THE UNIVERSITY OF WESTERN AUSTRALIA

Particles
The Physics Work Experience Newsletter

Did the Chicken Cross the Road?

Particles is a 'mini-newsletter' which is produced as part of the *School of Physics Science Journalism Work Experience Programme*. This edition was created as part of the work experience by: Caylem Weeks and Tom Reglar, Year 10, Peter Moyes Anglican Community School, Perth, WA

Professor Jingbo Wang,
Quantum Dynamics and Computation Research Group

Have you ever wondered if you could sit on your couch and clean your kitchen at the same time? Sounds crazy, but in the quantum world, such a feat is just a walk in the park. How can one move to the quantum world? Well, the quantum world is not a specific place within the universe, more a way of interpreting and understanding the universe. Over time, equations have been developed to explain the quantum universe, but conventional technology cannot even begin to solve these equations in all but the simplest situations. Professor Jingbo Wang of the School of Physics at UWA is taking steps towards fixing that problem.

Jingbo is the head of the Quantum Dynamics and Computation Research Group, which has been working on the theory behind quantum computers. Her research students Josh Izaac, Mitchell Chiew and Kooper De Lacy are all developing and working on different aspects of quantum computation.
Regular computers work with bits. Bits are very simple, they are either a 0 or a 1 and can only be one or the other. Quantum computers, however, work with qubits. Qubits are similar to regular bits, however they have the possibility of being both a 0 and a 1 at the same time. This means that a single Qubit can perform multiple operations at once, and when combined with other Qubits, will exponentially increase the computing power of the machine.

The first step in creating a quantum computer is to trap a particle, whether that be a photon, electron or atom. Jingbo explained that single particles would be captured through various methods. However, it is not as simple as going out into nature and leaving a trap for an particle to stumble into. One of these methods include using laser-light to trap particles in the troughs of the lasers' overlapping wave-lengths. These particles once captured, can be manipulated to act as Qubits. Simple logic such as 'and' and 'or' functions are applied to the Qubits, but with vastly different outcomes to a traditional bit. Due to the complex nature of a Q-bit, 3 Qubits can perform 2^3 = 8 calculations simultaneously. When

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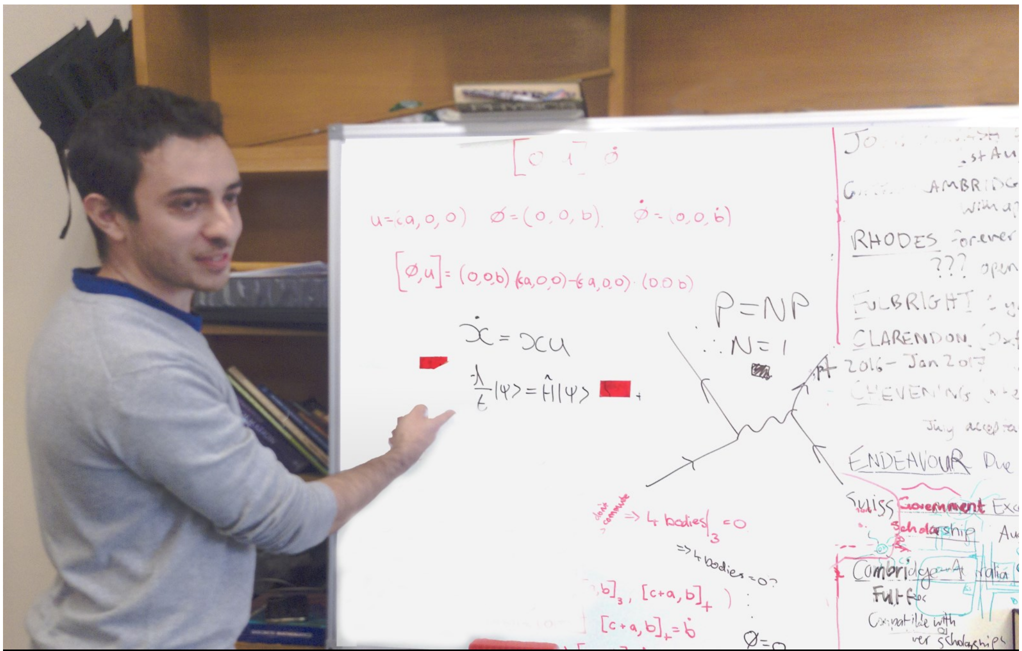

Josh Izaac, explaining the math behind quantum computation

you string together 50 qubits, you have over a quadrillion calculations done all at the same time. This incredible computing power not only excites scientists, but also will have a profound effect on the way we process information.

Jingbo went on to say that there are problems for which we have the equations, but due to technological limitations, regular computers cannot solve said equations. One such application includes the development of new drugs, where a quantum computer holds the promise of simulating chemical and biological processes accurately, therefore allowing biochemists to design thousands of new drugs from first principle theories rather than live human testing, which can be time consuming and costly. Another example of this would be in materials manufacturing, where we know what qualities we want from a material, however it is near impossible to find the correct combination of existing materials that will produce the final material that has the desired characteristics.

Traditional computers don't have the same processing power as quantum computers but quantum computers don't have the same versatility as regular computers. Quantum computers have specific functions. They work for a purpose. As far as we know, quantum computers will be used to solve complicated mathematical equations and thus will be placed in, for example, massive data-centres/exchanges for better filtering and response times. However, don't be thinking that you will be tapping away at a smartphone-scale quantum computer. Regular smartphones, PC's, TV's and the like will still have a place in society and are unlikely to be replaced by their possible quantum counterparts. One can barely keep track of their phone, rather than have to worry about whether it exists or does not... or both!

Due to her research, Jingbo has visited many world leading research laboratories and travelled to every continent on the planet except Antarctica. During a conference that she attended over 10 years ago, she had the opportunity to witness a single trapped atom in a research lab. This demonstrated to her the nexus between theoretical and experimental physics, and how much closer we are to developing a working quantum computer. Today we can trap and manipulate the quantum states of individual particles, ranging from simple atoms to electrons or even photons.

Physicists are researching a range of different methods to bring a quantum computer to life. In 2013, Google and NASA bought a 'quantum computer' from D-Wave. However, the 'quantum computer' received controversial reviews from physicists world-wide, with statements being made that the computer is just a simulated quantum computer, and not a real one. Physicists are discovering many new ways to develop new types of quantum computers, which are far more powerful than 'simulated' quantum computers. To add to that, physicists are also constructing different theories as to the most efficient way to trap atoms for use within said quantum computers. It is anticipated that quantum computing will soon become very prominent and new uses for such technology will be discovered over the next 100 years.

While a full working quantum computer is yet to be designed, very simple versions of quantum computers have been built. Mitchell is working on improving existing quantum gates so as to improve the efficiency of quantum computers. In doing this, he hopes that one day, quantum computers may be able to simulate complex quantum dynamics that evolve over time via the Schrödinger Equation. The quantum state is represented by a mathematical wavefunction that encodes all information about the system. Quantum physicists study the Schrödinger Equation to see how the state of a quantum system changes as time goes by. This equation is very difficult to solve using current technology and quantum physicists world-wide will benefit from improved quantum gates to solve advanced equations like the Schrödinger Equation.

Working in the same realm as Mitchell, Josh is working on the idea of the 'Quantum Walk'. Quantum walking is analogous to classical walking, where a walker's current state is described by a probability distribution over positions. The walker in a quantum walk is placed in a superposition of positions. Imagine you have a virtual city and you design a classical-walk computer program to find the number of coffee shops in the city. Every time it meets a crossroad, it has a 50/50 chance of turning left or right, upon which it will detect the number of coffee shops on that street. In the quantum world, however, it would have the ability to travel both left and right, meaning the coffee shops can be identified within the city much quicker than the classical-walk computer program would be able to identify said coffee shops. Of course, a quantum computer would not be used to find the number of coffee shops within a city, but the above analogy describes how a quantum

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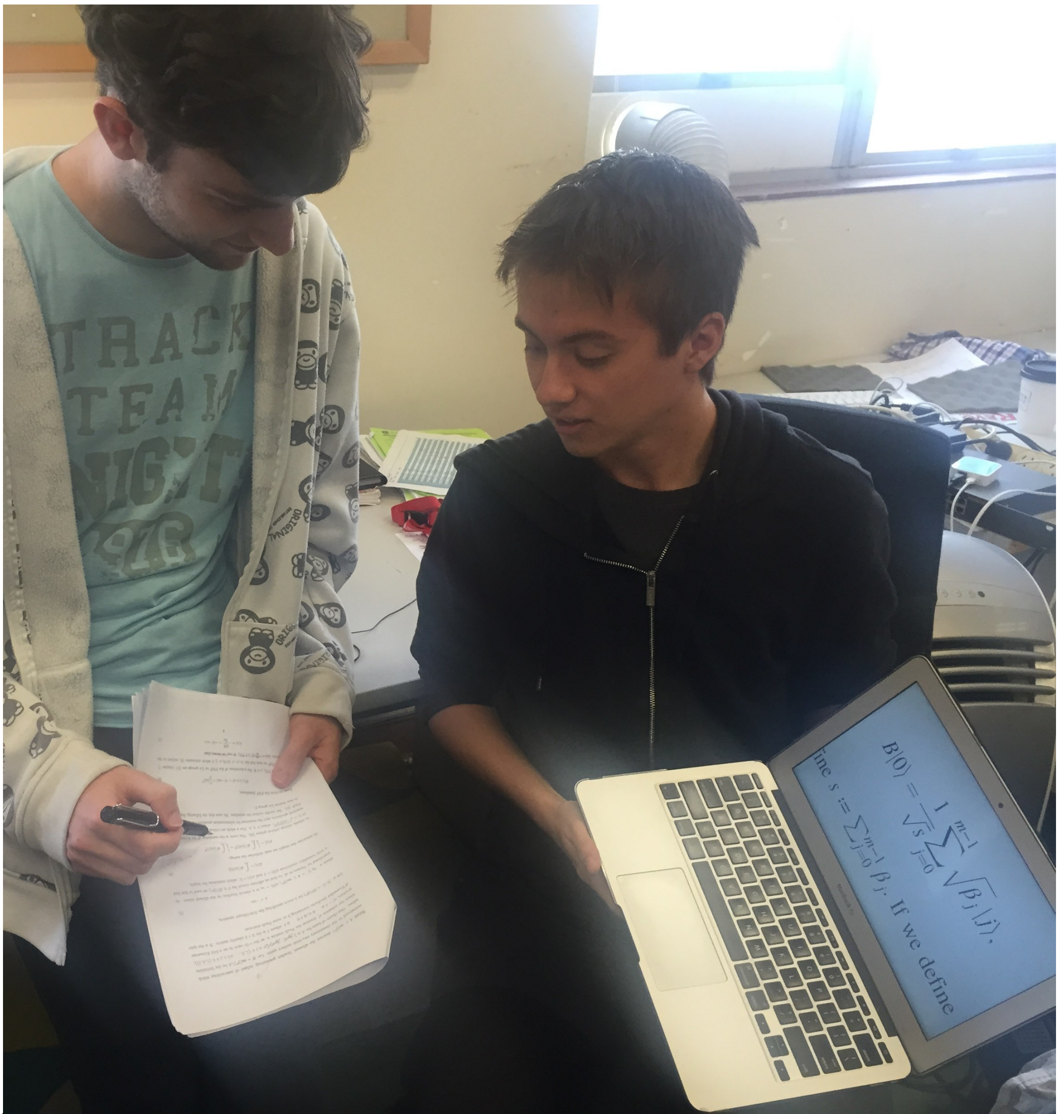

Research Students Kooper De Lacy (left) and Mitchell Chiew (right)

computer is incredibly efficient at finding every possible way of doing something through a quantum walk.

While both Mitchell and Josh are working on components that could be changed or equations that may be calculated with a quantum computer, Kooper de Lacy is working on proving quantum computers are better than their classical counter-parts by providing a method to create quantum circuits able to attain an arbitrary state. The goal is to prove a quantum circuit will use less gates than a classical computer (it is hypothesized a quantum computer will need at most a polynomial number of gates, where classical computers use exponentially many).

Kooper is not, however, referring to regular day-to-day computers like the ones we have in our office spaces. Instead, he is referring to the massive super-computers used by scientists and mathematicians to solve difficult problems via computation, such as those required by the *Square Kilometre Array* (SKA), spread across Western Australia and South Africa which is being designed to take in massive amounts of data collected from telescopes which scan the universe.

Quantum computers are still a while away, but the development process is being accelerated by Jingbo and her research students along with their collaborators across the world. Quantum computers will soon have a great affect on the world of science and our surrounding world.

Erwin Schrödinger's famous *Schrödinger's Cat* thought experiment shows how an electron can be both in one state or the other simultaneously. This highlights how different and unknown the world of quantum physics can be. Using this very same thought experiment, we can work out whether the chicken actually did cross the road. If we assume that the chicken is within a locked cage and that the lock on the cage door will only release due to a decaying atom, then we can assume that if the atom begins to decay, the chickens cage is unlocked, and can cross the road to the other side. If the cage is not unlocked, the chicken does not cross the road. This can be mathematically explained by the equation at the bottom of the page.

The equation describes the probability of the atom decaying and the cage unlocking, meaning the chicken crosses the road, but also describes the probability of the atom not decaying and the chicken staying put in the cage, thus not crossing the road. But until you check if the cage is unlocked, our theoretical chicken is both walking to the corner shop and trapped in an inescapable cage for the rest of eternity.

$$\Psi = \alpha \left| \varphi^{atom}_{excited} \, \varphi^{cage}_{locked} \right\rangle + \beta \left| \varphi^{atom}_{decayed} \, \varphi^{cage}_{open} \right\rangle$$

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Heads Up!

Professor Ian McArthur

February 12th 2016 was a red-letter day for the School of Physics. The School hosted a special event to a packed Ross Lecture Theatre celebrating the announcement of the discovery of gravitational waves and the contribution of researchers at UWA to the discovery.

The event was chaired by the Vice Chancellor Professor Paul Johnson. If ever there was an example of "Pursue Impossible", it was the 40-year quest by our own Professor David Blair and his Gravity Wave Research Group toward the discovery of gravitational waves. The event that produced the gravitational waves detected on 14th September 2015 in the two LIGO advanced interferometric gravitational wave detectors in the US was the most cataclysmic event ever observed by humankind – the merger of two black holes of 29 and 36 solar masses, with the energy equivalent of 3 solar masses being thrown off in the form of gravitational waves.

Whilst the gravitational waves were not detected by instruments at UWA, David Blair and his team made key contributions to the exquisite technology that underlies the LIGO detectors in the US. This was recognized by the fact that 21 of the 56 Australian authors on the Physical Review Letters paper announcing the discovery were from UWA, many of them current and former PhD students.

Back in 2005, the Gravity Wave Group at UWA predicted that the advanced LIGO detectors then being designed in the US would run into a problem called "parametric instability" when they tried to ramp up to full laser power being bounced back and forth between mirrors in the two 4km long arms of the interferometer. Few wanted to believe them and work on LIGO proceeded. However, in 2014, at 25kW of laser power, parametric instability set in – the design power is 800kW. Fortunately for LIGO, David Blair and his research group at UWA, including Associate Professor Ju Li and Dr Chunnong Zhao, had painstakingly built a miniature version of the LIGO detectors at the Gingin research facility in which they not only observed parametric instability, but also researched techniques to overcome it.

Some of these techniques were rapidly implemented at LIGO in 2015 (with the help of UWA PhD student Carl Blair, David's son) and allowed the detectors to reach power levels of 100kW, sufficient to observe the 14th September binary black hole merger. Carl is now working at LIGO to implement measures to get the power up to 200kW.

But there is more good news! As recently announced on June 16th, another black hole merger was observed on Boxing Day 2015 by the LIGO detectors. This shows that the event rate is much higher than anyone had predicted or dared hope for – so that when LIGO reaches full design sensitivity, event rates of thousands per year are possible. This really opens up a new window on the Universe – Gravitational Wave Astronomy, part of David Blair's 40 year dream.

Meanwhile David and his team are pursuing another dream – to build a full scale Southern Hemisphere gravitational wave detector at Gingin. Watch this space! Speaking of celebrations, the School will again be holding its annual Alumni Evening in October. A great chance to catch up with old friends and to hear about what is happening in the School of Physics. Please watch out for the date, which will be announced by email and on Facebook.

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