

Questioning the Foundations:
Which of Our Basic Physical Assumptions Are Wrong?

There may be a false assumption in the Minkowskian geometry that led to block time, which disagrees with quantum theory on whether the future already exists. A short look through the clues about time.

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Abstract

Work on quantum gravity has highlighted some inconsistencies with time, and there may be a false assumption in our overall view of time. In a short look through the clues, here it is shown that the two levels of time we seem to find in physics, block time and the apparent motion through time, can't both be real. Given the fundamental unpredictability of small-scale events in quantum theory (widely accepted for eighty years) the two levels disagree over whether the future is already decided, and whether the future already exists. Assuming that only one level is real leaves two possibilities. Both are examined, and the essence of the Rietdijk-Putnam argument, which led from Minkowskian geometry to block time. Some of the clues, such as the permanent age differences between objects left behind by time dilation (which have been measured very accurately recently^[1]), are not well addressed in views in which motion through time doesn't exist. Special relativity (SR) has been extremely well confirmed by experiment, but the spacetime interpretation has not, and because it defines time as a dimension different from the others in some ways, time could also be different in other ways. These two points make a false assumption in the Minkowskian geometry possible. Even a minor one could remove block time, leaving a dynamic universe as in quantum theory.

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Introduction

The problems with time are central in physics, and need a solution. But we can't even agree on whether time exists - the 2008 FQXi essays on the nature of time vary widely. When physicists disagree about whether or not a phenomenon exists, as they did with the aether, one possibility is that something like it exists, but not very like it. This allows both views to seem right. With the aether, by 1950 the *question* had changed - George Gamow wrote that many physicists now thought it was space itself that vibrates when light travels. This was a different kind of medium from the one being talked about before, and could partly explain both earlier views. I'm going to argue that time is rather the same.

Many of the 2008 essays look at how time can be defined in the mathematics, or suggest ways forward within theories. To me it's initially a conceptual problem, needing a view of time that can explain specific conceptual clues. Block time has an odd habit of making people think these clues are unreal. But because they might be real, the first thing is to look at them with the mathematical landscape set to one side.

Some of the clues are hard to fit into our present picture. But they might be needed - from the quantum gravity coalface, Lee Smolin is well known for saying *"I believe there is something basic we are all missing, some wrong assumption we are all making... More and more, I have the feeling that quantum theory and general relativity are both deeply wrong about the nature of time. [...] We have to find a way to unfreeze time."*^[2]

There's a need to look at the holes in the jigsaw, and allow for them. There are missing pieces. The nature of time may well include elements outside our present ideas, that we haven't yet found. But if that's so, then it's possible that one or more of our present assumptions is false. And yet block time *depends* on these kind of assumptions, such as those in Minkowskian geometry. These are untested (and some are near to untestable, because assumptions would have to be made about the experiment). But even a minor difference to the rules about simultaneity at a distance, for instance, could remove block time. So I'll start by setting out a general possibility.

Recently people have been questioning the spacetime interpretation. For instance Lee Smolin and colleagues published a paper on phase space and momentum space^[3] in 2011, and Hořava gravity, which takes spacetime apart and reinstates Newtonian time at high energy levels^[4], caused widespread interest in 2009.

When the early assumptions were made, Minkowski was defining time as a dimension, and he made the new dimension as similar to the others as possible. But it still wasn't very similar, and with the differences, it's not really comparable to anything else we know about. This conceptual isolation makes it more likely that as well as (or instead of) the differences we've accepted, there might be other differences we haven't yet found.

But Minkowski's interpretation worked very well mathematically, and was self-consistent. People also found significance of an unscientific kind in the wider picture that went with it. At the time there was far less reason to question it than there is now.

A century later we know a lot more about the physical world, but we still don't understand time.

We may have been held back by too often assuming that Minkowski's assumptions about the time dimension are inseparable from SR. But a theory can be absolutely right without its interpretation being right, and only the core of SR has been confirmed by experiment.

The fact is, every time someone assumes block time is right, they're assuming Minkowski assumed right - about something we simply don't understand. The reason he may have been wrong is that physics is full of equivalence. Often more than one conceptual picture is described by similar mathematics. So the true picture could be widely different from what we imagine, or perhaps only slightly different. Either would be enough to make block time false, and so explain the present confusion about time.

1. Two levels of time

Many physicists have an odd idea implied in their picture of the world. It's the idea that with time, there are two levels that somehow co-exist independently.

In the block time picture, which comes out of Minkowski spacetime, and was eventually proved to do so via the Rietdijk-Putnam argument^{[5][6]}, motion through time looks like an illusion, and nothing moves through time at all. The universe is a motionless 4-dimensional block, with no moment called 'now' moving through it anywhere. Instead it has many events and equally important 'now' moments, all sitting alongside each other in a static spacetime grid. This unchanging object it is just *there*.

But at another level this object has motion through time in it. Somehow time and change emerge from this frozen picture, it becomes possible for a mass to have a speed relative to another mass, and laws of motion appear. And then other physical laws, which also depend on there being a timeline (or rather, many), and behind them fundamental principles like cause and effect, which also depend on a timeline. And as the universe we observe appears, the one that constantly changes and develops, what emerges effectively includes what we call physics.

Now although we can't yet see how these two different levels of time could co-exist, it might seem very reasonable to assume that they somehow do. Many believe there is some deep-rooted psychological illusion that we all share, which gives the appearance of these adjacent 'now' moments being run in a sequence. But when they are run in a sequence, it looks very much like what we call *sense* appears, and they seem very predisposed to being run in that way. So because consistent physical laws emerge, it seems that something more fundamental than an illusion is happening.

So perhaps the two levels co-exist in some other, as yet unknown, way. Much of our science really depends on the idea that they do. No-one has found a way out of the reasoning that led to block time, but some physicists don't invoke illusions to explain motion through time (which to me is a bit like filling in the empty spaces on the map with 'here be illusions'). Instead, many leave the unexplored areas blank. This sometimes means taking the two levels to be part of the nature of the time dimension itself.

The reason there seems room for this possibility is that we see time as a dimension very different from the others. John Wheeler once summed up the relationship between time and the other dimensions in six words - *"equal footing yes, same nature no"*^[7]. The 'equal footing

yes' is because time seems to be in the geometry along with the others. The 'same nature no' is a real problem, because there's nothing to compare time with.

So during the early 20th century, when the list of differences from the other dimensions was growing, anything we didn't understand about time would tend to get put on the list. And *the actual nature of the dimension* became a bit of a dumping ground for the unexplained. It still sometimes absorbs whatever needs absorbing - contradictions, problems, questions. But that leaves a view full of assumptions, and using a minimum of assumptions is one of the basic principles.

Nowadays many think the time dimension is static at one level, but has a kind of motion on it at another, though this motion is not like motion through space. It's a kind of motion that is conceptually undefined enough to exist when we need it to exist, and to disappear when we need it to go. At times it remains in a state of both existing and not existing (reminiscent of the overlapping states in quantum theory). The split level this implies looks like simply part of the dimension, and on the face of it, it might be. But on closer examination, the idea that these two levels co-exist starts to fall apart.

At the 'everyday' level, at which we have motion through time, there's quantum theory. The idea of hidden variables goes against some fundamental elements of physics, and the large majority have accepted for eighty years that there's an intrinsic randomness about events at the particle scale. Until after an event has happened, there's no way to know exactly what will happen, and it seems that what will happen doesn't yet exist. And as all larger events are made up of these smaller events, this suggests the future doesn't yet exist, and is still undecided. It's hard to argue that the future already exists at larger scales, but not at smaller scales. Any causal connection across scales would make that impossible, and (rather like the butterfly effect), a little would go a long way. So quantum theory shows us an unfixed world, which potentially allows us to be affecting events around us, and altering the future, as we seem to be.

But Minkowski spacetime leads to a picture in which the future is already laid out, and utterly unalterable. So of the two levels of time, at one the future already exists, but at the other it doesn't. In the light of this direct contradiction, it seems a reasonable conclusion that both levels can't be real - they contradict each other too deeply, and can only be accepted together in an approach that is not what we call physics (unless alongside a hidden variables view of quantum theory). To me this contradiction, along with others about time, means that one level is real and the other is not.

2. Possibility I. Block time is real, motion through time is not

Those who invoke illusions think the same thing. They also think that only one level is real, and to them the real level is block time. But in taking that view, the number of phenomena that must be demoted to unreal is large. It amounts to anything that could be called a *process*, and that includes a lot of our world.

And in the view that there's an illusion at work, it's not clear that the number of illusions can be kept down to one. To explain what we observe, that approach is seen by some as needing two separate and interacting illusions. The first, for motion through time, is often seen as a deep-seated psychological phenomenon, which living creatures have evolved with built in from the

start. The second, for time dilation, is sometimes seen as analogous to a 4-dimensional perspective-type effect. Some think this second illusion distorts the first one.

The psychological illusion, if it one, is well synchronised. We all seem to share the same effect, and a shared illusion, such as a rainbow, can be expected to have an external physical source. So a physical mechanism is still needed - loose suggestions have been made, such as the mind having somehow latched onto the direction in which entropy increases, at an early stage.

Invoking unexplained illusions is an extreme measure, but if it at least fixed all the problems with time, then it would look better than it does. But that approach still leaves problems and contradictions, and the best it can do with some of them is to imply that they're unreal.

The analogy with perspective, for the second illusion, is far from being a close one. Our 3-dimensional perspective effect is well understood, and makes distances look shorter. If a horizontal pencil is turned away from the viewer and angled into a third dimension, it looks shorter. The effect takes something real and distorts it, leaving no traces afterwards. When the pencil is returned to its original position, the effect disappears.

But time dilation does the opposite, whether or not it's a 4-dimensional equivalent of this effect. If motion through time is an illusion, time dilation would seem to be an effect that takes something *unreal* - motion through time - and distorts it. *And yet it does leave traces afterwards.* We find that time dilation leaves behind it permanent age differences between objects.

3. Possibility II. Motion through time is real, block time is not

So it's worth examining the other possibility, which is that of the two levels, the one with motion through time is the real one. When objects accumulate elapsed time at different rates, permanent age differences remain. This is suggested in experiments that compare clocks that have moved differently or have been at different heights in a gravity field, which have got very accurate recently^[1].

It's not so much that these lasting traces make time dilation look real. It's that they make motion through time look real. Whatever motion through time is, it seems to happen at different rates in different places, and the age differences that remain when objects are brought back together suggest it may be more than an illusion.

And special relativity, although its present interpretation seems to lead to no motion through time, is full of motion through time. SR describes a moving, shifting world, like the surface of some ocean. Everything is in a state of flux - time rates shift, the masses of objects shift, things get distorted in relation to each other. Moving objects are spread out across space in a complex network of simple relationships, and almost everything keeps on changing and moving through time. And for some reason the speed at which an object is seen moving affects the rate at which it seems to be changing.

Perhaps all this motion through time and change is real. Or perhaps the universe is a 4-dimensional block - *either way* we don't yet understand the effects between us and what is underneath what we see. But the deduction here suggests that what is underneath what we see is real, and that motion through time is real. One question is what happens to these lasting age

differences between objects in the block time picture. One might expect them to disappear when the universe is looked at in that way, but traces remain.

In block time, in the same way that a cube has many slices, the universe has many adjacent moments. But unlike with the cube, these slices are not even, and the block has a strange uneven 'grain' within it, the result of all the time dilation due to motion. When objects move differently and come back together, the time slices are irregular around where they travelled through space. If there's no moment called 'now' moving along through the block anywhere, then it's hard to explain why this uneven grain is there.

4. An area left to one side

The main reason block time was left to one side in the 20th century was that no-one could find a way on from there. It took sixty years to find a rigorous proof that spacetime leads to it, but the result was well known before that. So by the time block time became officially certain in the standard picture, in 1966, we were already immersed in it. But if instead the proof had been found in 1910, before people were used to spacetime, the whole set of ideas might have been questioned far more than it was. And the inevitability of all events - such as our species evolving and going through the exact history that it has - also might have been questioned more than it was (that is, if anything could have been different).

Instead the questions were often set to one side. No-one wanted to investigate an illusion, but the fact that it might exist made the difficulties less real. Like the nature of the time dimension, the illusion absorbed questions and problems. And because time is so hard to define, it was sometimes possible to adjust the definition until the problems seemed to be reduced.

What made me question things was that if motion through time is an illusion, then the laws of physics seemed to exist within it. But to some it seemed that the two levels of time might co-exist as part of the dimension, allowing the principles of science to quietly go on applying at a different level. So when people tried removing the timeline motion from our picture, they didn't think they were necessarily removing the pillars of physics as well.

And the area was often left well alone. Even during recent efforts to forge a theory of quantum gravity, which took off during the '80s and have been central since then, at first it didn't seem certain that we would have to take our view of time apart and question everything about it.

Only in the 21st century really, when other avenues had been tried, did we start to look at time as a key issue. It was like one part of the engine of a car that no-one wants to dismantle until everything else has been tried. But nowadays it has become clear that we may have to make progress on that front, in one way or another, before we can get to quantum gravity.

5. Block time and gravitational time dilation

For a long time, the idea that time is an illusion was more a way of ending a train of thought than a way of starting one. Because to some it looked capable of going off into psychology or other areas, it was natural to leave it at that point. But in physics we can still limit what an illusion might or might not do, and look to see if the idea could be self-consistent, and fit with the clues that we have.

Both kinds of time dilation behave like distortions of *motion* along the time axis, like a slowing of motion through time. So if there's an illusion, then it's getting 'slowed down' somehow. In looking at how an illusion might fit into the general picture, gravitational time dilation is the simpler of the two. We have some idea of how it works.

In general relativity (GR), a mass is thought to affect both space and time around it. We have a comparatively clear picture of what curvature does to space - at a given radius, the distances to be covered are in some situations longer than the Euclidian distances, by

$$(1 - (2GM/Rc^2))^{-1/2} \quad (1)$$

This effect can be seen as increasing distances by stretching them, perhaps by giving everything further to travel on a path along the curved floor of the indentation in space.

Curvature also affects time by the same factor, as part of a rough symmetry between space and time in GR. Applying this to time, there's now further to travel along the time axis locally. As with space, the extra distance is hidden and can't be observed directly, so instead any motion along the time axis near a mass - real or unreal - might appear to be slowed. This gives the right set of time rates.

These changes to the axes are thought to be real. Space curvature is not seen as an illusion, and that of time is equivalent. The static time axis in block time is subject to curvature, and as far as there the picture works.

But now try adding an illusion into the mix. If the illusion is affected by these local changes to the time axis, then it runs deep, and would need a physical basis. Without one, it's hard to see how it could be that precise. The time rate differences from GR mean that in the Earth's field, near the surface, the length of one second varies by about 10^{-13} seconds for each km of height. The nearer the centre of the field, the slower the time rate.

One can try to say that because distances along the time axis are changed, this happens to distort the illusion of motion through time that living creatures see - in an incidental and entirely unconnected way. The graded pattern of distances gets imprinted on the illusion, and then looks like a pattern of speeds. But it seems far more likely that gravity and this effect are directly connected. What we actually observe is a set of changes to the time rate near a mass.

And one can't help thinking that a gravity field is a synthesis of closely linked effects, and that this explanation for the time rate, in which two unconnected effects combine, is a bit contrived. To get the full effect, you need living creatures. Without them we'd all be missing something. But this pattern of time rates across the field has a complicated structure, and seems more likely to be actually part of the field, and something we simply don't understand yet.

This view of a gravity field looks even worse when one finds it isn't supported by the other kind of time dilation. With motion time dilation, whether or not a further illusion is thought to distort the first one, the picture doesn't seem to support the gravity one, or take any support from it either. They arrive at a similar result in different ways. And each has the illusion hooking up with

other effects in order to explain the whole setup, in a way that, to me at least, is deeply unconvincing.

Anyway, there are various ways of seeing these things. Some think the time axis is stretched or compressed, perhaps in a perspective-type way. But then motion through time is still rather needed, as it looks like what actually gets distorted. It's also possible to see the time axis as shifting to a different angle, but none of these approaches fully removes the timeline motion, and it keeps on reappearing. And *when all the clues are taken together*, the universe looks dynamic and full of action, not static. This also fits with what quantum theory suggests.

We find this timeline motion everywhere in physics - much of the history of 20th century physics in relation to time has been about attempts to make the motion go away, and much of the confusion arises because it won't. Attempts to remove it are like attempts to remove a structural beam from a house. But perhaps it can't be removed - it may be a fundamental feature of the universe, and one that needs to be understood.

So block time may be an obstacle that needs removing, to unblock the road to quantum gravity. But if so, then the Rietdijk-Putnam argument, or the landscape it arose from, would have to contain a false assumption. Although this bit of reasoning has not been refuted in the forty-five years since it was found, it is certainly ripe for reviewing. But the false assumption would probably be in the underlying spacetime landscape, as that's where the assumptions about the nature of time were made - which led to the other set of assumptions about the nature of time.

6. Three logical steps

The essence of the Rietdijk-Putnam argument has three steps. The first is the assumption of a specific, limited simultaneity across a distance, coming from Minkowskian geometry. Unlike Newton's simultaneity, this relative simultaneity is different for observers moving differently.

The second step is the crucial one. From that idea, and from the ideas surrounding it, it seemed to follow that *the same event can be in the past for one observer, but in the future for another*. That single point, when examined closely, transformed humankind's view of time. If to one observer the event is in the past, then it is inevitable. But if to the other observer the same event is still in the future, then a future event is inevitable.

And if the placing of the event in the past or the future depends purely on the observer's viewpoint, it seems that the difference between past and future depends only on our perception of them.

The third step is to stand back and apply step two everywhere. If this can happen with one event, it can potentially happen with any event. As any future event approaches, there will always be a frame, a hypothetical one at least, in which it has already happened. This makes the entire future seem inevitable.

And then, in what is really a fourth step added on sometimes, one says that if past and future are interchangeable, it's hard to see how there can be a moment called 'now' moving along, and defining a difference between them. This is what has led many to invoke illusions to explain

motion through time. But our picture of things is still incomplete, and it may be premature to do that.

It seems to me much more likely that one of the assumptions that led to block time is false, than that block time is real. A chain is as strong as its weakest link, and so is a chain of reasoning. A single false idea, hiding in there somewhere, could be enough to stop the universe freezing up. It also seems that it would be far better for physics if this were the case. A slight difference to the rules about simultaneity at a distance, or about frames of reference in relation to time, arising because we still don't know exactly what SR is describing, would remove the shadow of unreality that block time casts across the field. Removing it would be easier for physics to deal with than being left with everything unreal, except for one thing - block time. Like the cuckoo in the nest, block time threatens to throw out everything except itself.

And yet it arose from ideas that *included* motion through time, and also the concept of a present moment - and various things that it later seems to show not to exist. So like an electric drill that risks cutting its own power cable, the reasoning attacks some of its own foundations. I'm not saying that this necessarily makes it wrong, I'm just showing how much room for error there is, given that SR itself is not fully understood. So I would urge people to question the assumptions that led to block time.

Many of these assumptions have not been tested - some of the rules for 'now' moments and frames of reference can't be confirmed. It's hard to know if a distant event can truly be said to happen before or after a nearby event. Within the light cone, where events are in range of each other, there's a clearer sequence - one can say an event happens before another if it can influence it by getting a light signal there in time. This short range way of relating events has meaning, based on causality. But it doesn't mean there are long range time links across space, as in Minkowski spacetime.

The readings on clocks and the motion of light at short range might give the impression of general simultaneity links across space. But long range simultaneity might be more hypothetical, and not real in any active way. It might not hold enough meaning *to allow an event to be both past and future, in two different viewpoints*. So which of our basic physical assumptions are wrong? To me, that one. We've assumed that scenario is possible, but if it isn't, block time falls apart. Our whole view of time depends on that one untestable idea.

There's another thing that suggests simultaneity links are not necessarily to be depended on. In standard SR, two observers moving differently can't relate their 'now' moments at all. If a walking observer tries to calculate what time it is 'now' inside a moving car some distance away, only nonsense comes out. If someone in the car does the reverse calculation, the two answers will simply not match up. So relating 'now' moments across a distance can sometimes have no meaning at all. And 'now' moments are not meant to exist anyway.

And yet we depend on relating 'now' moments in other situations. And this setup is not enormously far from one Roger Penrose has looked at^[8], linked to the Rietdijk-Putnam argument. Two observers, near each other but moving differently, are in different relationships with an event some large distance away, in relation to which they are both moving. The planes of simultaneity of the two observers go either side of the distant event, leaving it in the past for one, but in the future for the other. This creates paradoxes, and seems to lead to the

inevitability of all events.

But there may be a rule we don't yet know about that prohibits relating 'now' moments across a distance in this way. And whatever the reason for that is, it might be similar to the reason for our inability to relate the present moments of two differently moving observers, as above.

Removing block time is easier said than done. What I've given here is more an example of the kind of answer the problem might turn out to have. But the kind of possibilities I've mentioned would be a small price to pay if some such thing were true, and we should be open to them - the cost of the alternative seems a lot higher.

7. Conclusions

The main conclusion here is arrived at by comparing two levels of time, after showing that they can't both be real. If they contradict each other about whether the future already exists, that removes the possibility that they co-exist (perhaps just as part of the nature of the time dimension). Instead only one of them can be real.

With block time real, the world of processes that we observe, and basically of physics, would be unreal - but the required illusions simply don't seem to work. And motion through time leaves traces behind it. The conclusion is that motion through time is real, and block time must contain a false assumption, or comes out of a landscape, spacetime, that is incomplete or wrong.

That would mean some present assumptions are false. I've mentioned one - that an event can be both past and future in two different viewpoints. Many other assumptions stem from it, and in that sense it's a basic assumption.

The idea that motion through time is an illusion in the perception of living creatures seems far-fetched and unworkable, for reasons above, and others. But block time seems to point to our *perception* of time for the difference between past and future, because in the accompanying picture, the difference is observer-dependent. This idea is fascinating, but on close examination, it's a reason to think that both block time and the accompanying picture must be false.

Block time is only ever accepted alongside the idea that there are things we don't understand about it. It's often taken as read, and the surrounding questions are so hard to deal with that people sometimes believe it without looking very far into it.

But if the two levels of time can't co-exist - as I've tried to show - and only one can be real, then block time is surprisingly incompatible with our scientific view of the world. The unchangeable future is hard to square with a range of good theories - including not only quantum theory, and anything with dynamics in it, but also anything with cause and effect in it. And if motion through time has to be unreal, the laws would then reside within the illusion, and physics would risk being the study of what an unexplained illusion does.

In fact, some think the laws are built into the time slices in the block, like with the frames of a film. But if an illusion then moves us through them, that looks highly contrived, and needs living creatures to make sense of it. I've tried to show the lengths that physics has gone to in order to accommodate block time, and suggest that instead we question it.

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