Philosophy pulls strings

In trying to interpret the string theory "landscape" and the meaning of space–time in a quantum theory of gravity, physicists should consider knocking on the door of their nearest philosophy department, says **Steven Weinstein**

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Different worlds Issues such as the nature of the multiverse can bring physicists and philosophers together.

String theory, like any mathematical theory, presents physicists with a host of technical challenges in how to extract predictions about the real world. As a unified theory of gravity and particle physics, string theory should, on the face of it, be amenable to experimental test because it must at the very least reproduce all observed phenomena. But extracting unambiguous predictions has proved difficult.

Bound up with these ostensibly technical challenges are some rather philosophical conundrums. For example, how should the theory be tested in view of the very many different universes that it is able to describe, and what is the meaning of space and time? While fruitful collaborations between physicists and philosophers are rare, there is little doubt that string theory forces us to tackle issues that cross both disciplines.

The anthropic landscape

The first set of philosophically flavoured conundrums concern methodology. Although string theory requires 10 (in some cases 11) dimensions, it prides itself on having only one free parameter: the string tension. Originally it was hoped that the Standard Model of particle physics, which has 19 free parameters, would somehow fall out of string theory as the unique low-energy, 4D vacuum state. As such, physicists would be able to explain why these 19 parameters take the values that they do.

In the last few years, however, string theorists have discovered that there is a vast "landscape" of at least 10^{500} such vacua, and that each of these corresponds to a universe with a different set of fundamental particles, interactions and parameters. Although the existence of so many vacua makes it seem "likely", in some sense, that the Standard Model will show up in one of them, it now seems decidedly non-generic. Only if there were an infinite number of vacua would the situation be any worse from the standpoint of uniqueness.

One reaction of string theorists to this loss of predictive power has been to invoke the anthropic principle. Originally employed by cosmologists to explain what appeared to be improbable values of certain cosmological parameters, the anthropic principle states that what we can expect to observe must be restricted by the conditions necessary for our presence as observers. In other words, the world is observed to be the way it is because that is the only way that we humans could ever be here to ponder such questions in the first place.

The use of anthropic reasoning in the context of the string-theory landscape depends on a somewhat hand-waving extension of the currently popular cosmological model called "eternal inflation". In this model, "the" universe is simply "our" universe – one of an infinite number of universes that make up the "multiverse". The string-theoretic extension of this model posits that each universe may have a different low-energy vacuum state (i.e. it may correspond to a different location in the landscape). String theory would, it is supposed, ultimately assign a probability to each of these vacua – although given that researchers do not yet have sufficient knowledge of the dynamics to be able to derive such a probability measure, this is highly speculative.

The hope of anthropic proponents is that the world we see is explained by its being *typical* among those universes that allow the existence of observers, intelligent life, conscious life or something along these lines (preferences differ depending on who you ask). Advocates of this anthropic interpretation of the landscape – the most prominent of whom have been Andrei Linde and Leonard Susskind at Stanford University and Alex Vilenkin at Tufts University, all in the US – therefore suppose that it is reasonable to expect that humans are such typical observers.

Philosopher Nick Bostrom of Oxford University in the UK, who calls this the "self-sampling assumption", has been one of the more audible advocates of anthropic reasoning among philosophers (2002 *J. Philosophy* **99** 12). The present author, on the other hand, has argued against this style of reasoning by pointing out that the assumption that we are *typical* observers is both ambiguous and unmotivated (2006 *Class. Quantum Grav.* **23** 4231–4236). Meanwhile, cosmologists Anthony Aguirre of the University of California at Santa Cruz and Max Tegmark of the Massachusetts Institute of Technology have suggested that nature itself might give us a clue as to which sort of reasoning we should employ (2005 *J. Cosmo. Astropart. Phys.* JCAP01(2005) 013).

Proponents of anthropic reasoning tend to see the huge number of possible vacua as necessarily implying that a universe *like* ours is inevitably a low-probability event (and therefore merely allowed by, rather than predicted by, the theory). Other string theorists, however, say that were somebody to discover that our universe *was* well described by a statistically unlikely vacuum, string theory would nevertheless be judged to be perfectly adequate. Discomfort with the low probability might lead us to question the assumptions that gave rise to our probability distribution in the first place, as string theorist Michael Douglas of Rutgers University has suggested. Or we might simply point out that no matter what the distribution is, any *particular* vacuum is highly unlikely, and so we should be no more surprised at observing one rather than another.

The general problem of assigning a probability distribution to a set of possibilities in the absence of any prior knowledge has been discussed by philosophers over the years, especially in conjunction with attempts to ground inductive reasoning in Bayesian methods. Indeed, John Norton of the University of Pittsburgh has recently argued that one can, and sometimes must, characterize complete ignorance about a physical system *without* appealing to a probability distribution at all (*Philosophy of Science* at press). In fact, Douglas and Shamit Kachru of Stanford have recently suggested something along these lines as a way of characterizing the landscape (*Rev. Mod. Phys.* **79** 733–796).

Tackling space–time

When dealing with any theory of quantum gravity – including, but not limited to, string theory – one must eventually face deep conceptual issues that relate to the quantization of space–time. String theory has for the most part postponed dealing with these issues, as the theory itself currently consists of an interrelated "web" of perturbative theories that makes sense only at energies low enough that space–time is effectively classical.

However, at sufficiently high energies one expects that the classical approximation of space–time will break down, and instead the non-perturbative (and unknown) theory at the centre of the web – sometimes called M-theory – must be invoked. In such circumstances one must face squarely the problems encountered already by researchers working on alternative theories of quantum gravity, such as loop quantum gravity and other "canonical" approaches.

Among these is the notorious "problem of time", which concerns how one should formulate a quantum theory in which there is no classical spatial and temporal structure with respect to which one can characterize physical states and their evolution with time. There is also a related problem of how to define observables in such situations, given that observations are usually idealized as taking place in local regions of classical space–time.

> Quantum theory could be an artefact of the assumption that the world has a single time dimension

Once one addresses such questions about what it means to formulate physics in the absence of a classical space–time background, one is then confronted with the question of what it means for classical space–time to "emerge" from the theory. In ordinary quantum mechanics, some physicists and philosophers think it legitimate to postulate that classical behaviour arises via the interaction of quantum systems with a macroscopic environment, while others object to this sort of "open system" analysis and instead characterize the emergence of classicality as being merely apparent. This, for example, is the view of "consistent histories programmes", which attempt to explicitly realize the many-worlds interpretation of quantum mechanics.

In both cases one ordinarily postulates a background space–time. In the open-system analysis, the interaction with the environment is a process that occurs over time; while in the consistent-histories approach, the background space and time characterize the quasi-classical histories that are supposed to emerge from the quantum theory. In a full theory of quantum gravity, however, one expects there to be no background space–time at all, and so a new notion of emergence is required.

In canonical approaches to quantum gravity these difficulties have been addressed, if not resolved, for example in the work of philosopher Jerermy Butterfield of Cambridge University and physicist Chris Isham of Imperial College London (arXiv:gr-qc/9901024). In string theory, however, the notion of emergence begs for further discussion, and could lead to fruitful collaboration between physicists and philosophers.

The future(s)

Finally, philosophy could help with the quite general question of whether there are ways to describe the world that do not involve matter being distributed in three large (i.e. non-compactified) space dimensions and one large time dimension. String theory and other approaches to quantum gravity – indeed all contemporary physical theories – assume that our world is well described on ordinary energy and length scales as a 4D space–time, and go on to contemplate elaborations (extra spatial dimensions in the case of string theory) and modifications (such as quantization of space–time in the case of loop quantum gravity) of this basic structure. But long-standing difficulties in interpreting quantum mechanics, such as the measurement problem and the emergence of classicality, and the conceptual and technical difficulties involved in non-perturbative quantum gravity could mean that this picture is incorrect.

For instance, one might contemplate multiple time dimensions. Physicists Itzhak Bars of the University of Southern California (2001 *Class. Quant. Grav.* **18** 3113–3130) and Chris Hull of Imperial College London (arXiv:hep-th/9911080) have explored different ways that multiple times might enter into string theory. Another possibility is that quantum theory itself is an artefact of the assumption that the world has a single time dimension. For instance, perhaps a "classical" theory with multiple time dimensions could explain non-local phenomena such as entanglement.

This idea is highly speculative, of course. But explorations along these lines would seem to be an excellent collaborative exercise for philosophers and physicists, given the closely intertwined nature of the philosophical and mathematical aspects of the problem. We can of course resist such speculation by simply insisting – in the spirit of Kant – that it is an *a priori* truth that observers are properly idealized as time-like world lines in a 4D space–time. But we might be more adventurous, in the service of both physics and philosophy.

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