None of the explanations for how quantum computers achieve speed-up is universally accepted.
While Deutsch didn’t suggest that quantum parallelism requires access to *all* of Hilbert space – every possible quantum state of a wavefunction – Poulin’s work shows that a quantum system is able to explore much less of it than might be imagined.

For Steane and many other quantum theorists, the real key to quantum speed-up was instead the phenomenon of entanglement – the ability to place two qubits in co-dependent states, in which a measurement performed on one of them instantly fixes the state of the other one. So, for example, if two entangled spins are anticorrelated, a measurement revealing one of them to be “up” compels the other to be “down”.

Ever since entanglement was first highlighted by Albert Einstein and his co-workers in 1935, it has been seen as perhaps the central “weirdness” of quantum theory. The weird thing about it is that as soon as one of the qubits is measured, the second qubit assumes its correlated value immediately, faster even than information could be sent between the two qubits via a light signal. In Einstein’s view, in which faster-than-light communication is forbidden by special relativity, this “non-local” influence showed that quantum theory was incomplete and must be underpinned by a deeper layer of reality. His idea was that each quantum entity is described by “hidden variables” that already have specific values before they are measured. But subsequent theory and experiment has shown that entanglement is indeed a genuinely non-local effect, and incompatible with hidden variables.

As Steane wrote in his paper, a quantum computation “uses entanglement to generate and manipulate a physical representation of the correlations between logical entities, without the need to completely represent the logical entities themselves”. In other words, the computer uses the entangled relationships between qubits to manipulate them together rather than one by one – doing only what is necessary, without extraneous intermediate steps.

Therefore, says Fuchs, “Quantum computers can skip steps that would have to have been taken on a classical computer. Computational steps somehow ‘count for more’ on a quantum computer with respect to the necessary classical steps. That’s a completely different idea than parallelism.” Although Steane feels his argument remains valid today, he admits that “it is an issue of interpretation that cannot be settled by an experiment or a mathematical proof of some kind”.

Meanwhile, Dan Browne of University College London suggests that quantum-computational speed-up is more about the interference that is possible between quantum states than it is about entanglement. Quantum interference is familiar from the double-slit experiment for quantum particles. It is subtly different from classical wave interference, and arises from correlations between the probabilities of
Feature: Quantum computing

One oddity of quantum experiments is that their outcomes can depend on the order in which you make the measurements

Robert Raussendorf of the University of British Columbia in Vancouver, Canada, suggests that we are currently more clueless than ever about where the quantum speed-up comes from. If it’s not from the vastness of Hilbert space (of which Deutsch’s many-worlds view was one expression), not from entanglement and not interference, then what? “As far as I am aware, right now it’s pretty silent in the theatre where this question is played out – that’s because the main candidates are all dead,” Raussendorf says.

But he says that recently a new candidate has appeared on the scene, called “contextuality” – a notion that goes back to work done in 1967 by Simon Kochen and Ernst Specker, which examined hidden-variable theories in a manner analogous to that published the previous year by the Northern Irish physicist John Bell. Bell’s theorem helped to prove that the existence of hidden variables is not compatible with the non-local effects that are apparently manifested by entangled states. This led to the now widely accepted belief that hidden variables do not exist.

Kochen and Specker, meanwhile, considered the implications of hidden variables for the issue of experimental context. One oddity of quantum experiments is that their outcomes can depend on the order in which you make the measurements of the variables – for example, whether you measure a particle’s position or momentum first. In other words, there’s a dependence on the context of measurement. In contrast, outcomes in classical experiments are non-contextual: you get the same result regardless of the order of measurements. Kochen and Specker showed that any hidden-variables theory is incompatible with the contextuality that we see in quantum mechanics.

Recently, Joseph Emerson of the University of Waterloo in Canada and his colleagues have argued that, rather than the non-locality of entanglement, it could be the contextuality of quantum physics that supplies the hidden resource needed for at least some forms of quantum speed-up. “Contextuality is the first speed-up candidate about which I am excited,” says Raussendorf.

The myth of quantum spice

Some feel that this debate about the “how” of quantum computation is a red herring. “Researchers attending most conferences in quantum computing never mention these issues, or only in discussions over beer,” says Franco Nori of the University of Michigan in the US. Most people in the field, he says, are focused on immediate practical issues, such as “how to achieve longer coherence times for entangled qubits, how to achieve more operations within each coherence time, how to couple and uncouple qubits controllably, and so on”.

But for others, the problems in explaining quantum speed-up bear on the whole matter of how quantum computers are sold – sometimes literally so. That was clear in the heated debate about whether the world’s first commercial quantum computer advertised by the Canadian company D-Wave in 2012 was a true quantum computer at all, or just a fancy box of tricks

particles’ positions that make the joint probability differ from the sum of the individual ones. Entanglement is one facet of interference, because it too involves correlations, but it’s possible to have interference without entanglement.

Casting doubt on entanglement

For a long time it was widely believed that entanglement could indeed account for the rapidity of quantum computation. That view was cast in doubt, however, by a paper written last year by Van den Nest (Phys. Rev. Lett. 110 060504), in which he outlined a scheme by which quantum computation could be carried out using an amount of entanglement that, by many standard measures, could be arbitrarily small. “Even when the amount of entanglement present in the computation turns out to be very small,” says Van den Nest, “the computation may still be just as powerful as a fully fledged quantum computer that uses lots of entanglement.”

However, he adds, “Asking how large the entanglement must be to yield useful quantum computations is too vague a question to be meaningful, since there are many non-equivalent ways of quantifying it.” It may even turn out, Van den Nest says, “that entanglement plays no decisive role for quantum speed-ups in the first place”. Indeed, work done 15 years ago by Daniel Gottesman (now at the Perimeter Institute in Waterloo, Canada) that formed his PhD thesis at the California Institute of Technology, has long shown that it is certainly not a sufficient ingredient. “High amounts of entanglement do not guarantee speed-ups,” Van den Nest says.

Gottesman’s thesis contained a theoretical technique he developed for studying a class of quantum logic gates that are commonly known as the Clifford group. With this technique, known as the “stabilizer formalism”, many of the current quantum information-processing algorithms can be constructed from the Clifford group, in particular those designed to correct errors that develop in the computation. “Quantum circuits built using the Clifford group are able to make very entangled states, or states consisting of large superpositions, and can cause widespread interference between different branches of the wavefunction,” Gottesman explains.

Despite that, the stabilizer formalism shows that there is an efficient classical algorithm that can simulate the gates in the Clifford group. In other words, at least for this class of quantum gates, neither entanglement nor interference guarantees any advantage over classical circuits. “Therefore, Clifford group gates cannot give you an exponential speed-up over classical computation,” says Gottesman.
Thanks to our Boundary Element Method (BEM), designers don't need to mesh the air volumes around the objects. No need to draw boxes or spheres with appropriate proper ti es around the en ti re arrangement as in FEM programs. The posi ti on of objects can be easily shi fted without any meshing.

The Spot Size Calculation in LORENTZ v9.2 gives you the radius of a circle which encloses a specified fraction of the beam. This new calculation can be used during parametric analysis.

Run Spot Size Parametrically

The Spot Size Calculation in LORENTZ v9.2 gives you the radius of a circle which encloses a specified fraction of the beam. This new calculation can be used during parametric analysis.

Boundary Element Method (BEM) Solver

Thanks to our Boundary Element Method (BEM), designers don’t need to mesh the air volumes around the objects. No need to draw boxes or spheres with appropriate properties around the entire arrangement as in FEM programs. The position of objects can be easily shifted without any meshing.

Put our Software to the Test

Send us your model, whatever the level of complexity. We will show you how to get results from your exact design - no canned demos.

Contact us for an evaluation and start improving productivity today. A live demo is also available.