Analogue logic for quantum computing

Digital logic, or bits, is the only paradigm for the IT world, and up to now researchers used it almost exclusively to study quantum information processing. But European scientists, in a series of firsts, have proved that an analogue approach is far easier in the quantum world.

Modern computing is digital, a series of 1s and 0s that, once combined, create powerful information processing systems. The system is so simple – on or off, yes or no – that it almost seems dumb. It is that very simplicity that gives digital computing its power. It works very well.

But we have a problem. Silicon circuits are getting so small that they will soon be bumping up against a fundamental physical limit.

“We know very well that, as the miniaturisation of computers continues, at some point the carriers of information will have a size that approaches that of atoms,” warns Nicolas Cerf, coordinator of the Covaqial project. “As classical physics becomes inapplicable, we will have to look at quantum mechanics for our future information processing systems.”

And that is exactly what quantum scientists have been doing for the last 20 years. Essentially, they have been attempting to reproduce the classical, digital, computer of 1s and 0s in the microscopic world by using particles to carry information as quantum bits, or qubits. Up to now, it really was the only game in quantum town.

Logic, but not as we know it

But this is changing. Covaqial led the charge for a new type of quantum information processing when it began four years ago. It looked at an analogue logic paradigm for the quantum world, using continuous variables instead of 1s and 0s.

“In classical computing, there have been attempts to create an analogue logic, but no major success,” notes Cerf. “But it turns out, for a variety of reasons, that using an analogue approach, like continuous variables, might work very well in quantum computing. We felt it was a promising approach, so that is why we started up Covaqial.”

Unlike qubits, where one atom or particle carries the information, continuous variables (CV) use an ensemble of atoms or photons to carry the information – the first with matter and the second with light.

Both digital and analogue approaches to quantum information science use the peculiar properties of quantum particles as the ‘signifier’ of the information carried, such as the spin of a single electron or the polarisation of a photon for qubits, or the analogue properties of a group of electrons or photons for CV.

“It is the collective property of this group of electrons, or photons, that becomes the information carrier in CV. When you have this many particles you can call it continuous even though there are many very small steps in the information-encoding variable,” relates Cerf.

The upshot, though, and what makes CV interesting, is that it is much easier to manipulate, control and experiment with than individual particles. Quantum teleportation using qubits, for example, was described in the early 1990s and proved experimentally five years later. In contrast, teleportation with CV was proved experimentally just one year after it was theorised. All because CVs are much easier to use.

Cat out of the bag

The field looked promising, and after a series of spectacular results Covaqial proved that CV could provide elegant solutions to some of the fundamental issues affecting quantum information processing.

“We achieved the first major result after less than one year. It was an experiment demonstrating quantum memory,” explains Cerf. “It’s like classical memory, so it is really a prerequisite for the field.”

The team demonstrated memory for a light pulse stored in an atomic ‘ensemble’ during one millisecond using CV. It might not sound like much, but remember light travels several hundred kilometres in that time. Even if looped in an optical fibre, the energy is so delicate that it would disappear in well under a millisecond. They did this at room temperature, whereas atomic qubits generally need to be super-cooled.

The second result created an optical ‘Schroedinger’s cat’. Schrödinger’s cat was a thought experiment that illustrated how objects can have two distinct states at the same time, in this case a dead cat and a live cat.

Covaqial created a light pulse – an ensemble of photons – simultaneously in two states. “It is very important for the development of a quantum repeater, which will allow quantum communications to extend to much further distances,” Cerf reveals.

Finally, for the first time ever, an experiment demonstrated interspecies quantum teleportation. Teleportation occurs where the state of one particle is moved onto another particle. “It had been done before with photons or atoms, but this is the first time it worked from photons to atoms. These were our most impressive results, but we had many more,” notes Cerf.

As a result of their work, CVs are now a hot topic in quantum information processing, and Covaqial propelled Europe to leadership in the field. Now, the team will continue their work in a new European Commission project, COMPAS, starting in a few months.

“Strictly speaking, Covaqial was about quantum communication, but all the results will be essential for the development of quantum computing,” explains Cerf. “COMPAS will attack directly the challenges of quantum information processing using CVs.”

Further helping to usher in the era of the analogue quantum computer.

Source: ICT Results