ScienceWise

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NEWS

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The Editor's Corner

Natural laboratories

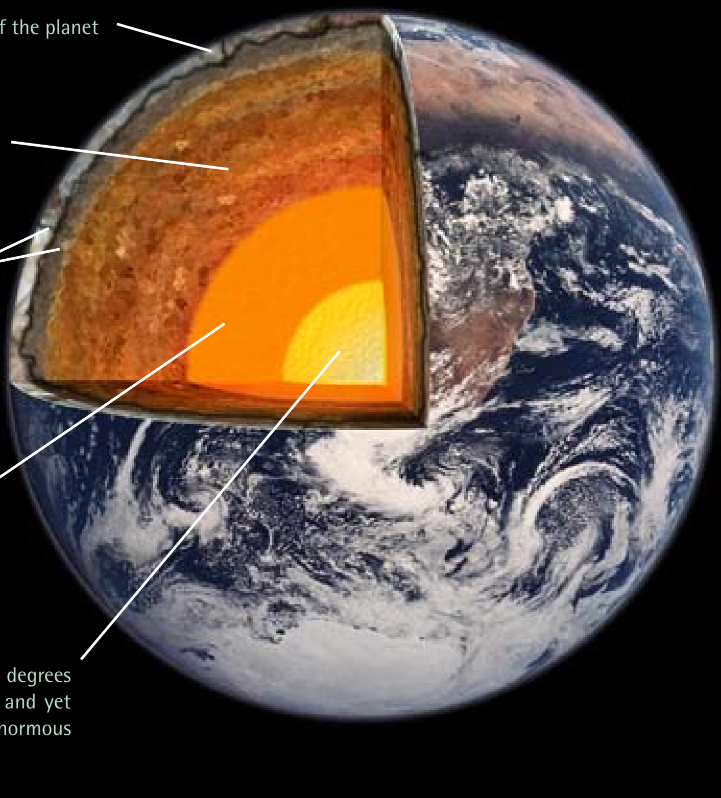
Dr Tim Wetherell

The basis of the scientific method is to make observations, formulate a theory based on those observations and then design experiments to test that theory further. In some fields such as chemistry and physics this is often the way things move forward. It's usually possible to design experiments in the laboratory that will test various aspects of current theory. But in some other sciences such as astronomy and parts of geoscience, it's a lot harder because the things you theorise about are massive, remote and largely uncontrollable.

Astronomers can't double the mass of a star to see what happens. Earth scientists can't open up planets and see what's inside. In some ways that makes such areas of research particularly interesting and challenging. Science becomes more like a detective mystery to solve. You have to build up a picture of what's going on from the clues you can find and clever logical reasoning.

We're running a story in this issue about a new model of tectonic plate movement. But have you ever stopped to consider how we know that there are such things as tectonic plates in the first place . Or how we know that our own planet has an iron core?

It's impossible to drill to anything like the necessary depths to see the internal structure of the Earth and yet we've been able to figure out a very detailed picture of the inside of our planet from numerous careful observations of natural phenomena (see page 6). Humans have also figured out a great deal about the structure of the universe billions of light years away without ever leaving our own solar system. Steven Hawking is quoted as saying "We are just an advanced breed of monkeys on a minor planet of a very average star. But we can understand the Universe. That makes us something very special." Sometimes when I watch the news, I wonder about the advanced bit, but I think he's basically right. It is amazing what reason and logic can accomplish. There should be more of it!



Boxing clever

David Salt

Making sure that what we think is good for box-gum woodland restoration, actually is.

Box-gum grassy woodlands were once a widespread and productive ecosystem in south eastern Australia. However, since European settlement we've lost (largely through clearing) around 90% of the woodlands. Of what's left, only around 5% is regarded as being in good condition, although, the description of 'good' is a relative term because we simply don't know how today's woodlands compare with pre-European woodlands. We do know that most of what is left is degraded and experiencing declining biodiversity.

How do you manage, protect and improve important ecosystems like the box-gum grassy woodlands when you have no benchmarks of what a healthy ecosystem might be? That's the daunting challenge facing a new collaborative research project between scientists at ANU and the ACT Government which is seeking to determine how to best manage grassy box woodlands on the northern boundary of the Australian Capital Territory – in the Mulligans Flat and Goorooyarroo Nature Reserves.

Adrian Manning is working on the science to enhance box-gum grassy woodlands.

"We're looking at ways of improving grass box gum woodlands for biodiversity by setting up various manipulations and treatments in Mulligans Flat and Goorooyarroo reserves," says Dr Adrian Manning, a Research Fellow at the Fenner School of Environment and Society. Adrian manages research on the project.

"Our treatments include adding dead wood, using controlled burning and excluding kangaroos that are currently over abundant at the site and are having a major impact on the system," says Dr Manning. "The ACT Government is also going to build a feral-proof fence around one half of the experiment to keep out foxes, cats and dogs. The idea being that we can look at the effects of all these treatments and the interactions between these treatments."

Conserving box-gum grassy woodlands is not a new issue; it's one that ecologists and conservationists have been pondering for decades. Adding 'fallen' timber, managing fire regimes and controlling grazers and predators all seem like logical things to do. Why do we need to experiment with them?

"The experiments are crucial because we really don't know how these treatments will work or interact," says Dr Manning. "And our record of protecting grassy box woodlands isn't very good.

"So far, conservation efforts have involved fencing out stock, trying to stop people taking out dead wood (usually as firewood) and tree planting. The hope is that fencing out stock might allow tree regeneration but in a lot of cases these ecosystems have changed so much that fencing by itself isn't enough. Phosphates have been added and exotic understoreys, often grasses, have come in. Which means, in most places, there's actually been a regime shift. The system has changed so much it's operating in a different way. It's not just a case of relaxing those threatening processes and letting the system recover. We know that simply leaving an area alone doesn't always work.

"One example of this is that we're still witnessing the disappearance of species from box-gum woodlands, even those placed in a reserve. Mulligan's Flat, for example, was set aside as a reserve in 1995. At that time it had brown tree creepers, a threatened woodland bird species. Several years after it was declared a reserve it lost its population of brown tree creepers – they've become locally extinct in that woodland. And we're seeing similar things happening in other reserves. So, threatening processes are not being reversed by creating reserves. Therefore there's a need for proactive conservation, and what we're trying to do is provide the evidence for how this might be best done in box-gum woodlands."

A line of ACT Parks and Conservation Officers forms to herd kangaroos out of a 'roo exclosure' treatment.

The woodlands experiment is unique on a number of scores, including its scale of operation.

"We're not being half-hearted with our treatments," says Dr Manning. "It probably hasn't been approached in such an intense way at one site ever before. For example, with the addition of dead wood we've added at least 2000 tonnes of timber, which would make it one of the largest types of experiments like this, at the very least in Australia.

"And working closely with a government partner is another noteworthy aspect of this project. I think and I hope that this project can show the way that researchers and conservation agencies can work together so there's more of an integration of restoration conservation and research and we get a more evidence-based approach to conservation. And these timber treatments are a good example of this.

"I mean we could just say: 'fallen timber provides important refuge for small mammals so just add timber' and not specify how much or in what distributions. But what we want to do is take a bit more of a scientific approach and tease out what works and what doesn't. So, if you're going to add timber, let's test how much you need to get the desired effect and how do you spread it.

"In our experimental design we're looking at different distributions, clumping or dispersed patterns and mixtures of both. And that's important because timber is expensive to move so you don't want to put on any more than you have to.

"I think that's a good illustration of why it's important for science to be involved rather than simply saying 'let's add more timber'. What we hope to do is to inform that process of restoration and demonstrate the value of such a process."

The woodland enhancement experiment has many partners. In addition to ANU and the ACT government, there and several researchers from CSIRO Sustainable Ecosystems and CSIRO Entomology, with a variety of PhD and honours students studying different components in the system.

"One of the unique things about this project are the linkages between ourselves, the ACT government and other research institutions," observes Dr Manning. "The idea is not simply that we are the scientists and they are the government who are doing things for our experiment. Rather, we own the experiment together and we work together to make it happen. What we learn and achieve is shared. It can take longer to set up such a process but I believe the benefits are also more long lived."

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"Timber!" Another log is dropped into the nature reserve. 2000 tonnes were brought into the reserve.

When push comes to shove

Tim Wetherell

New 3D model of the earth's crust may change theories of continental drift

Most people are aware that the continents of the earth sit on top of various tectonic plates that in turn, slowly drift across the surface of the planet. In places they collide and one plate passes beneath another in a process called subduction.

For decades it has been widely believed that the force of impact between plates drives one plate beneath the other. A new three-dimensional tomographic map of the earths crust developed by Dr Simon Richards and Professors Gordon Lister and Brian Kennet is helping geologists understand the shape and dynamics of subduction zones and how these zones may well define how continents move around the earth.

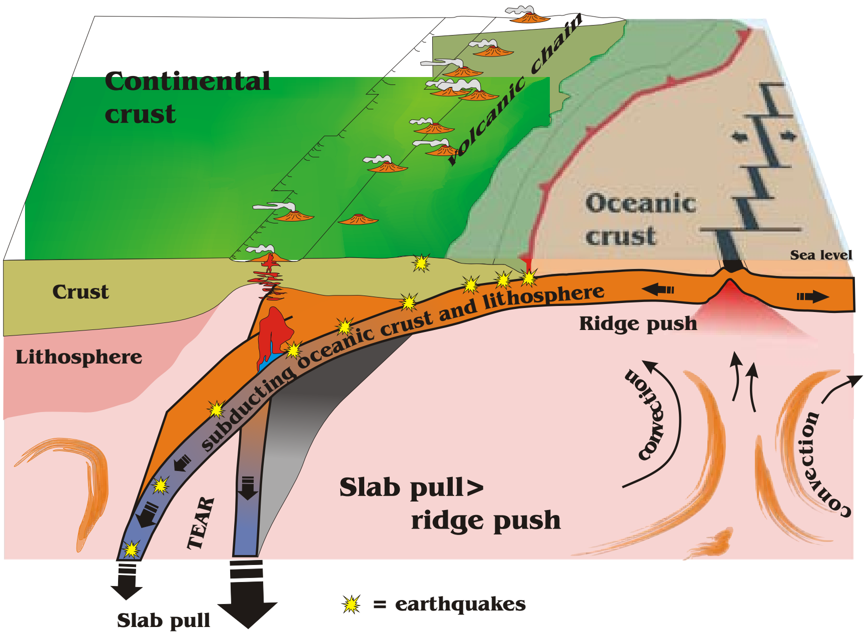
It's actually quite difficult to probe the structure of the earth a few hundred kilometres down. The depth is too great for ground penetrating radar and sonar images created by small probe explosions on the surface. To get around this the researchers take advantage of the millions of tiny earth tremors and quakes that occur almost constantly around the globe. The vast majority of these are so small as to be imperceptible but each one sends seismic shock waves through the planet. By having a large network of sensitive recorders across the world and by recording data from them all simultaneously, it is possible to build up a sonar picture of the earth's interior. Although extraction of tomography from the raw data is a highly complex task, the researchers have been able to build up a large-scale model of much of the earths crust extending down in places by over a thousand kilometres.

Just like sound waves in air, the shock waves that travel through the planet are strongly reflected at places where the density changes abruptly. This means that the technique is particularly suited to the study of subduction zones, where cold dense surface rock protrudes deep in to the hotter mantle.

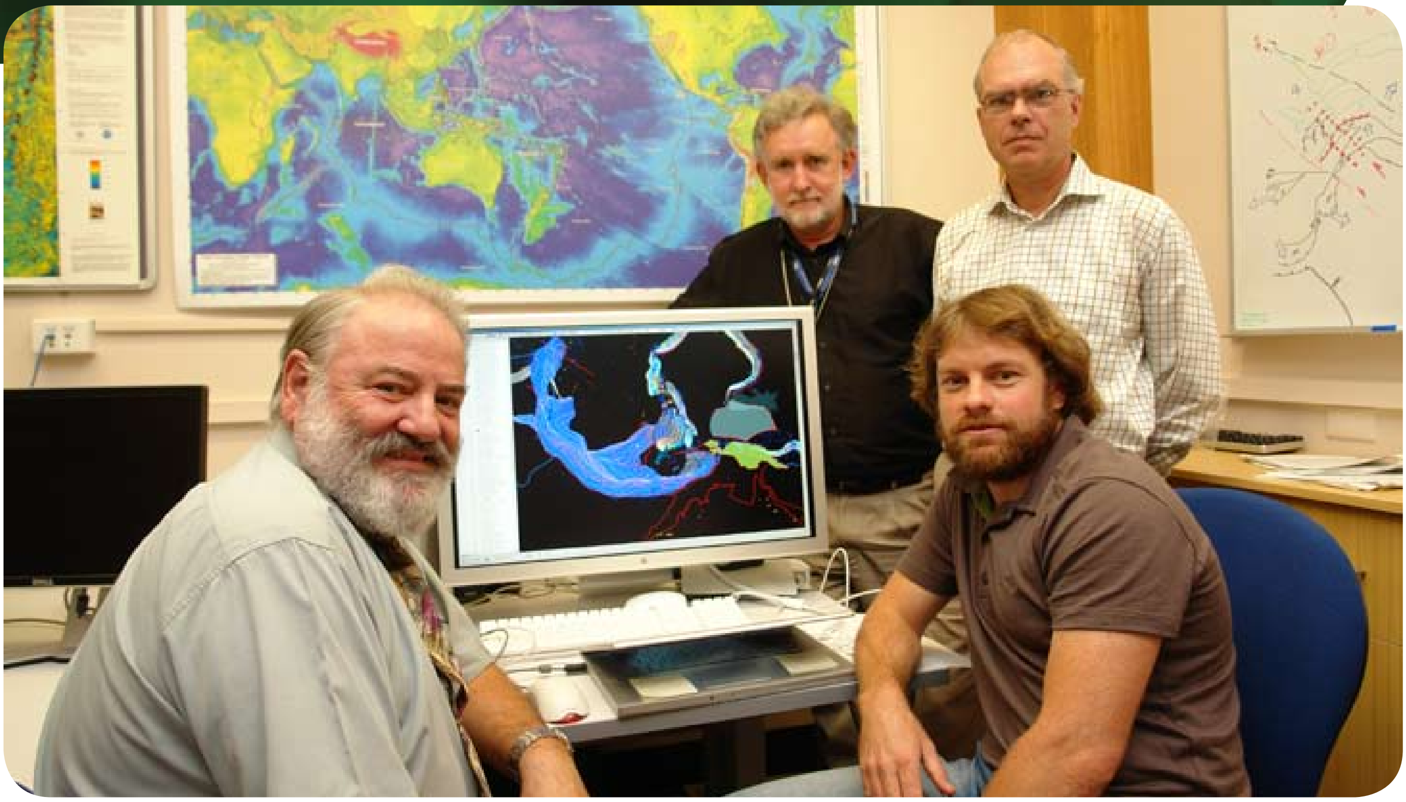
The rock that makes up the subducting plate (typically oceanic seafloor) contains fluids trapped within and between crystals. When these are plunged into the surrounding mantle - which is often hundreds of degrees hotter - they induce a variety of effects. As the cold rocks heat up and recrystallise, the escaping fluids interact with the overlying mantle which, when combined with stretching of the lithosphere below the overlying plate, induces the generation of magmas at depth. These magmas rise to the earth's surface where they form volcanic activity at the earth's surface. Plate subduction is the process causing volcanism around the Pacific rim today. This process also has the side effect of scavenging/concentrating minerals from the mantle/subducting plate and transporting them upwards with the magma flow. The practical upshot of this is that highly concentrated mineral deposits such as gold and copper are often found in the vicinity of subduction zones.

Dr Richards explains that "the detailed models that we are now able to develop show that certain structures found on the subducting plate are frequently associated with a high concentration of earthquakes and whilst it's very difficult to predict the timing of such quakes, the model does help pinpoint places where these events are highly likely." Unfortunately for us, one such zone is a couple of thousand kilometres off the north east coast of Australia. A large quake there could have the potential to generate a tsunami similar to the one in the Indian Ocean on Boxing Day 2004, though this time hitting land on Australia's eastern coast. "The interpreted geometry of the subducted plate there is alarmingly similar to the structure of the slab below Sumatra," says Dr Richards.

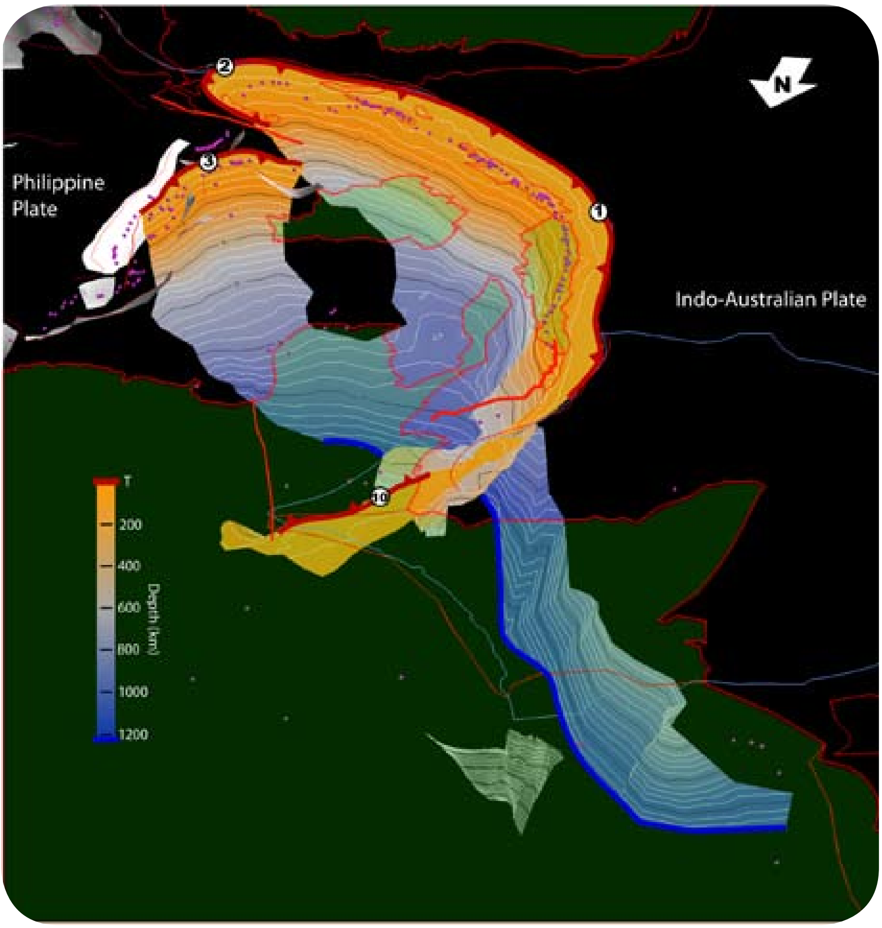
Better identification of areas likely to be affected by large earthquakes and exploitation of mineral assets are two very practical uses for this new model but from a purely scientific perspective, it is showing us just how important subducting slabs are in controlling the motion and shape of plates. Where two plates collide it was once believed that the force of the convecting mantle forced the



A simplified image of a hypothetical subduction zone where an oceanic plate and lithosphere is undergoing east-directed subduction beneath an overriding continental plate. The weight of the sinking oceanic plate as it subducts, known as slab pull, drags the trailing plate behind causing rifting between two plates. Old crust is subducted while new crust is formed at these spreading centres. Subduction zones are where most of the worlds volcanoes and earthquakes are located so understanding the geodynamics behind subduction is key to understanding when, where and how these sometimes devastating natural events occur.



Dr David Falvey from the ARC, visits professors Gordon Lister, Brian Kennet and Dr Simon Richards in the visualisation lab.



A snapshot from the 3D Virtual Earth looking across India and SE Asia towards Western Australia. The contoured surface is the interpreted shape of the subducted part of the Australian plate which now lies deep within the mantle below SE Asia. The Australian plate (i.e. the fused Indo-Australian plate) is moving northwards at around 5 cm per year and as a consequence, has been subducting beneath SE Asia for millions of years. As the plate enters the mantle at the subduction zone, it bends and contorts resulting in the present day shape of the slab. Volcanoes and earthquakes in Sumatra, Java and Timor are all a result of this subduction process.

underlying plate down into the mantle. Whilst Dr Richards acknowledges this is definitely the case in some areas, the majority of subduction zones visible on the model seem to operate quite differently. The edge of a tectonic plate is denser that the underlying mantle so it sinks slightly into it. The forward movement of the plate then causes this leading edge to plane down into the mantle. This has the potential to tear continents apart such as the case when South America broke away from Africa around 130 Million years ago.

Dr Richards believes that as the leading edge of the plate planes down into the underlying mantle, it causes extension in the region immediately in front of it. In effect this creates a suction that draws the overlying plate towards the retreating hinge of the subducting plate. This is the situation with South America and Africa. A subduction zone off the west coats of South America created the vulcanism that formed the Andes. It also has the effect of continually dragging South America to the west, away from the African continent. The Atlantic ocean separating the two continents is being pulled apart and the tearing crust is replaced by the formation of new oceanic crust by up-flow of mantle. So, while the Pacific Ocean is being consumed by the westward motion of South America, the Atlantic ocean is growing larger. In this way, it is subduction that appears to be controlling the drift of continents.

Beyond the test tube

David Brittan

Supercomputer quantum chemistry in the twenty-first century

Chemistry is the study of whether or not substances react and what they produce if they do. Chemists know how different chemicals interact from their experiments, but what if they could predict how they react by simply running a computer program? If they could do so this would reduce the amount of reagents needed and make experimental chemistry more efficient. This dream has been largely realised over the last 50 years with major advances in computational chemistry, however problems still remain, and work performed in the ARC Centre for Excellence for Free Radical Chemistry and Biotechnology is helping to solve them.

The reactivity of chemical compounds is governed by energies: how much energy is released or required for a reaction to take place, and how large an energy barrier exists between the reactants and the products. These energies can be determined using computers, and are used to predict how fast a reaction is, and whether it will occur or not. However, the energies must be determined very accurately for these predictions to have any relevance in the real world.

There are many different ways of working out these energies, but the best methods are based on quantum mechanics. As objects get smaller and smaller, the physical laws that normally govern how things behave start to break down. The "Newtonian" mechanics that describes how cricket balls, cars and bicycles move no longer holds for the electrons in molecules; they do not even have definite positions and speeds, but instead have a wave function Ψthat defines their properties.

This wave function, as well as the total energy of the molecule, is determined by solving the Schrödinger equation. This equation can only be solved exactly using pencil and paper for some very simple cases such as the hydrogen atom; everything else needs to be treated approximately using computers.

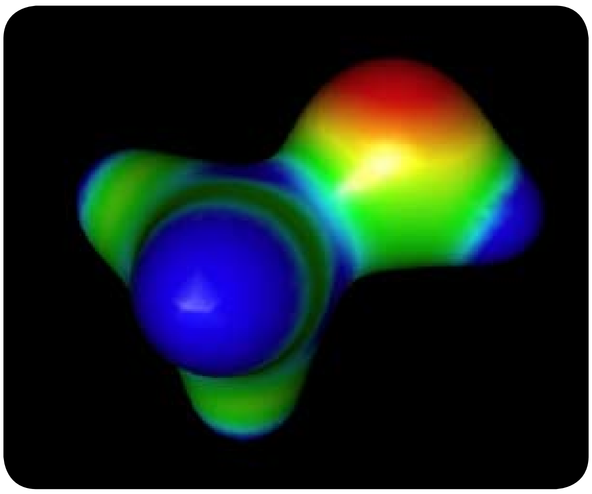
The better the approximation, the better the results. However, the most accurate quantum mechanical methods (termed "ab-initio" methods) are far too time-consuming for systems with more than a few atoms, even with supercomputers. Molecules of relevance in biology or polymer science are often much, much bigger than this, and an enormous amount of research has been directed towards finding ways of doing the quantum mechanics that capture the essentials, but work faster than the old methods. This allows chemists to predict and rationalise the products they obtain and determine how fast reactions occur for large compounds that are relevant to real-world applications.

One major advance in this area is Density Functional Theory (DFT). In 1964, Hohenberg and Kohn showed that instead of solving the Schrödinger equation, the energy of a system could be obtained from the "electron density" Ψthe probability of finding an electron at each point in a molecule. This is a much simpler mathematical object than the wave function, so the calculations are intrinsically much quicker than the best of the approximate quantum-mechanical methods, and the results are, in principle, just as good. The problem is that no one knows the true relationship between the electron density and the energy. Even the way to go about approximating the true relationship is unknown. So chemists and physicists are forced to use a trial-and-error approach, designing new methods based on a series of assumptions. If a new method works, then the assumptions the method is based on are probably good ones, and the assumptions can then be refined to generate better methods.

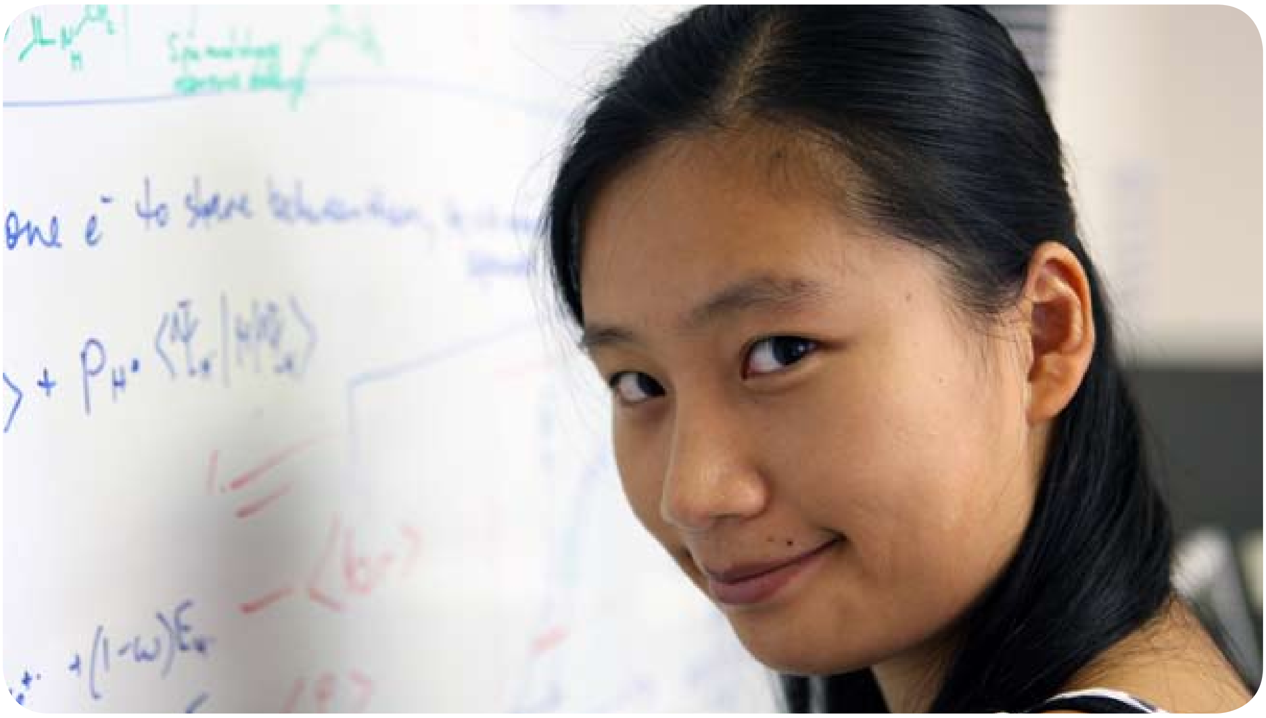
Unfortunately, while DFT gives excellent results in many cases, even the best of these methods do not work well in all situations.

Dr Michelle Coote and her team at the Australian National University in the ARC Centre for Excellence for Free Radical Chemistry and Biotechnology are addressing this problem, in collaboration with Peter Gill and Andrew Gilbert, also at the Australian National University.

They are trying to determine when and why DFT methods fail, and whether or not the problems can be eliminated.



Supercomputer model of a molecule



Dr Leaf Lin of the ARC Centre for Excellence for Free Radical Chemistry and Biotechnology Photo: Norman Plant

This will allow chemists to make more accurate predictions on large molecules of relevance in biology and polymer science, reduce the computer resources required for smaller molecules, and help design better DFT methods that work for a broader range of problems.

Until the failures of DFT have been properly characterised, Michelle Coote's research group will use state-of-the-art ab-initio methods to investigate reactions of interest in polymer science and biology. Although these methods are extremely time-consuming, reactions involving quite large molecules with up to 20 "heavy" atoms (atoms other than hydrogen) can be treated very accurately, but the calculations require a supercomputer with an extremely large amount of memory. Together with many other chemists, the Coote group uses The Australian Partnership for Advanced Computing National Facility; the fastest computer in Australia. It has 1680 processors, 3.56 terabytes of memory and a peak speed of more than 11 trillion calculations per second. It was the 26th-fastest computer in the world when it was completed in 2005, and is currently ranked 200th fastest.

Some members of the ANU quantum chemistry team, David Brittain, Dr Leaf Lin, Dr Mansoor Namazian and Jennifer Hodgson . Photo: Norman Plant

At present, massive computers such as these are required to perform accurate calculations on all but the smallest of molecules, and those with more than 20 "heavy" atoms are a significant challenge. Many molecules of interest in biology and polymer science cannot be investigated accurately for this reason. DFT methods allow much larger molecules to be investigated, however they are not yet accurate enough for general use, and until their failings have been characterised, they will be used with caution.

Computational chemistry is an exciting science that offers much insight into chemical reactivity, and yields information that is complementary to experimental data. Unfortunately, only small- to medium-sized molecules can be treated accurately at present, but the boundaries are continually being pushed, and it will not be long before accurate techniques are available that can be applied to large molecules as well.

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In the eye of the dragonfly

David Salt

New insights into visual control of flight

Have you ever marvelled at the dazzling aerial control exhibited by dragonflies? One moment they hang mid air perfectly stationary, and in the next they dart away like a lightning bolt. Part of their aerial mastery relates to how they 'see' their surrounds and scientists at the Research School of Biological Sciences (RSBS) have discovered that the middle eye of the dragonfly is a lot more sophisticated than previously believed.

All insects have two large compound eyes on the sides of their heads, and three simple lens eyes or ocelli in the centre. There are two small lateral ocelli and a larger middle one called the median ocellus. In the dragonfly, the median ocellus is curved.

"Ocelli are generally thought to have poor resolution," says Josh van Kleef, a PhD student at RSBS who is leading the research on dragonfly vision. "The general belief has been that they're there to measure general light levels which can be used to stabilise their flight. The idea is that if they detect that light levels are falling they're heading down, and if the levels are rising they're heading up. This information is then used to guide their movement."

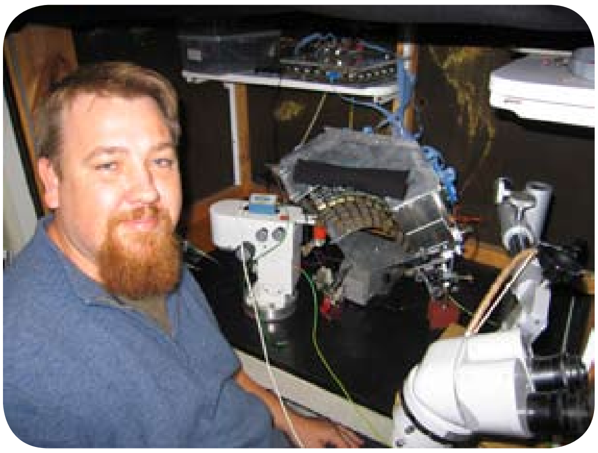
However, Mr van Kleef's research is revealing that a dragonfly's middle eye does a lot more than simply pick up on general light levels.

"The median ocellus is a simple lens containing about 1500 photoreceptors," he explains. "These photoreceptors are connected to 11 large neurons (nerve cells) which go from the retina all the way down the neck of the dragonfly to the insect's motor centres. It's a very direct route from a visual response to a change in movement, and allows for a very rapid response to their environment.

"Now, we've demonstrated that the neurons in the middle ocellus have a much better resolution than was previously believed. They seem to be focussing on the horizon rather than average light levels.

"We created a special display that's able to produce UV and green images. It's long been known that large ocellar neurons respond to UV and green light but no other researchers have tested for both wavelengths of light in the same test rig.

"We showed that if you move images of bars (rows of lights) in front of the dragonflies, that they can detect them. What's more, we discovered that when you switch from green to



Josh van Kleef with the dragonfly test rig

UV these neurons become very directionally selective. This demonstrates that dragonfly image perception through its median ocellus is much more sophisticated than was previously appreciated."

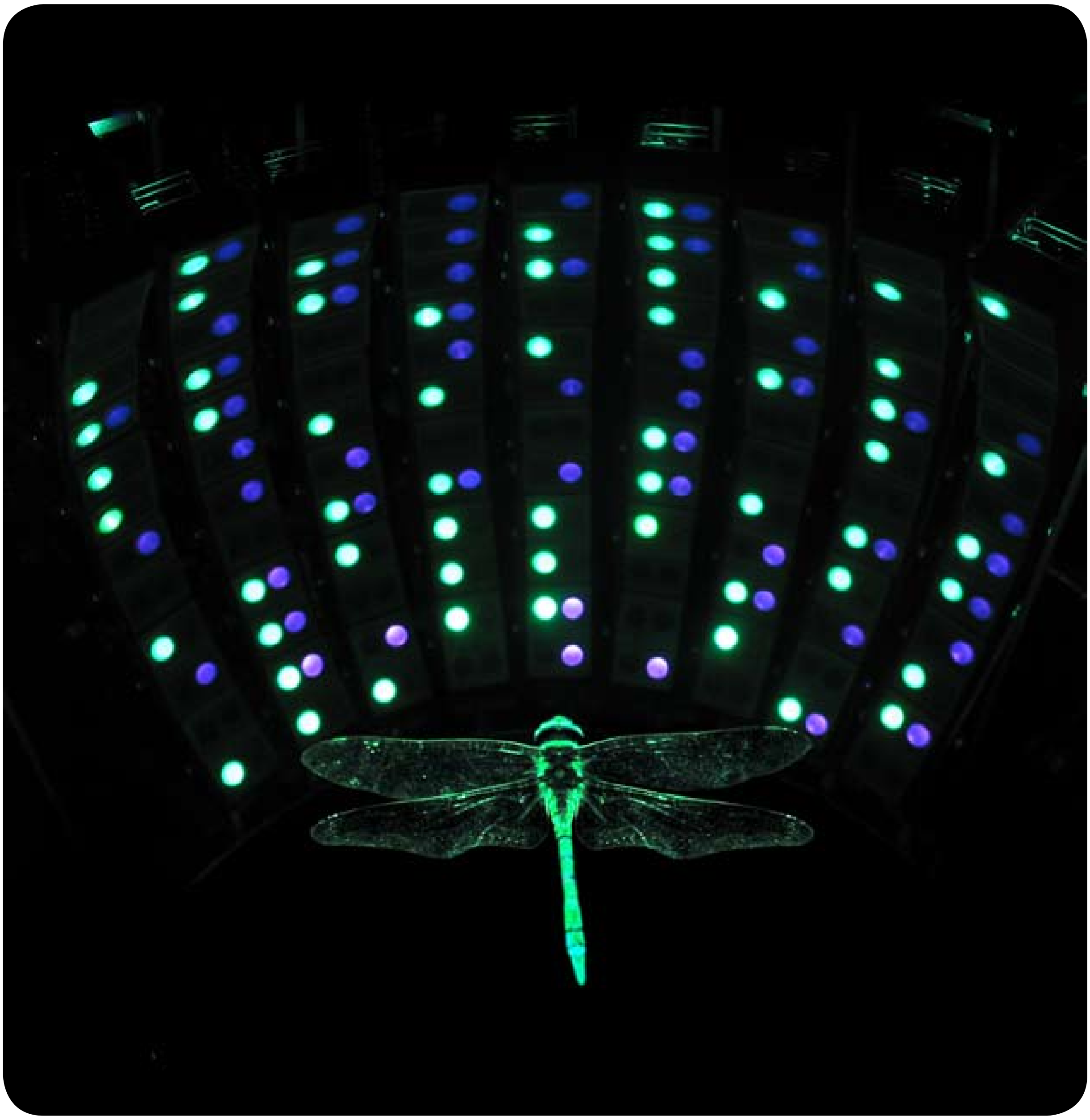
Mr van Kleef's tests and analysis showed that the optimal speed for the directional responses was about 750 degrees per second.

"That's very fast," he says. "But it makes sense because dragonflies move quickly so they're looking for very fast movements. We think it's crucial for them in stabilising their flight to be able to pick up on sudden movements where they're pitching up and pitching down very quickly.

"These types of movements are not picked up quickly by their large compound eyes. The other thing about the compound eyes is the information takes a longer time to go through the brain; it's processed a lot, and therefore at each synapse there's another delay, whereas the neurones in the median ocellus go from photoreceptor to the motor centre and they're able to do the calculation in one step."

Understanding how dragonflies fly and interpret their environment is far from a purely academic question. It's one that is of particular interest to those building small flying robots called micro-aerial vehicles which typically have wingspans of less than 30 cm.

"A dragonfly's capacity for rapid darting and precision hovering is of great interest to designers of micro-air vehicles, and the research we're doing is in part supported by the US Air Force. Stabilizing small air vehicles is a really big problem in terms of control and the forces at play on the vehicle. It's much harder than for larger, more stable aircraft.



Dragonflies are shown a shifting display of green and UV lights.

"Dragonflies are supreme fliers. If we can work out how they can control their flight movement we'll have some good ideas on how to effectively program micro-air vehicles."

And where does Mr van Kleef source the dragonflies for his research?

"The dragonflies we work on are a local species that we catch down on the banks of Sullivans Creek," he explains. "It's great, I feel like Huckleberry Finn; we go down with big butterfly nets and catch our dragonflies."

Which begs a question: If dragonflies are so perceptive and such great movers, how do they let themselves get caught by a slow human with a butterfly net?

"Dragonflies might be great fliers but when there are lots of others around they tend to be more worried about these other dragonflies than me," laughs Mr van Kleef. "They get caught up in this mating game where the males patrol a bit of real estate down on the creek –they zoom back and forth along a track around 10 metres or so in length. If another male comes they fight it off, and if a female comes they try and mate with it. They get quite crazy when the numbers are up, and they're all focussed on each other rather than a big human standing nearby with a butterfly net."

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