What Is “Fundamental”?

In ordering the levels of description in physics, alongside emergence, the idea of explanation is needed

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Abstract

To order the levels of description in physics, and find out what makes one layer more fundamental than another, the concept of emergence helps. If one phenomenon is the result of another, and clearly emerges from it, that places them in order, and shows which runs deeper. But here it is suggested that alongside emergence, it’s also helpful to use the idea of ‘layers of explanation’. Explanation is a concept that comes very much from human thinking, but then so does some of the surrounding landscape.

In science we have a series of layers, each emerging from the one underneath it. It might seem that from Planck scale physics emerges particle physics, from particle physics emerges chemistry, from chemistry emerges biology, and from biology emerge jazz, the internal combustion engine, sarcasm, and so on. So how do we put these layers in the correct order, and decide which of any pair is more fundamental? Some criteria don’t seem to work in all cases, including size, composition, and simplicity. So is there a single criterion that always works, as there should be if ‘fundamental’ has a clear meaning?

Looking only at physics (where the questions are often simpler), it seems that more fundamental means ‘at a deeper level of explanation’, and that to put this hierarchy in order we need to think about each layer *explaining* the one above it. That’s because the levels we identify in physics are in the first place to some extent - and not necessarily in an obvious way - levels of conceptual understanding. The view here is that ‘fundamental’ has an objective element involving emergence, and a parallel subjective one, involving explanation. The two give the same directional ordering of the layers.

1. Putting the layers in order

For the meaning of *What Is “Fundamental”?*, the notes with the question make it clear that rather than ‘what thing is fundamental in the universe?’, it’s ‘what does the word fundamental mean?’. To ask that, one needs to ask what ‘more fundamental’ means.

I’ll apply this to physics only, because biology has a lot of unanswered questions. A look at some of the discussion in and around last year’s essays shows what a difficult question it is. But here I’m glad to say it’s not relevant. We don’t know how life fits into the pattern I’ll describe - it might be some kind of exception to it, or a complicated part of it. But either way, physics is simpler, and either way, I’ll just describe the pattern. That means leaving out downward causation, which may be just an aspect of life and mind (or of complex organisation). And my view is that mind is not fundamental to the physical universe, although some loose views of quantum mechanics try to say otherwise.

Emergence means that one phenomenon is the result of another underlying one. What emerges is new, coherent and lasting, but the relationship with what it emerged from can be tenuous and unpredictable. So in principle, to describe a hillside that was carved out by erosion, one might give a long list of details of wind direction and rainfall. Heat might be described, instead of via a temperature in a single number, in terms of the behaviour of many particles. But most phenomena have more causes than one, so it’s easier to identify emergence than to pin it down. And alongside emergence, it’s worth remembering that each layer is a slice of our understanding of the universe.

But to strip it down to basics, how do we put *butter*, *milk*, and *cow* in the correct order? Either emergence or explanation should create the same directional ordering of the layers. With emergence, one way is if we can actually monitor it happening. If we see butter being made from milk, we know that milk is at a deeper level than butter. And if we see milk emerging from a cow, we know that the cow is at a deeper level than either.

In a minute I’ll giving another example, more to the point but harder to solve, again with three layers that need putting in order. On the way there, let me show these ‘layers of explanation’ helping to redefine a problem we have in physics: the problem with time. How we order the layers in that area is so important, it both affects this question and is affected by it, so it’s worth looking at it here.

Special relativity is well tested, but the way we interpret it is not. Taking the two together, as we do, the result seems to be telling us to put the apparent flow of time at a more superficial level than the underlying structure of the four-dimensional block. So some think the flow of time is emergent, and more superficial.

But thinking about that, many laws of physics, such as laws of motion, *depend* on a flow of time. An orbiting object, if one tracks its position, is a little further on each second. And as its position changes, it turns out to be going by a physical law that can be written down. This law uses time. So the question arises: which is more fundamental, the laws of physics, or the apparent flow of time? And it becomes clear that wherever we put the laws of physics in the ordering of the layers, the flow of time might need to go underneath them.

But it then becomes difficult to put the four-dimensional block underneath *both* of those, because the laws of physics become too superficial to fit with some other parts of our view of them. So like with the farming-related question, we now have three layers that need putting in order - our laws of motion, the apparent flow of time, and the four-dimensional block. It's certainly a way of understanding the problem, and it suggests that when we have a complete explanation for these things, it may go with a different ordering of the layers than the present one.

And trying to put these layers in the right order leads to an interesting point. In the view of the world that many take at present, with block time, the flow of time is a comparatively shallow, emergent effect. But if so, then as it emerged, physical laws such as laws of motion were already pre-implied, and frozen into the block. This leads to a major problem for *both* the illusion time idea and the emergent time idea. Either of them makes time a more superficial effect, but the trouble with that is, it means these laws were just sitting there in the block, implied in the ordering of the time slices there, and apparently waiting for something more superficial to come along and make them work. And something did.

That looks contrived - what were the laws doing there, sitting in the block in this 'just add water' sort of way? With illusion or emergent time, we have to assume some shallower effect just happened to arrive later, in a largely unconnected way. And when it did, it was so appropriate that it allowed these deeper pre-implied laws to function, by running the time slices in a sequence, or making them appear to run in a sequence. But the idea that the time slices were run in a sequence *by chance* simply doesn't work - because they contain laws of motion, their very nature means they were 'born to run'. To me this point, along with others, makes illusion time and emergent time - and indeed block time - all look very unconvincing.

One answer to this point, more often implied than stated, is the idea that all of this is part of one thing - the time dimension. The implication is that the time dimension is a slightly weird, different dimension, with two levels built into it, as part of its nature. One level is frozen (as suggested by spacetime), the other has motion along the time axis (as suggested by other physics).

But this can't be the case. It can be shown that the two levels disagree on whether the future already exists, because the level with motion contains the randomness of events in QM. If one accepts this randomness, as the large majority do, then only one of these two levels can be real, as they give two different versions of the future - one open, the other closed. And the disagreement between them turns out to be a disagreement between QM and spacetime. (It doesn't involve SR, which like QM is well tested, but is ultimately separate from its present interpretation.) Because spacetime is untested and perhaps untestable, it's worth pointing out that this is a disagreement between well tested physics and untested physics.

Other points that suggest a need to rethink our view of time are in my previous FQXi essay, from 2012, which dealt with illusion time and other things. But emergent time, which is a wider set of possibilities, was left out - it made sense to include it here, as ordering layers of emergence is central to both this question and the ones about time. The 2012 essay also left out a series of experiments done in 2015, which have cast doubt on the idea that the apparent flow of time is emergent. The presently favoured view of time, with the apparent flow emergent, goes with (and arose from) a single idea, which experiment now seems to have shown to be wrong. It's the idea that the world is reversible at the particle scale.

Because some equations are reversible, the idea is that at a small scale, you just have reversible processes, and that's the real underlying physics. But at a larger scale and a more superficial level, the consistent direction of time is thought to emerge, perhaps due to thermodynamics, and increasing entropy. But now we find that the directional entropy goes right down to where the reversible physics is meant to be. So we can't say it emerges further up the scale. And it seems that those reversible laws are an incomplete description of the world, because the small-scale world is not reversible after all.

This result is very new, and it's early days, but it may turn out to be crucial. The experimenters flipped the nuclear spins of some carbon-13 atoms in liquid chloroform, using a magnetic field. They then flipped them back again, and if the world was reversible, they should have gone back to how they were. But instead they didn't, and doing this many times rapidly, the whole process was shown to be affected by entropy. In their discussion at the end of the paper[1], the experimenters ask what they call the 'puzzling question' of how the Schrödinger equation can lead to a strictly non-negative relative entropy. They say the initial conditions must be taken into account, but one of them, Mauro Paternostro from Queen's University in Belfast, said in an interview[2]: "*Our experiment shows the irreversible nature of quantum dynamics, but does not pinpoint, experimentally, what causes it at the microscopic level - what determines the onset of the arrow of time.*"

It may take a while before the implications of this filter through, but what was found at that scale was time working apparently just as it does in the large-scale world. That means an explanation is still needed, and it leaves the presently favoured view of time, with the time asymmetry arising as an emergent aspect of a reversible world, looking even less like a viable explanation than it did before.

There are differences between space and time, however we take them. Given that time is seen as a unique dimension, there could be more differences than the ones we've already accepted. If so, perhaps Minkowski spacetime is oversimplifying things (because of similarities between space and time), and is characterising time as more like space than it is in reality. If that's the case, then as a result, it's telling us to put the layers in an order that is in conflict with the ordering suggested via conceptual physics.

And by conceptual physics, I don't mean intuition. I mean something that's much more valuable to us in our attempts to make progress - intuition has been a disaster area, ever since Aristotle. But using conceptual thinking can at first glance look like going by intuition, and because of that, it's sometimes undervalued and avoided. Taking the conceptual points into account (facts that are known from experiment), such as the permanent age differences between objects left behind by time dilation, might seem like clinging to intuition. But instead it can simply be a case of looking at the clues.

Nowadays a growing number of physicists are looking outside the standard view of time, and attempts have been made to replace or partially replace Minkowski spacetime, that have had a significant amount of interest[3],[4],[5]. But it took a long time for this to happen. More generally, a large number of physicists have started to see spacetime *itself* as emergent, as incompatibilities with QM become more apparent. But spacetime is (or was) meant to be about the dimensions, and utterly fundamental.

What all this tells us about what we mean by 'fundamental' is simply this - to get to what's fundamental, we sometimes need more than just ideas about emergence. We need a full explanation. Anyway, it seems that in the case of time, the mathematical picture and the conceptual one give different answers.

Conceptual physics went down in people's estimation during the 20th century, but partly because it was hard to make progress there. Many decided that only the mathematics of a theory counts, and its confirmability by experiment. And the conceptual department got left behind, for instance in quantum mechanics. Instead, progress was made in the mathematical and experimental departments. But it may be that to find a theory of everything, we still need to find an underlying picture.

2. What's at the deepest layer?

The question of the deepest layer has bearing on what links the layers generally. Einstein and Wheeler both thought the deepest layer would be conceptual - both said that in the future a conceptual basis for physics will be found. Einstein expressed the need for a conceptual basis in the last sentence of his last article[6], and six years earlier he said that one will be found in the future, while talking about questions relating to QM[7].

He wrote: *"It may appear as if all such considerations were just superfluous learned hairsplitting, which have nothing to do with physics proper. However, it depends precisely upon such considerations in which direction one believes one must look for the future conceptual basis of physics."* Einstein also mentioned what he called '*the principle of the universe',* and said that it *'will be beautiful and simple'.* John Wheeler said that at the bottom of it all, we'd find not an equation, but an utterly simple idea.

This is also about the question of where the ongoing process of unifying physics goes - we've been unifying different phenomena for centuries, trying to move towards getting it all under one heading. So what does physics unify *into*? Does it unify into some mathematics, or into a picture? If the deepest physical layer is a conceptual one, that would fit with the idea that explanation is part of what links the layers further up.

David Deutsch has talked about explanations, and has emphasised the need for physics with an explanatory side. He says the key element of a good explanation is that it is "...*hard to vary, because every detail plays a functional role"*[8]. So while emergence is loose and hard to pin down, explanation can be tight and unambiguous. It's often more likely to lead to mathematics, and links the layers better.

3. Conceptual physics

Conceptual physics is not philosophy, and it's not metaphysics, though it sometimes gets called names like those. (It's also not the teaching method of the same name.) It's the backbone of all our physics, but its importance is often hidden. It has led to almost every major breakthrough, and is always in there when the leap is being made, doing what it does, at least three minutes before any equations are written down.

This sometimes involves making a connection between two things that have been seen as separate - Einstein, for instance, made a connection between freefall and no gravity. Newton made a connection between the force that affects the apple and the force that affects the moon. De Broglie made a connection between matter and aspects of waves, which led Schrödinger to his mathematical breakthrough.

So even though the goal is a mathematical description, conceptual physics is what gets us there, and we sometimes can't do without it. Victor Weisskopf was taught by Schrödinger, Heisenberg, Bohr and Pauli, and was present at the birth of quantum mechanics in the 1920s. He was later a well-respected and much loved teacher at MIT, who saw conceptual understanding as more important than mathematical derivation. His well-known phrase was 'search for simplicity'. According to him it was partly Paul Ehrenfest's influence that led him to this emphasis on the conceptual side.

Conceptual physics needs to work hand in hand with the mathematics, and if it gets behind, as it did in the 20th century, one kind of progress can still be made, but not another. Some 20th century theories have been hugely successful, such as quantum field theory. But not every problem can be tackled with an incomplete picture, and we may have reached a point where a different approach is needed to move forward. String theory has split into a large number of theories, and looks less likely to provide a clear way through. So for some challenges of the 21st century, we may need to brush up on our conceptual thinking. But although conceptual analogies are needed generally, this isn't because an analogy can provide evidence for anything. In physics, whether an idea is intuitive or counterintuitive has no direct bearing on whether it can help with progress.

It's straightforward to show reason to think concepts are the backbone of physics. There may or may not be other civilizations out there, but suppose we make contact with one in the next few hundred years. We might find their mathematics is nothing like ours. Physics is full of equivalence, and the same mathematics can describe many different pictures. And if you have a picture, it can often be described mathematically in many different ways. So the aliens might have developed a very different mathematical culture from ours.

But if we talked with them about heat, we'd all agree that the bits of matter in a hot object are moving around more than in a cold one. This idea is not just a set of concepts, it's also an explanation. And in its day, it was one of several competing explanations, one of which turned out to *true* - or a lot truer than the others.

To me this gives reason to believe that the conceptual puzzles of the present era, such as QM, will turn out to have explanations. The idea that current or future interpretations for QM are all just different ways of seeing it, is unconvincing. But anyway, the point I was making is, whatever the mathematical differences with the aliens, we could go for a drink with them and talk about conceptual physics, and we'd find some common ground there, if nowhere else. So conceptual physics is important.

4. Levels of description

The general levels of description we have provide some insight into the more specific ones, and the whole process. Areas such as chemistry, and beneath it particle physics, were defined by the development of technology capable of probing different scales. But what selects the place where one level ends and another begins, for instance the borderline between chemistry and particle physics, was often more about what kinds of experiments could be done in each.

The timeline also shaped things. Chemistry was pinned down in the 19th century, and by the later part of the century, the map had become complicated. But at the same time, a simpler world of particle physics was beginning to appear underneath it. Then the same thing happened again. During the 20th century particle physics got increasingly complicated, with the standard model loosely equivalent to the periodic table. But once again, towards the end of the century a simpler world was beginning to appear underneath it, with Planck scale physics. So as we zoom in, at present we seem to penetrate the layers at about one layer per century. But there may be no new layer in the 22nd century, not only because theory has got far ahead of experiment, but also because the Planck scale looks like a very basic boundary.

The way we describe these layers in our view of the world is often seen as having no subjective element. Outside factors, such as the technology, and what is actually there to be discovered, seem to determine how the layers are laid down. And it has to be said, a lot of things about the periodic table and the standard model look like what might be called universal truths.

But what our technology found has also helped to shape our *understanding*. So there can be a hidden subjective element, parallel with the objective one. And as we zoom in to smaller scales, how we set out what we find depends partly on our conceptual picture, and what areas of explanation it provides. There's always an element of preference in how we describe concepts, and 'fundamental' is partly about concepts. So it's slightly loose, just as Occam's razor is very loose. Matt Leifer once said 'Simplicity is in the eye of the beholder', when talking about Occam's razor. Well, there's a touch of that in fundamentality as well.

And the subjective element in how we interpret what we find means that if we ever talk to aliens about conceptual physics, although we'd agree on some of the basics like what causes heat, and other things that have been clearly explained, there might still be major differences - about things that have not been clearly explained. After all, our present picture is far from complete. One look at the wave-particle duality will show that. When we look at it, we don't know what we're picturing. And we don't know if aliens, if we met some, would believe in this wave-particle duality - it's hard to guess whether they would. But in our view of things, it's absolutely central to the universe, as it affects both light and matter, which is pretty much everything.

So it becomes clear that our overall picture of the universe might be our own, and unique to us. And if that's so, then the layers within it would surely be connected by explanation, alongside anything else. Whether our picture of the universe is correct, incorrect, or a bit of both (and a bit of both is a good bet), whatever else it is as well, it's a set of explanations. From there, it's a straight path to the idea that 'more fundamental' means 'at a deeper level of explanation'. If this is so, then the question *What is "Fundamental"* might be seen as exposing, to some extent, the importance of conceptual physics.

5. Deeper also means more wide-ranging

There are plenty of hints that can be gleaned from experiment using a conceptual approach. It's a rational process, though conclusions are often drawn without even thinking about them. But it still serves us well, and in relation to this question, it helps put the layers in order.

For instance, how do we know that mass is a very fundamental property of matter? Matter always responds in the same way via its mass, across the board - whatever matter happens to be doing, and whatever state it finds itself in. This suggests that mass runs deeper than whatever matter happens to be doing, and whatever state it finds itself in. So this leads to a principle for using observation to help put the layers in order - in some contexts, more fundamental means *with less variation in behaviour* across a range of situations. The deeper a level is, the more consistent and wide-ranging its behaviour will be.

Saying that a level of description is more fundamental than another also means that it has a wider range of phenomena above it in the stack, and resulting from it, or connected to it. This applies within both the physical side and the mental side - emergence and explanation. In either, the effect of a phenomenon spreads upwards and outwards through the layers, so the further down it starts, the more areas it reaches.

This leads to a general way to define fundamental, covering both emergence and explanation, but it's usually looser than one would want it to be. In a sense it works upwards, and is about how large the range of phenomena 'further up' is, that can be related to a single phenomenon, by showing that their descriptions can in principle be reduced to, or explained by, the more basic one.

It's even harder to penetrate the stack working downwards, and what can be inferred about the deepest layers is not straightforward. Attempts to reach a theory of everything are seen by some as attempts to reach a mathematical description of the world so fundamental, that it covers everything above it in the stack. But if it's to be a real theory of everything, it would surely shed some light on the puzzles we need to solve during the present era, such as that of time, and that of quantum mechanics.

And a close look at those puzzles shows that in both cases, a conceptual solution is needed. So if it's to cover *everything*, whatever is at the root would need to contain concepts that cover those particular questions. To me that means there's reason to believe, and not just because Einstein and Wheeler said so, that what lies at the deepest level is conceptual. I'd say the only way to avoid this point is with the idea that the puzzles of time and QM might not have solutions at all. In fact there's good reason to believe that they have, but to tackle that argument, I'll point out a third puzzle, and one that must surely have a conceptual solution.

It's about energy. We don't have an all-embracing definition for energy, and in particular we don't know what an object's total energy is. But we do know it can be conserved, even if the total energy is comprised of several different forms of energy, and even if their quantities vary within that total. This is unexplained. The different kinds of energy are widely different, and we don't really know what links them up. Some think an object's total energy is purely a mathematical entity, without any direct physical significance.

But if the object's total energy then changes (perhaps because it emits radiation), its *inertia* will change in proportion. That makes all this look rather different. It makes the total energy look like something real. But if so, then the different kinds of energy it contains would all have to be linked in some way that we simply don't understand yet. They would all have to have some common element, just as gin, whisky, vodka, beer and wine all contain alcohol. We don't know what that common element could be, but like time and QM, this puzzle needs a conceptual solution.

These points suggest that what lies at the deepest level, if there is a deepest level, and if anything understandable to us is to be found there, is an explanation - perhaps in the form of a conceptual picture. It would be a physical explanation, at the deepest level of physical explanation, with many layers above it. It might have standard aspects of 'fundamental', such as small objects that are components of other things. But being an explanation, it might also include 'larger' things, such as overarching principles, or wider patterns. It would certainly lead to new mathematics, and interpret existing mathematics. But if anyone ever puts it on a t-shirt (which was never a good idea, and which may be less practical than it seemed), rather than algebraic text, they might need to print words - and perhaps pictures as well.

References:

1. T. B. Batalhao, A. M. Souza, R. S. Sarthour, I. S. Oliveira, M. Paternostro, E. Lutz, R. M. Serra, *Irreversibility and the arrow of time in a quenched quantum system,* Phys. Rev. Lett. 115, 190601 (2015), arXiv:1502.06704v2

2. Lisa Zyga, Phys.org 1.12.2015, *Physicists confirm thermodynamic irreversibility in a quantum system,* http://phys.org/news/2015-12-physicists-thermodynamic-irreversibility-quantum.html

3. Amelino-Camelia, G., Freidel, L., Kowalski-Glikman, J., and Smolin, L. (2011), *The principle of relative locality,* Phys. Rev. D 84, 084010 (2011), arXiv: 1101.0931v2

4. Hořava, Petr (2009). *Quantum gravity at a Lifshitz point*, Phys. Rev. D 79 (8): 084008, arXiv: 0901.3775v2

5. George F. R. Ellis, Rituparno Goswami, *Space time and the passage of time.* arXiv:1208.2611v4 Aug. 2012

6. Einstein, A. Preface to: *Cinquant'anni di Relatività* (Fifty years of Relativity). Giuntine-Sansoni, Florence, 1955, p. XX.

7. Albert Einstein: Philosopher-Scientist, from The Library of Living Philosophers Series, Cambridge University Press (1949).

8. David Deutsch '*A new way to explain explanation'*, TED talk, October 2009

https://www.ted.com/talks/david_deutsch_a_new_way_to_explain_explanation/transcript?language=en

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Note: words such as 'later' are sometimes used here to mean at a more superficial level, just as 'pre-' can be used in physics to mean at a deeper level.

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