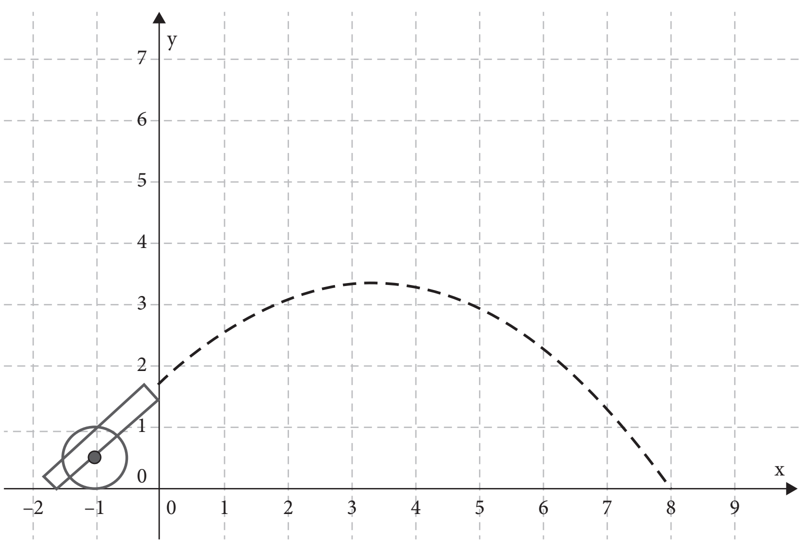


Figure 7.5 The motion of a cannonball

To see the deep similarity between the two motions, we have to visually render the motion, which means taking the position at different times and representing it in a single image. Then we have to filter out the differences in size, color and so on and just focus on the shapes of the trajectories. Figure 7.5 shows the cannonball.
Figure 7.6 shows the planets.

Finally, we have to zero in on the right quantities. Position is the first order variable. That is what we directly see. Velocity is the rate of change of position (called the first derivative). Acceleration is the rate of change of the rate of change of position (called the second derivative), and it turns out to be the quantity that we need to focus on. That is what I meant by saying that the physical laws often relate not the immediately visible properties of a system, but higher order quantities or derivatives of those properties.

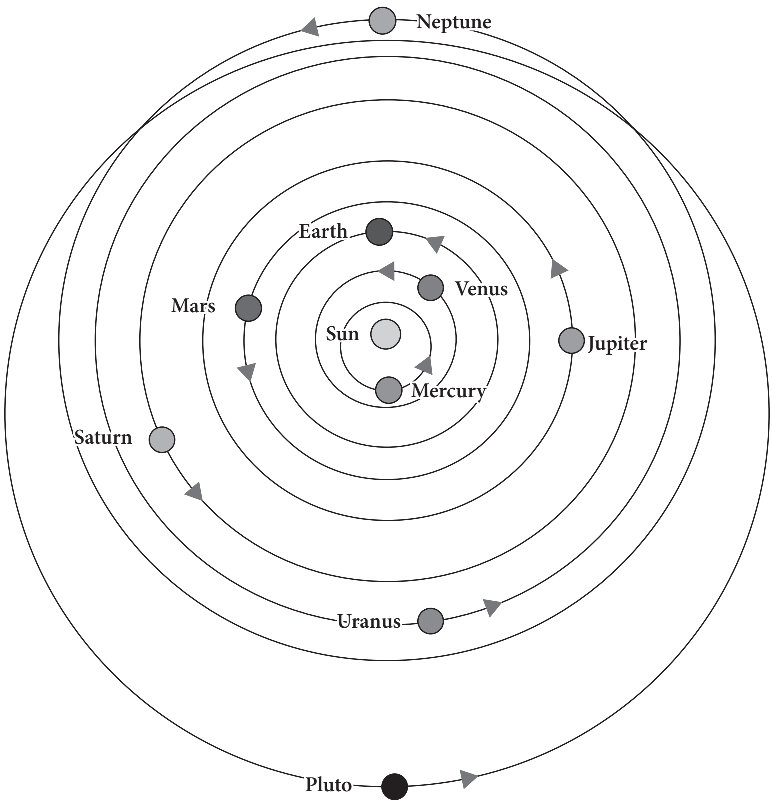


Figure 7.6 The motion of the planets

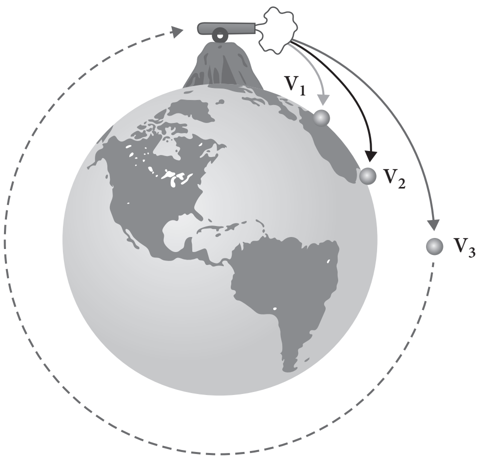


Figure 7.7 A smaller body falling towards a larger body

In both the cannonball and planet cases, there is a smaller body falling towards a larger one in a way that is clearly depicted in Figure 7.7.

A version of this diagram occurs in Newton's Principia. And now, because of the way it is rendered in this image, you can see clearly that the cannonball is *doing the same thing* as the planet, and that if it was shot with a greater velocity, it would attain orbit. So, a planet orbiting the sun is *just like* a cannonball falling towards the earth, but with a greater tangent (or forward) velocity.[6] The law that describes the acceleration of the smaller body towards the larger is (of course) Newton's law of gravitation, which applies not just to planets and cannonballs, but to all bodies—and the insight that led him to it (what he called his 'most excellent idea') involved not cannonballs, but (famously) an apple falling from a tree. The story is that Newton, home from Cambridge because of the plague, saw an apple fall from a tree and was struck with the analogy to planetary motion. Much of physics follows the model of a search for hidden patterns in the phenomena and their expression in the form of law. And visual representations very often play a central role. The process of abstraction and depiction that goes from the first of the images of the cannonball and planets to the last transforms a temporal pattern into a spatial one and renders an abstract higher order pattern concrete and salient.

This kind of thing is very much in evidence in Galileo's notebooks not just as a way of rendering the pattern. You see him throughout his

[6] Newton (1846).

notebooks playing with diagrams, filtering out the obvious dissimilarities, trying to condense into a diagram that he can directly see, the rather abstract pattern exhibited by apparently very different motions. A good diagram can depict a set of relationships that it would take many words to describe. It takes a Newton to discern the pattern implicit in cannonball and planetary motion, but every freshman in a physics class can see the similarity when it is presented diagrammatically as above. These kinds of visual representations are typically encountered first in concrete form, and later guide the imagination. Whether one is thinking about gravity or fluid dynamics or electromagnetism, the diagrams one learned in one's first physics class will stand in for the objects themselves and guide one in solving problems and forming expectations for how the systems will behave. Learning to picture things in the right way is a good part of understanding. The field diagrams shown in Figure 7.8 are encountered first in books, used in solving problems, and become indispensable in imagining electromagnetism.

Intriguing research on chimp cognition suggests that the ability to think about higher level patterns might be bound up with the ability to create concrete visible representations in a manner that is not well understood. In a study of problem solving in chimpanzees, Thompson, Oden, and Boyson look at the ability to solve puzzles that require matching relations-between-relations.[7] Merely matching (first order) relations can involve for example, training the chimps to match the identical items. Experimenters might place

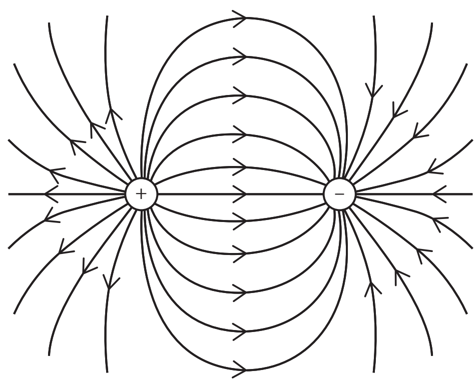


Figure 7.8 Common field diagram

[7] Thompson, Oden, and Boysen (1997).

a bunch of items on the floor (2 cups, two forks, two balls, two shoes, etc.) and the task is to sort them into matched pairs. The higher order task—matching relations-between-relations—involves getting the chimps to sort pairs into matched and unmatched ones. They are to match *pairs* of identical items (e.g. two identical shoes) to other matched pairs (such as two identical cups) and pairs of mismatched items (e.g. a cup and a shoe) to other such pairs (e.g. a pen and a padlock). It was known that non-language-trained chimps cannot solve the higher order problem, but language-trained chimps (chimps that have a simple vocabulary and the ability to compose some simple sentences) can. What Thompson, Boyden and Oden found, however, was that it is not the syntactic ability, but the availability of labels (words or concrete markers) that can be associated with relations that puts the higher order task in reach. Chimps with no language training, but a history of associating tags with pairs—red diamonds with matched pairs and blue circles with mismatched pairs—solve the task spontaneously with non-differential reinforcement. It is done in two steps. First, they put a blue marker by the matched pairs and a red marker by the blue pairs. And now they just have to sort red markers from blue ones.[8] What the labels allow them to do is effectively convert a higher order task into a lower lower order perceptual recognition problem. This strategy of converting a higher order pattern recognition task into a lower order one by creating representations that render those higher order patterns concrete and visible is precisely what we are doing when we draw diagrams of higher order relations. And it is easy to see the deeply iterative nature of the process. Any new quantity that can be introduced can become a term in relations with other quantities; from energy to entropy the introduction of new terms, denoting quantities far removed from the visible qualities of everyday sense, reveal unsuspected patterns buried deep in the phenomena. I'll say a little more about this towards the end.

4. The Logic of Images

Everything I've said so far about the role of visual representations is good. They render patterns that we don't immediately see concrete and visible, thereby transforming a complex higher order pattern recognition problem

[8] Thompson and Oden (1996).

into one that is simply a matter of looking. Science, quite appropriately uses the imagination opportunistically to aid computation and facilitate a sense of familiarity, exploiting whatever tools there are at hand. But there is a dark side to all of this that manifests itself in the philosophical controversy surrounding the relativistic image of time. Because they are imagistic, spacetime diagrams give us a sense that we are seeing what spacetime really looks like. And the way that the diagrams work leads to some quite special (specifically philosophical) misunderstandings.

Let's see how these visual images work. Formally, they work by creating a point of view outside the Universe, and treating the Universe as an object in the field of vision. We imagine that it's just a generalization of a bird's eye view of space. We all know how a bird's eye view works.

Figure 7.9 is a bird's eye view of a soccer field.

A bird's eye view is not a view from *outside of space*. It's a view from outside a two-dimensional surface that utilizes the third dimension of space. There *are* such points of view and they are points of view that an observer could literally occupy. But when we generalize this idea of a bird's eye view, we do it in ways that *can't* be interpreted as literal truth. That's not by tiself a bad thing. We do it in physics all of the time. These are the little falsehoods that grease the wheels of science. We turn a problem we can't solve, or a situation we can't depict, into one we can by fudging in ways that don't matter AQ2

Figure 7.9 Bird's eye view of a soccer field
Source: © Shutterstock/Can Berkol.

for the purposes at hand. We just have to keep track of the little lies to make sure that we aren't drawing conclusions that depend on them.

Figure 7.10 shows a bird's eye view of the solar system.

What we are doing here is projecting the solar system (which is the system we want to depict) into a plane (a two-dimensional surface) and then looking down on it from a point of view outside. So we are pushing the whole system into the field of vision by suppressing depth, and then casting ourselves in the (fictional) position of someone looking from a point in an external dimension. This isn't a terrible distortion at the distances depicted, because the farther away from the solar system we get, the more accurate it will be.

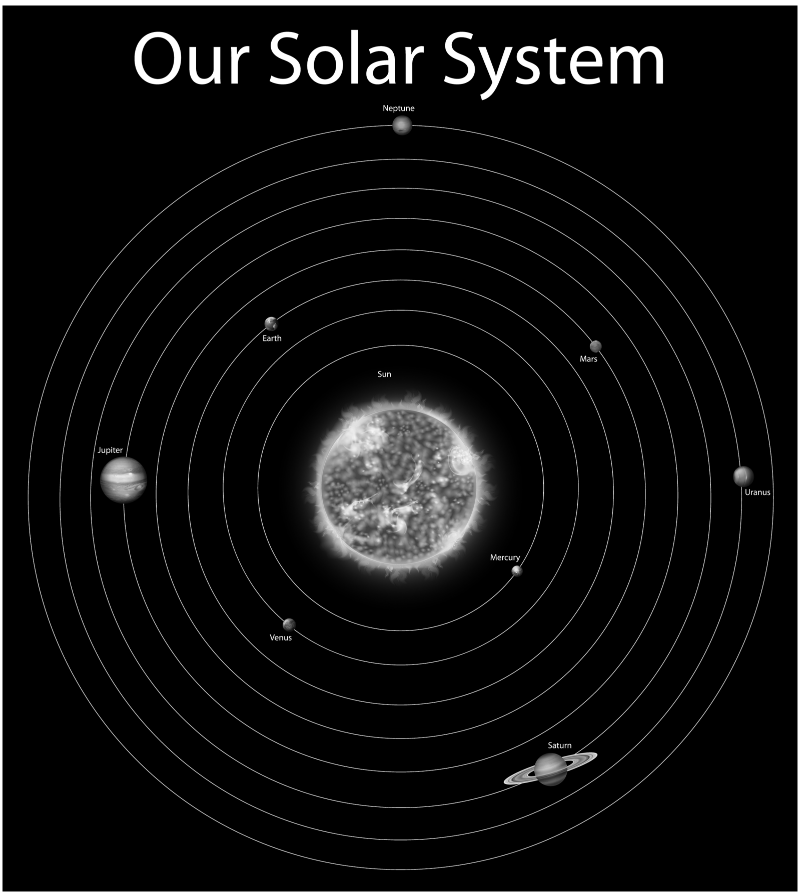


Figure 7.10 Bird's eye view of the solar system
Source: Freepik.com/bgrfx.

So far, we have just been looking at spatial dimensions. If we want to include time in a model like this of the Universe, we would usually set it in motion and see how it looks over an extended period. How the image changes in time would represent how the solar system changes over time. In that case, time remains external; outside the frame, so to speak. It is not depicted by any of the spatial dimensions inside the frame, but rather by how the image itself changes over time. What is represented inside the frame at any given moment is just the three spatial dimensions of the solar system.

Now we move to special relativity. This is where we start using spacetime diagrams and treating of time as one of the dimensions *internal* to the Universe (Figure 7.11).

So now, we are not just suppressing depth, we are suppressing *two* of the spatial dimensions in the image and using one of the spatial dimensions to represent time.

Representing time along a spatial dimension is nothing new. We do that when we write down time-lines or use calendars (Figure 7.12).

We do it with musical notation, where a temporal sequence of notes is represented by their spatial arrangement on the page (Figure 7.13).

In the four-dimensional image, we are combining it with the spatial dimensions and looking at the geometry of the whole manifold. The reason that we move to this four-dimensional representation is (as I said) that it turns out to be the way of representing relativity that most perspicuously reveals its content. There are some differences in the geometry of a special relativistic and pre-relativistic universe, but we could just as well represent the content of relativity without using these kinds of four-dimensional

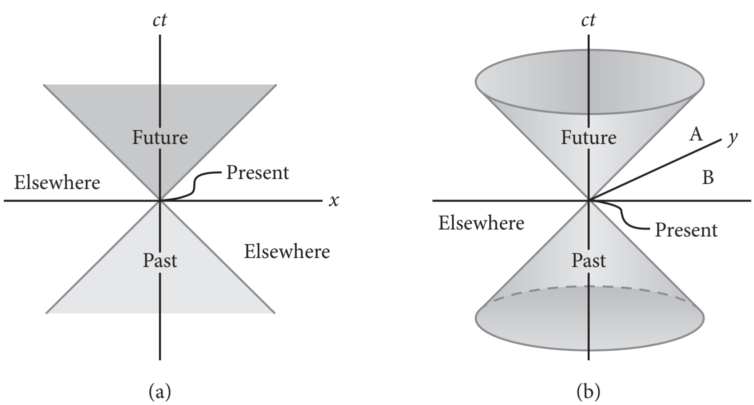


Figure 7.11 Special Relativity

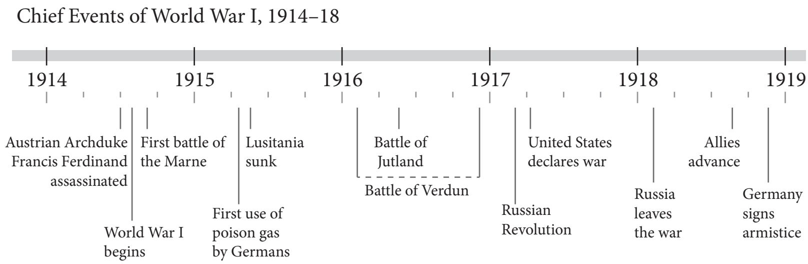


Figure 7.12 Timeline of events related to World War I

Figure 7.13 Musical notation

Source: © Shutterstock/Ariel Schrotter.

images (e.g. with coordinate representations or algebraically), and we can represent pre-relativistic physics using them as well. The four-dimensional image itself is just a way of representing space and time that is flexible enough to let us represent the full range of ways that space and time might relate to one another and to compare them with one another.[9]

It wasn't Einstein who actually came up with this way of visualizing the content of his theory. He was still using the clumsy apparatus of reference frames in the paper in which the special theory of relativity was introduced. It was Herman Minkowski (a mathematician in Konigsberg and a teacher of Einstein's in his undergraduate days), who introduced it two years after the publication of the theory. Einstein resisted the new formalism at first but the four-dimensional vision was embraced by the rest of the physics community and it quickly became the canonical way of presenting special relativity.

Since the spacetime of special relativity is flat and infinite in every direction, one doesn't often see visual representations of the Universe as a whole in that setting. What you see are light cone diagrams drawn over parts of spacetime or comparisons of the trajectories of different systems in spacetime.

Figure 7.14, for example, illustrates trajectories of material objects and light in Minkowski spacetime.

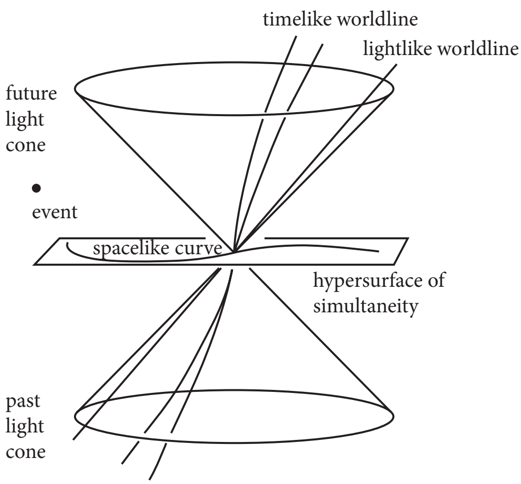


Figure 7.14 Trajectories of material objects and light in Minkowski spacetime
Source: NASA/LAMBDA Archive/WMAP Science Team.

[9] When things are represented in this four-dimensional way, new possibilities open up and the relativistic geometry comes into view.

With general relativity, things are different. In Newtonian mechanics and special relativity, spacetime is the fixed background against which the dynamics plays out. In general relativity, space is curved. The field equations (which are the central equations of the theory) relate the curvature of space to the matter content. In this setting there is a lot of interest in specifically global geometry. Spacetime as a whole becomes the focus of interest. There is a variety of solutions to the equations with different global geometries. The equations are prohibitively difficult to solve, but the simplest solutions were discovered quickly in the years after the theory was published and they are enough to give a qualitative sense of the differences in global geometry. Although in empirical terms, we don't really know what the global geometry of the Universe is, there is what is called the Standard Model of cosmology that gives the best current understanding. You have probably encountered it in some form. Figure 7.15 shows a familiar image of the Standard Model, with the Big Bang singularity in the past and accelerating expansion.

Don't mistake this for a view of space. It presents a four-dimensional view in which time itself is portrayed as one of the dimensions explicitly included. In spacetime diagrams, time is usually represented vertically going up the page. Cosmology uses a different convention, with time going along the horizontal axis. So the bright spot on the left is the Big Bang and the widening as we move along that axis represents the expansion of space.

Two things have happened in the image in Figure 7.15:

(1) The Universe as a whole, *including time*, has been pushed into the content of the image. From the time (at least) of Aristotle through Newton when people talked about the Universe, they would have meant a spatially extended thing. They would have thought of it, that is to say, as a very big object. Time would have been left outside the frame, as the parameter in which the very big object evolved. This image includes all four dimensions. We saw the beginning of this in special relativity, where time was pulled into the content of the image, but there was no attempt in special relativity to represent spacetime as a whole;

(2) The self, or the observer, has been *ex*cluded from the Universe (and placed in imaginary external dimension). You (the person looking at the image) have been taken out of the Universe and cast implicitly in the position of someone looking at all of space and time from a point of view outside.

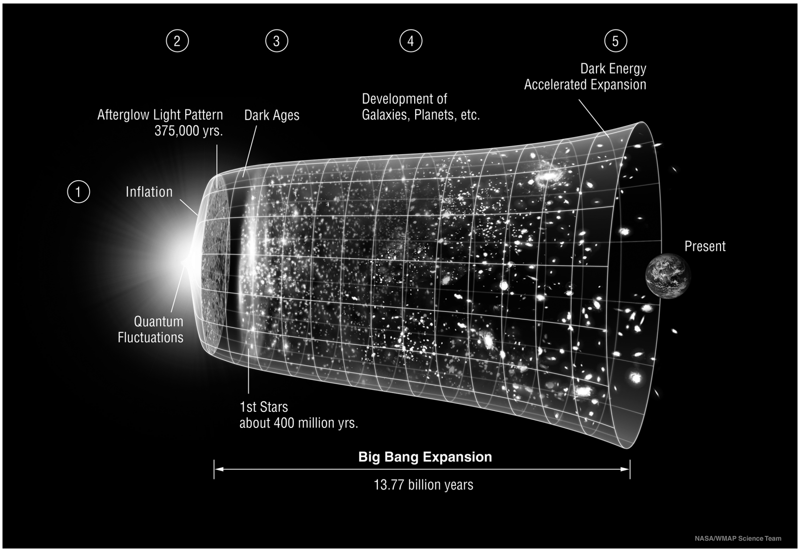


Figure 7.15 Big Bang singularity in the past showing accelerating expansion

So, there we are. We now have a way of thinking about the cosmos as a whole—all of space and time together.

Physicists and philosophers, when they think about the cosmos in this extended sense, lean imaginatively on images like this. This is what we do to stabilize the Universe as a whole as an object of thought. It is probably what you would have called up if I had asked you what sort of image you have in mind when thinking of the Universe. This external view of the cosmos is sometimes a God's eye view of the Universe, and that accords nicely with the traditional idea that God is outside of space and time.

You should be struck or impressed, or perhaps stirred, that creatures like us, with our limited view of a tiny part of this unimaginably vast totality, should have a theory with that kind of scope. It is amazing, if you think about it, that we can pull all of reality somehow into the content of a thought trained on an object that falls squarely within our field of view.

5. The Problem

The problem with all of this is that it is disastrously and trenchantly misleading. All that we have really done is created a low-dimensional representation *of* (space and) time *in* (space and) time. And we've done it by artificially creating a point of view outside of space and time from which it could supposedly be seen. In reality, there is no external dimension and hence no point outside of space and time from which one could even *formally* construct of a point of view. All that exists is spacetime itself.

And what people on both sides of the time wars—Block Universe enthusiasts and friends of becoming alike—do when they say things like that on a four-dimensional representation the future is *already* there, it *already* exists, or that the Universe is static, is make an almost silly mistake. They conflate the time in which the image is *embedded* with the time that is *depicted* in the image.

They are looking down at an image *of* time *in* time and judging not from the point of view in the internal time depicted in the image, but from the point of the view of the external time in which the image is embedded: the time in which they (creators and users of the diagram) are themselves located.

When you watch a movie or a play, there is the internal time-line of the story and the external time in which the movie is embedded. If you watched a movie of Nixon's life and marveled that it took him twelve minutes to complete law school, you'd be making a mistake because it took twelve minutes in your time frame, but four years in the internal time-line of the movie. In this case, the movie itself has some duration and the story unfolds as you watch.

In spacetime diagrams time is represented by one of the spatial dimensions, so there is no 'unfolding' in that sense. But one should still judge things by the internal time-line of the image, and if one is going to interpret that content of the image correctly—i.e. if one is going to interpret it so that what is depicted in the image is time itself—then it is simply false that the future is there *already*. In a four-dimensional representation, things happen when they happen and at no other time, just as they do in a three-dimensional representation, and just as they do in life. Nor is there a point of view from which your future could now be visible to an appropriately situated observer. There is no point outside the manifold from which one could even *formally* construct a point of view. And the *now* in that phrase, if it refers to the internal time of our world, doesn't make any sense. Your future is visible from the future for beings in the future, and nobody else.

Those are confusions that come from creating an image of time *in time*, and then looking down at it and judging things from the perspective of the embedding time. In literal fact, there is no time outside of time and there can be no question of whether time itself is static or changing. The pictures one sees in philosophical discussion of the whole four-dimensional manifold growing or evolving implicitly embed the manifold in an external time-like dimension which has no actual physical analogue.

The mistake is easy to diagnose but it is incredibly hard to exorcise. Even when it is pointed out, it tends to persist in the most resilient way. Because we are viewing the images in real time, it is almost irresistible to think that there must be a meaningful question about whether the object portrayed is static or changing. But the object portrayed here is time itself. The very distinction between static and changing invokes an external time, and the literal content of our theories recognizes none.

6. Time from the Inside; How the Mind Makes Music

How then, are we to recognize in these images time as we know it? Where, in this picture, are we to find change? Where is the passage of time? Where is the familiar flux of everyday life and the surge of process? Where, in short, are all of the things we think of as essential to time as we encounter it in experience? When friends of becoming ask these questions, they ask them as objections. The rhetorical force of the question is supposed to be that these things have somehow disappeared from the conception of time that physics is asking us to accept.

There is, however, an answer. The answer is that we find them on the *inside*. We recover the familiar flowing time of everyday sense by seeing how things look from the point of view of an inhabitant of the Universe whose life is extended in time. We recover it, that is to say, by seeing how time looks not from the point of view of a fictional creature occupying a non-existent standpoint outside of time, but from the real point of view of a creature *in it*, a creature who experiences time as we do: second by second, minute by minute, and day by day. And thinking through in detail *how* that works is very illuminating. It teaches us something about where all of the things that are so central to our experience of time come from. It teaches us something about the change, the flux, the development and growth. It teaches us something about the sense in which our lives, and the Universe in which they are embedded, *unfold*.

The fact that we experience the world from inside means two things. It means that how things appear to us at a time is implicitly relativized to the moment from which they are viewed, and it means that over time, our view changes. The most direct formal analogy to change due to change in point of view, is changes in how things look as you move around an object in space. When you walk around a stationary table, your visual experience changes but not because of any difference in the table, but because of the change in your point of view. And just so with time. Time itself doesn't change. Time itself is just the dimension in which the events of your life, and the larger history of the Universe, are laid out. But your point of view on time does change. You view time from different temporal standpoints over the course of your life, and because of memory—that is, because we accumulate information about our pasts and that guides how we think about the future—changes in temporal point of view make a big difference to our experience.

There is no better way to get a sense of this than to consider what it is like to listen to a piece of music.[10] If it's not a piece you've heard before, you start without memories or expectations of what is to come. Before the first note sounds maybe you don't even know if it a symphony, a piano concerto, or a pop song. Once the first note is sounded, some of those big questions are answered. That note is registered and recorded. Now you have at least some memory and some new expectation relevant to what will happen next. A second note is registered and added to memory. Your earlier expectation is confirmed. A new note is registered, compared against expectation from previous cycles, added to memory, a new expectation is generated, and new, more definite expectations begin to take shape. The cycle repeats, with memories accumulating and expectations becoming more definite. The mind begins to discern patterns and recognize motifs. It jumps ahead and completes a theme before the notes register. You form new memories at every stage and expectations based on those memories. Every note is encountered as part of a melody in progress, a partially recollected and partly anticipated whole, and the whole process is a drama rife with suspense, surprise, delight, disappointment, and recognition.

The notes themselves occur in the world one at a time. They are never there together in the world so to speak (co-present in time). It is in the memory and expectation of the subject that they are brought together on the larger scale of the piece as a whole, setting up the cross-temporal pattern

[10] There is a long history of looking at music in connection with temporal phenomenology. Husserl (1964) contains a very famous and beautiful discussion. Music involves a single sensory modality; in the simplest cases, it is non-representational; a musical piece forms a closed unit that can be listened to in a single episode. Musical experience is temporal experience distilled and purified.

of resonance and reverberation that makes them musical.[11] It is essential to the musical experience that listening *itself* is a temporally extended process, that is, that the song is revealed in stages and that the stages follow a particular order. Because the drama of the piece—the emotion and suspense, the crescendos and diminuendos, the tension and resolution—happens in the listener's mind.[12]

Without the listening mind, there are only notes distributed across time in the way that colors can be arrayed across a surface. It is in the listening mind that they come to life as music. It is the listening mind that hears the tune *unfold*, with each note building on what was there before and creating anticipation of what is to come. It is there that they become music. The music is not just the collection of notes arranged in a sequence, but the pattern of resonance created by the mind that brings the weight of memory and the force of anticipation to the perception of note. It is in the listening mind that notes meet one another and resonance is created. It is the listening mind that brings the opening to bear on the close and that experiences the close in the light of the climax.

The same is true, of course, in life. A mind fed by a steady stream of experience, remembering and anticipating (and remembering what it anticipated, and anticipating what it will remember) builds up a complex pattern of cross-temporal resonance that gives it a sense of unfolding. You experience your life unfolding in the way that you experience a piece of music unfolding, with each moment being encountered first in anticipation, then in experience, and finally in memory.

All of this makes it clear exactly why time has to be *imagined from the inside*, and imagined as it is lived, if it is going to be recognizable to us as the familiar time of everyday sense. If you want to grasp a piece of music, even if you encounter it first as a musical score (so, in a spatially rather than a temporally ordered form) you have to *imagine listening to it*. You have to imagine how it would sound if the notes were encountered in temporal sequence, in the order in which, and at the intervals, intended. Because

[11] You don't just remember what you experience, you remember what you anticipate, and anticipate what you will remember. It's not simply that the parts of the song need to be simultaneously represented in memory to permit apprehension of patterns and recurrences. That is available also to the person looking at a musical score and it doesn't matter, for purposes of perception of these regularities whether he reads the score front to back or back to front, though it does of course matter to the musical experience. A piece played backwards is an entirely different experience than a piece played forwards because memory accumulates from the beginning to the end and not in the other direction.

[12] For a fuller discussion see Velleman (1996), Ismael (2010).

what your mind does with the notes *as they are encountered* and in the intervals that separate them is essential to the musical experience. And so it is with time. If you want to recover time in a form that you recognize from experience, you have to imagine not looking *at* it, but living *through* it. Because what your mind does with the events of your life *as they are encountered* and in the intervals that separate them is essential to temporal experience.

In one sense, the music is there in the world as a collection of notes laid out in time. In another sense, however, and the one I'm inclined to emphasize, the music isn't there until it is encountered as a temporally ordered sequence by the listening mind. The listening mind is where the notes are brought into interaction to produce the rich pattern of resonance that seems essential to the music *as* music. The structure that gives meaning to notes by their relationship to other moments is in the mind of the listener, where one note follows another in a manner that is cumulative and directed.[13] These two senses don't compete. Both are essential to understanding the musical experience.

And so it is, I think, with the felt quality of a life lived in time. In the world, events cast a short shadow. One occurs, and it is gone when the next one does. Each event knows about (or has information about) only what immediately preceded it. In the human mind, events confront one another in large bodies. It is we who capture and record and bring passing events together in large bodies. And the temporality of our experience—the sense of passage, flux, unfolding, all of the things that make time seem so different from space—are not properties of time itself: they are the qualities that time evokes in the mind of the agent who lives through it. That doesn't mean passage and flow are illusory any more than music is illusory. It does mean that they are mind-dependent in some very specific ways. Time as we know it is, in part (as Hermann Bondi once put it) a 'manufactured entity'.[14]

[13] The accumulation and directedness come from the nesting structure that memory builds. There is no direction of accumulation in the sequence of notes in time one way to see that is that you could take the same set of notes, keeping all of the internal structure intact, and listen to it backwards. In that case, you would be unfolding the same structure in reverse direction. Unfolding has something to do with the direction of the process of revelation; it is the process of piecemeal revelation, in a setting where there is memory that gives a direction to the 'unfolding'. There is a physical question about what grounds the asymmetry of memory. This is something that has recently become to come into focus. See Albert (2000) and Rovelli (2018).

[14] Only partly; the ways the ways in which time is not mind-dependent are equally important and equally to be emphasized. To understand time fully, one needs to understand the time of physics and the time of human experience and all of the layers in between. Rovelli (2018).

7. Objections and Replies

Objection 1: Is this all that there is? Is there nothing more to the controversies surrounding the relativistic conception of time?

Reply: It's certainly not all that there is. But it is a source of real confusion that is fueling imaginative resistance to the relativistic image and obscuring the other issues. The one real innovation that special relativity introduces in the geometry of spacetime is that there is no global present. What that means is that the intrinsic geometry of spacetime doesn't support the idea that there is an objective fact about which distant events happen at the same time.[15] Indeed, this is why in order to portray the relativistic geometry, we move to the four-dimensional image.

Whether there is a global present in this sense, however, can have no direct impact on temporal experience. It doesn't affect the localized form of becoming that I described above. It introduces an asynchrony between the world-lines of distant observers, but the asynchrony is too small to be detected at everyday speeds and distances.[16] Your life unfolds in a relativistic universe, just as it did in a relativistic one. My life unfolds, as do the lives of trees and frogs, and songs. The Universe is a collection of processes unfolding more or less in tandem depending on distance and speed, but there is no single globally defined time that stretches across the Universe as a whole. The everyday experience of unfolding and change and passage—the everyday kind of Becoming that we have good reason to believe in—has nothing to do with whether there is a *global* present.

A somewhat different issue that is often raised in opposition to the relativistic image is the question of whether there ought to be some objective fact of the matter about which moment is *now*. 'Objective' is understood here specifically to mean a non-perspectival, non-relational fact; a fact visible from a god's eye view, as they say; not a fact about which moment is now *at p* or which moment is now *at q*, but objectively, non-relationally *now*. The thought seems to be that the relational facts are eternally fixed (it is true at all times and places that every moment is *now* relative to itself and not relative to other moments),[17] so they can't do justice to the idea that at any given moment in your life, there is exactly one moment that is now.

[15] This is the innovation of the special theory. General relativity introduces additional innovations, making spacetime dynamic and dependent on the matter distribution.

[16] See Ismael (2017).

[17] Or rather, in the relativistic regime, every point is here-now relative to itself and not relative to other points.

Which moment that is (moreover) *changes* with time. This movement of the rolling present over the moments of history—that is, this ever-changing shift in which moment is *now*—is (we are told) the passage of time. The passage of time is said to be essential to time as we know it and missing from the relativistic image.[18]

The right reply to this is that it is nonsense. If we are going to make sense of now, and if we are going to make sense of passage, we have to make sense of them from the perspective of the embedded observer. From the embedded perspective of any person at a specific moment in her life, there *is* undeniably and non-relationally, a particular moment that stands out as now. And that moment changes in the straightforward sense that it is different at different points in her life.[19]

Objection 2: Not everybody thinks in pictures. Some people think algebraically; some people think in words. Why do you focus so much on the relativistic *image* of time?[20]

Reply: There are reasons endemic to the subject that spacetime physics is more amenable to visualization and I focus on it because it is the source of the mistake that I'm interested in here. Since Minkowski, geometry has been the focus of spacetime physics and the content is most naturally carried by diagrams. In special relativity, trading the clumsy use of coordinate systems for Minkowski's geometric representation was a huge leap forward in terms of understanding the physical content of the theory. Computations are very often geometric. One can come to understand time dilation and length contraction, the Twin Paradox, or the funny behavior of time at the horizon of a black hole, for example, by seeing the way that world lines are shaped, bent, or stretched in the presence of massive objects. In general relativity, the equations are simply too hard to solve explicitly and calculation simply won't get you very far. The most powerful results forego calculation almost entirely. Roger Penrose's seminal results, for example, which really revolutionized work in general relativity,

[18] This is the kind of thinking behind Mctaggart's argument for the unreality of time Mctaggart (1908). Mctaggart introduced it as an inconsistency at the heart of our temporal ideas. He argued that the tensed, dynamic notion of time that people associate with Becoming is incompatible with the untensed conception of a network of fixed temporal relations among events. Historically, reactions to the argument have ranged from simple dismissals as a logical confusion to a deep and unanswerable proof that our temporal concepts are incoherent. I share the view that the argument is confused and the reason for its tremendous influence is that it puts formally the imaginative difficulty of finding passage in the world when looking from an external perspective.

[19] A more formal treatment of this response can be found in Ismael (2017).

[20] This is an objection suggested by Philip Kitcher.

emphasize conformal and causal structure. The notion of a closed trapped surface and the reasoning that led to his 1965 singularity theorem was geometric through and through.[21]

There are large areas of physics in which images play little role, of course, and large areas of human thought in which in which it is words not pictures that are guiding the imagination.[22] In those cases, we are not tempted to think the representation should bear a resemblance to what is represented. Even in those areas, however, we are transforming a higher order pattern recognition problem into one that the biological brain can deal with. Language and algebra are acquired skills, artificial overlays for brains made to navigate bodies through space and our capacities for both to some extent piggyback on those.[23] We learn to calculate by writing down numbers on a page and moving them around. Mathematical vocabulary is often spatial; you *carry* numbers over, you raise numbers to a higher power, you move and manipulate them in ways that correspond to mathematical operations. The external aids go away eventually, but only for simple calculations and even then they are often retained imaginatively. Take the paper and pen away from many mathematicians and you cripple them. There are larger issues in the background here about the role of external aids—words, diagrams, symbols—in guiding the mathematical and physical imagination. The especially intriguing suggestion of the work on chimp cognition mentioned above is that the ability to think about something abstract and intangible—something like entropy, inflation, spacetime—may be bound up with the ability to create concrete visible or tangible aids. Those external aids are playing a number of different roles—stabilizing abstract concepts or quantities as an object of thought, allowing us to combine them with others to form new thoughts in a kind of open-ended ratcheting up of complexity, facilitating computation, and so on.[24] The delicate question is to understand explicitly what 'bound up with' amounts to. Whatever the right characterization of that relationship is,

[21] Penrose (1965).

[22] There's a rich body of psychological research on the ways in which spatial thinking is exploited in thinking about abstract matters from time to social relationships. Boroditsky (2000), Tversky and Lee (1998, 1999), Tversky (2005, 2011), Tversky and Suwa (2009), Tversky et al. (2013).

[23] Giaquinto (2007, 2008).

[24] Clark (1998). The case that I've spoken of—exploiting the rich representational properties of space together with our native pattern recognition abilities to render spatiotemporally distributed patterns visible—is a particular example of just one of those roles. But it is also the one that is most apt to lead to confusion. Perhaps it is the explicitly conventional nature of words and symbols, but nobody looking at Y (the Greek letter often used to symbolize the quantum state of the Universe) is apt to mistake it for what the Universe *looks like*.

there's no question that the ability to create such representations is one of the most powerful tools in our cognitive arsenal and a strategy that we exploit with great effectiveness in physics.

8. Conclusion

Our minds are made to process spatial information. We recognize first order patterns just by looking and physics exploits those native capacities for pattern recognition by giving us images whenever it can. Images play myriad roles. They help us understand by depicting a set of higher order relationships in a form that we can grasp immediately. They help us compute by translating a computation into a question of spatial manipulation. Perhaps most importantly from a philosophical point of view, images lend imaginative content to what our models and theories are telling us about the world.

The physics of space and time, in particular, is awash in images. The problem with some images is that they lead to some very specific kinds of confusions having to do with time. The introduction of the relativistic image of time led to claims that relativity shows that time is static, that the passage of time is an illusion, and then to a backlash from people who insisted that physics had lost contact with everything essential to time as we know it. And so began the time wars that have raged for over a century now.

Could this all be just a matter of being fooled by a picture? Not *just*. But it is the source of one of the strongest philosophical arguments against the relativistic conception of time: viz., that it represents a world radically at odds with our experience. We are movers through space and our feeling for motion is as rich and dynamic, as alive and pulsating, and as different from the t dimension in a spacetime diagram as the musician's concept of music is from the line of notes along a page. Anybody looking from the outside and failing to recognize the familiar time of everyday sense in the t dimension of a spacetime manifold is to be excused. But it is a mistake to expect that time should look from the outside the way it feels from the inside. Our experience isn't *of* time; it is in time.

Time is not something that we look *at*. It is something that we look *out of*. And if we want to find something in physics that answers to the familiar flowing time of everyday sense, we should see what relativity tells us about how time would look not from the imaginary perspective of an agent outside the Universe, but from the inside, through the eyes of the embedded observer.

If it seems strange to say that something that presents itself as a deep philosophical controversy really comes down to the (mis)-interpretation of an image, I think that is testament to the powerful, and perhaps ineliminable, role that images play in guiding the imagination.

References

Albert, David, *Time and Chance* (Cambridge, MA: Harvard University Press, 2000).

Boroditsky, Lera, "Metaphoric structuring: understanding time through spatial metaphors", *Cognition* Apr 14;75(1) (2000): 1–28. doi: 10.1016/s0010-0277(99)00073–6.

Clark, Andy, "Magic Words: How language augments human computation", in P. Carruthers and J. Boucher (eds.), *Language and Thought: Interdisciplinary Themes* (Cambridge: Cambridge University Press, 1998), pp. 162–183.

Emery, Nina, Ned Markosian, and Meghan Sullivan, "Time", *The Stanford Encyclopedia of Philosophy* (Winter 2020 Edition), Edward N. Zalta (ed.), URL = https://plato.stanford.edu/archives/win2020/entries/time/.

Giaquinto, Marcus, "Mathematical Thinking: Algebraic v. Geometric?" DOI:10.1093/acprof:oso/9780199285945.003.0012 (2007).

Giaquinto, Marcus, *Visual Thinking in Mathematics: An Epistemological Study* (Oxford: Oxford University Press, 2007).

Giaquinto, Marcus, "Visualizing in Mathematics", in Paolo Mancosu (ed.), *The Philosophy of Mathematical Practice* (Oxford: Oxford University Press, 2008), pp. 22–42.

Giaquinto, Marcus, "Cognition of Structure", in Paolo Mancosu (ed.), *The Philosophy of Mathematical Practice* (Oxford: Oxford University Press, 2008), pp. 43–64.

Husserl, Edmund, *Phenomenology of Internal Time Consciousness*, First English language edition (Bloomington: Indiana University Press, 1964).

Isaacson, Walter, *Einstein: His Life and Universe* (New York City: Simon and Schuster, 2007).

Ismael, Jenann, "Temporal Experience", in Craig Callender (ed.), *Oxford Handbook on Time* (Oxford: Oxford University Press, 2010).

Ismael, Jenann, "Passage, Flow, and the Logic of Temporal Perspectives", in Christophe Bouton and Phillippe Hunemann (eds.), *The Nature of Time, The Time of Nature* (Chicago: University of Chicago Press, 2017).

Mctaggart, John E., "The Unreality of Time", *Mind*, 17(68) (1908): 457–474.

Newton, Isaac, 1642–1727. *Newton's Principia: The Mathematical Principles of Natural Philosophy* (New York: Daniel Adee, 1846).

Penrose, Roger, "Gravitational collapse and spacetime singularities", *Physical Review Letters*, 14 (1965): 57–59.

Penrose, Roger, "On the Gravitization of Quantum Mechanics 2: Conformal Cyclic Cosmology", *Foundations of Physics*, 44 (2014): 873–890.

Rovelli, Carlo, The Order of Time (New York City: Riverhead Books, 2018).

Savitt, Steven, "Being and Becoming in Modern Physics", *The Stanford Encyclopedia of Philosophy* (Fall 2017 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/fall2017/entries/spacetime-bebecome/>.

Schmidt, Susanna, Carla Tinti, Micaela Fantino, Irene C. Mammarella , and Cesare Cornoldi, "Spatial representations in blind people: The role of strategies and mobility skills", *Acta Psychologica*, 142(1) (2013): 43–50.

Thompson, R. K. and D. Oden, "A profound disparity re-visited: Perception and judgement of abstract identity relations by chimpanzees, human infants and monkeys", *Behavioural Processes*, 35 (1996): 149–161.

Thompson, R. K., D. L. Oden, and S. T. Boysen, "Language-naive chimpanzees (Pan troglodytes) judge relations between relations in a conceptual matching-to-sample task", *Journal of Experimental Psychology: Animal Behavior Processes*, 23(1) (1997).

Tversky, Barbara, "Functional significance of visuospatial representations", in P. Shah, and A. Miyake (eds.), *Handbook of Higher-level Visuospatial Thinking* (Cambridge: Cambridge University Press, 2005), pp. 1–34.

Tversky, Barbara, "Spatial thought, social thought", in T. Schubert and A. Maass (eds.), *Spatial Schemas in Social Thought* (Berlin: Mouton de Gruyter, 2011), pp. 17–38.

Tversky, Barbara and P. U. Lee,"How space structures language", in C. Freksa, C. Habel, and K. F. Wender (eds.), *Spatial Cognition: An Interdisciplinary Approach to Representation and Processing of Spatial Knowledge* (Berlin: Springer-Verlag, 1998), pp. 157–175.

Tversky, B. and P. U. Lee,"Pictorial and verbal tools for conveying routes", In C. Freksa, and D. M. Mark (eds.), *Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science* (Berlin: Springer, 1999), pp. 51–64.

Tversky, B. and M. Suwa,"Thinking with sketches", In A. Markman (ed.), *Tools for Innovation* (Oxford: Oxford University Press., 2009), pp. 75–84.

Tversky, B., J. Heiser, and J. Morrison,"Space, Time, and Story", in B. H. Ross (ed.), *The Psychology of Learning and Motivation* (Cambridge: Academic Press, Elsevier Inc., 2013), pp. 47–76.

Velleman, J. David, "Self to Self", *The Philosophical Review*, 105(1) January (1996): 39–76.

Wheelwright, Philip, *The Presocratics* (Indianapolis: Bobbs-Merrill, 1960).

Author Query

AQ1: Please provide text call-out for the figure 7.1

AQ2: Please confirm if the spelling tiself is fine here.