The nature of natural laws*

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THE SUN RISES EVERY DAY. Water boils at 100°C. Apples fall to the ground. We live in a world in which objects behave the same given the same circumstances. We can imagine living in a different world: a world that constantly changes, a world in which the Sun does not rise every day, a world in which water one day boils at 50°C, and at 120°C another day, a world in which apples sometimes fall from trees and sometimes rise into the sky. Only because we live in a world that displays stable regularities are we able to reliably shape our environment and plan our lives.

We have an intuition that these regularities are due to laws of nature, but we normally do not interrogate what these laws are and how they work in any basic metaphysical sense. Instead, we assume that science not only provides these laws but also elucidates their structure and metaphysical status, even when the answers seem partial at best.

In short, we assume that, thanks to science, there is a recipe of sorts for how the laws of nature work. You take the state of the Universe at a given moment – every single fact about every single aspect of it – and combine it with the laws of nature, then assume that these will reveal, or at least determine, the state of the Universe in the moment that comes next.

Layer-cake Model

I refer to this as the layer-cake model of the Universe, which dates back to the 17th-century philosopher René Descartes. Not long after Descartes embraced the idea of a deterministic universe, Isaac Newton presented a mathematical law for gravitation, which gave the concept a powerful quantitative update. The gravitational force on one body at one time is determined by the location of all the bodies in the Universe at that time; the state of the Universe plus the law of gravitation tells you how all bodies will move: a layer-cake model, indeed.

The influence of Descartes and Newton on how we think about laws of nature is immense – and not without justification. It has helped to unify whole fields of physics, including mechanics, gravitation and electromagnetism. It is still so widespread in the scientific community, and it has such a distinguished pedigree, that scientists may not even realise that they subscribe to the layer-cake model at all.

But the uncomfortable truth is that there are many aspects of modern physics that seem to provide counterexamples to the layer-cake model. To date, some of these alternatives have occupied only a rogue niche in physics. But they should be studied more deeply and understood more widely because they pose major challenges to our fundamental understanding of the Universe – how it began, where it is going, and what kind of entity, if any, is driving it.

The first massive challenge to the layer-cake model, Albert Einstein's theory of general relativity, appeared in the 20th century. The laws of nature that are core to the theory of general relativity, the Einstein field equations, do not immediately lend themselves to the layer-cake model at all.

The difference can be seen in the structure of the mathematics itself. An equation that adheres to the layer-cake model describes the changes that occur in space in terms of the underlying reasons for these changes. For example, Newton's equation for his second law of motion describes the acceleration of physical bodies in terms of the underlying forces causing that acceleration. The Einstein field equations, on the other hand, describe the very structure of spacetime as the change agent for moving physical bodies; in fact, most of the solutions to the Einstein field equations yield a spacetime structure that is incompatible with the layer-cake model.

When faced with this challenge, physicists do something highly revealing: they specifically search for solutions to the Einstein field equations that comport with the layer-cake model, and they rule out solutions that do not comport with the model as 'unphysical' – as artefacts of the mathematics that do not tell us anything about reality, or, at least, not the reality we live in.

Does the Future influence the Past?

In the case of general relativity, there are good reasons for doing this, but in other cases the challenge to the layer-cake model becomes harder to dismiss. In classical mechanics, for example, there is something called the Lagrangian formulation, which holds that, when moving between two separate points, A and B, a physical body will take the most efficient path. This does not look like the layer-cake model because, in order for the physical body to take the path of maximal efficiency, point B, which lies in the future, needs to be determined in advance. It looks, counterintuitively, as if the future is what determines the motion of the body in the past.

As strange as this seems, it turns out that you can derive the familiar Newtonian equations for motion from the Lagrangian formulation. Because of this, scientists often treat the Newtonian version, which comports with the layer-cake theory, as reflecting the true structure of the world. The Lagrangian version is understood to be an interesting and sometimes practical – but never metaphysically accurate – mathematical reformulation.

But the Lagrangian formulation is just the start. Physics has many other theories where the future seems to somehow influence the past. The peculiarities of quantum mechanics have led to the development of so-called retro-causal models. And such midcentury giants of physics as John Archibald Wheeler and Richard Feynman developed a theory of classical electromagnetism that basically says that future charges send light signals into the past.

I do not claim that any of these alternatives to the layer-cake model of the Universe is correct, but they are worthy of deeper study. The door has been opened for an investigation of alternative ways of how laws act in the Universe.

How do Laws influence the World?

In current philosophy, the layer-cake model has been defended by the philosopher Tim Maudlin, a professor at New York University. In his book *The Metaphysics Within Physics* (2007), he lists two key metaphysical features: laws are primitive entities, and laws produce the future from the state of the present. In this context, 'primitive' means non-reducible to anything else, or standing on its own. Primitive laws thus exist by themselves, and they exist not as concrete objects, like tables or cars, that we can experience and manipulate with our senses, but rather as abstract entities, similar to numbers. An immediate problem arises: how can laws influence any physical object in the world?

In principle, we face a similar issue with legal laws: how can these abstract laws that are passed by Congress influence our behaviour? But the answer is straightforward: once we get notice of a law and understand it, we can choose to abide by it. The fact that we can choose to follow the law means that we have freedom not to follow the law.

Laws of nature are different. An electron has no freedom not to follow the laws (even if they are indeterministic), and, more importantly, it is utterly mysterious how laws as primitive abstract entities are able to tell the electron what to do.

Two Davids: Lewis and Hume

In order to mitigate this problem of how electrons are able to obey the laws, another conception of laws was proposed by the philosopher David Lewis, which has been dubbed Humeanism about laws, in reminiscence of David Hume.

In *An Enquiry Concerning Human Understanding* (1748), Hume posed the following problem about the notion of causation. He illustrated the problem with the collision of billiard balls. When billiard ball A hits billiard ball B, which was initially at rest, we observe that billiard ball B moves after the collision; we say that billiard ball A caused billiard ball B to move. This seems to be unproblematic. At least, we know that, due to the causal relation between the two billiard balls, whenever billiard ball A hits billiard B, billiard ball B would move. But how does causation bind the motion of billiard ball A to the change of motion in billiard ball B so that billiard ball B always behaves the same when billiard ball A collides with it? For Hume, this question has no answer. We, as human beings, cannot directly observe this causal binding; all that we can observe is the constant motion of billiard ball A and the successive motion of billiard ball B. And that is all that we can be confident of saying about causation.

Lewis took this epistemic conclusion and turned it into an ontological one. Not only do we not experience how exactly laws influence physical objects, now it is said that the laws of nature do not influence or produce anything in the world. The layer-cake model is utter fiction. Instead, laws of nature effectively describe what is happening in the world. They describe the facts in the world, like a newspaper article reports facts in the world. Therefore, to emphasise the main idea of this proposal, I will call it the newspaper model of laws of nature.

Newspaper Model of Laws

The newspaper model is probably the most popular theory of laws of nature among professional philosophers, and it attracts a lot of active research right now. It is so attractive because it is metaphysically thin: there are no mysterious, unexplained relations of production as demanded in the layer-cake model. Laws merely summarise the history of physical objects.

The newspaper model, however, faces its own problem. Since there is no causal relation binding objects in the world, there is no reason why billiard ball B ought to move when being hit by billiard ball A. It may just remain at rest or move without being hit or break into parts or just vanish into thin air. Anything goes. If that were the case, the laws of nature would constantly change because they describe changing facts in the world. And still, billiard ball B always behaves the same way, and the laws remain the same too. How does that happen?

The metaphysical thinness has to be bought with Hume's principle of the uniformity of nature. It is a primitive unexplained fact within the newspaper model that the world always behaves the same way; billiard ball B always moves the same way when being hit by billiard ball A, even if nothing tells billiard ball B to behave so. Lewis reiterated Hume when he wrote that 'if nature is kind to us, the problem needn't arise.' In other words, just as in the layer-cake model, the laws of nature also remain the same over time and keep their structure in the newspaper model.

For example, Newton's laws remain as they were when written down by Newton, whether interpreted as producing the future or as describing the world. You cannot see from the formulation of the law what the metaphysical underpinning is. At least, not without more information.

All scientific laws are compatible with the newspaper model, including Newton's laws that tell us that the future state of the world can be calculated and deduced from the present state just as the present state was produced from the past. How can the newspaper model support a formulation of a law that looks like the layer-cake model? This is justified by the idea that Newton's laws are the most efficient description of the world (within the domain of Newtonian physics), balancing simplicity and informativeness. It might be possible to describe the motion of the planets in a different way. For example, you may create a long list with the exact times and the exact spatial coordinates of the planets; such a list would be very informative (more informative than Newton's laws are), but it would be too complicated. The best balance between simplicity and informativeness to describe the motion of the planets is exactly how Newton formulated his laws.

Not all scientific laws are, in fact, compatible with the layer-cake model, which requires that the past state produced the present state and the present state produces the future. In order for this to make sense, Maudlin adds a third feature: the stipulation of a primitive flow of time independent from the laws. Common sense would agree. The past determines the present, and the present determines the future.

The Flow of Time

But in physics and philosophy, a primitive flow of time is highly controversial. Some physical laws do not match this structure. The laws of retro-causal models of quantum mechanics (in which the future determines the past), for example, are clearly incompatible with the layer-cake model and with the idea of a primitive flow of time. The laws of special relativity do not fit the layer-cake model either, because they defy an absolute notion of simultaneity, which is part and parcel of Newtonian mechanics.

The Straightjacket Model

As a reaction to this narrow scope of the layer-cake model, the philosopher Eddy Keming Chen and the mathematician Sheldon Goldstein, at the University of California, San Diego and Rutgers University respectively, as well as the philosopher Emily Adlam, at Chapman University, have suggested an alternative. Laws may be primitive, but they nonetheless 'merely' constrain the physical possibilities in the world. Call this the straitjacket model of laws of nature. No notion of production and no flow of time is required. All that laws do is to constrain what can happen in the world. In this way, we combine the advantages of the newspaper model with the advantages of the layer-cake model, because we acquire the generality of the newspaper model and a reason for stable regular behaviour from the layer-cake model. Now we have a metaphysical underpinning for retro causal laws and the laws of special relativity because laws, in the straitjacket model, are primitive and govern the world by constraining what can happen.

Still, the straitjacket model suffers from the same metaphysical issue that plagued the layer-cake model. The layer-cake model was not able to account for how laws produce new states. In a similar vein, the straitjacket model does not specify how laws can constrain what happens in the world. It seems again that abstract laws have to latch on to the real world to tell physical objects how to behave. How laws are able to do so remains unanswered.

Metaphysical Glue?

The possible implications for any form of law of nature are profound. The layer-cake model seems to be intuitively plausible – the present is determined by the past – but we found out that it requires that laws somehow affect the objects in space and time without being themselves located in space and time.

Since the layer-cake model is too restrictive to capture other formulations of physical laws, like retro-causality and general relativity, the straitjacket model was developed. This model does provide a framework for retro-causality and general relativity, yet it suffers from the same metaphysical problem as the layer-cake model. The newspaper model, on the other hand, tries to introduce laws without any metaphysical baggage, and this seems to be a promising approach. Yet we seem to need a metaphysical glue to secure the stable behaviour of our world.

Best Model?

Given all this, which theory of laws best explains the regularities in our world? If the newspaper model were true, it would be a constant coincidence that the Sun rises every day or that the water in your kettle boils at 100°C, as there is no metaphysical constraint on how objects can behave. In contrast to many of my colleagues, I therefore find the newspaper model pretty unconvincing for explaining stable regularities. The layer-cake model and the straitjacket model fare better in this respect. The advantage of the straitjacket model is that it is general enough to capture unfamiliar laws of nature, like those describing retro-causality. But this virtue comes with a vice: the straitjacket model is so general that any law of nature would fit in.

The metaphysically interesting aspect of nature's laws is not that they constrain physical possibilities, but how they do that. Even if it is up for debate, the layer-cake model broadly addresses that question best. This works wonderfully with billiard balls. There are conditions where the model just can’t explain how laws of nature produce the future, like retro-causality; but instead of seeking a single new overarching model, perhaps we’d be better off sticking with the layer-cake, after all, and developing a separate tailored account for each type of situation where that model does not fit.

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