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Big Ideas: Theory of everything

How does the universe work? Finding out is the ultimate challenge, says Lisa Randall

Einstein's theory of general relativity was monumental. However, despite all of its successful predictions, general relativity cannot be the final word on gravity. The theory fails when we try to derive gravitational forces at extremely small distances of order 10?35 metres. At these length scales, which have to be probed if we want to understand issues such as the origin of the big bang or what happens inside a black hole, only a new gravitational paradigm can succeed.

Understanding gravity at all length scales and reconciling it with quantum mechanics isn't the only challenge faced by particle physics. Our theories of particle physics don't yet explain some important questions about particles and forces, such as why we have the particular fundamental particles we do and what is the origin of their masses. It is clear to physicists that we haven't yet arrived at the theory of everything. However, many physicists are optimistic that we can get there. One reason for that optimism is string theory.

According to string theory, the most basic indivisible objects underlying all matter are strings: vibrating, one-dimensional loops or segments of energy. Unlike violin strings, these strings are not made up of atoms which are ultimately made up of electrons and quarks. In fact, exactly the opposite is true. String theory's radical hypothesis is that each particle arises from the vibrations of fundamental underlying strings, and it is the character of that vibration that determines a particle's properties, such as its mass and charge.

These strings could conceivably move around in three, four or more dimensions. But calculations indicate that the correct number, including time, is 10 or 11, depending on which formulation of string theory you use. This remarkable notion, implicit in our best "theory of everything", tells us that there are many more dimensions of space than we see. Moreover, according to string theory, these extra dimensions can contain "branes", membrane-like extended objects on which particles and forces can be confined that exist in these extra-dimensional worlds.

Fascinating and beautiful as its formulation is, string theory still faces many problems. There are many possible models for the observable world that can arise from string theory, each containing different forces, different dimensions and different combinations of particles. We don't yet have the tools to determine whether string theory predicts the correct number of visible (to us) spatial dimensions, the particles, the forces, or the energy in our universe. Addressing unresolved questions in string theory appears to require a fundamentally new approach that goes well beyond techniques that physicists and mathematicians have so far developed. On top of this, the theory is defined at energies that are far higher than our biggest particle accelerators can reach, so testing the theory is going to be extremely difficult, requiring new ways of connecting the ideas of string theory.

Only with time will we know if our current approach to the theory of everything is the right one. But successful calculations about black holes and forces have given stunning indications that we might be on the right track.

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