Better cycling networks

Andrea Raith, right, now a lecturer at the University of Auckland, is at the leading edge of traffic problem solving.

Photo: Keri Moyle, www.signsoflife.co.nz

She started by developing solution methods for the design of wind turbines in Germany as part of her studies at the Technische Universität Darmstadt, near Frankfurt. "I devised bi-criterion optimization solutions for a new type of electricity generator in wind turbines. It wasn't off-the-shelf – it had to be calibrated for each location. We had to determine the parameters - size, diameter, number of magnets in the generators – so we could optimize efficiency and weight, which are conflicting objectives." She then extended the method to deal with more than two objectives, and it was used by a major wind power company.

She said she couldn't have done her PhD on transportation optimization problems at the University of Auckland without an NZIMA scholarship.

She applied bi- and multi-criterion optimization to three different problems. She studied the bi-objective version of the widely-known shortest path road network problem, which "included the safety and suitability of the route. It was fairly theoretical, comparing different algorithms and trying to improve them."

The second was the network flow problem about moving commodities, for example logistics networks through which goods are transported; "there wasn't an algorithm so we proposed one". The third problem was traffic assignment, for example road networks in rush hour, when everyone wants to get to work as quickly as possible. "Planners use these algorithms to see the impact of a new road on traffic patterns."

"They usually assume that people travel on the shortest route, and use a generalized cost function that converts time into cost and combines it with other vehicle costs. But it's not realistic - people choose different routes because of convenience or different objectives. With a toll road, for example, some people will use it because it's quicker, while others will always go the long way to avoid the toll. We came up with one algorithm and different ways of dealing with those objectives."

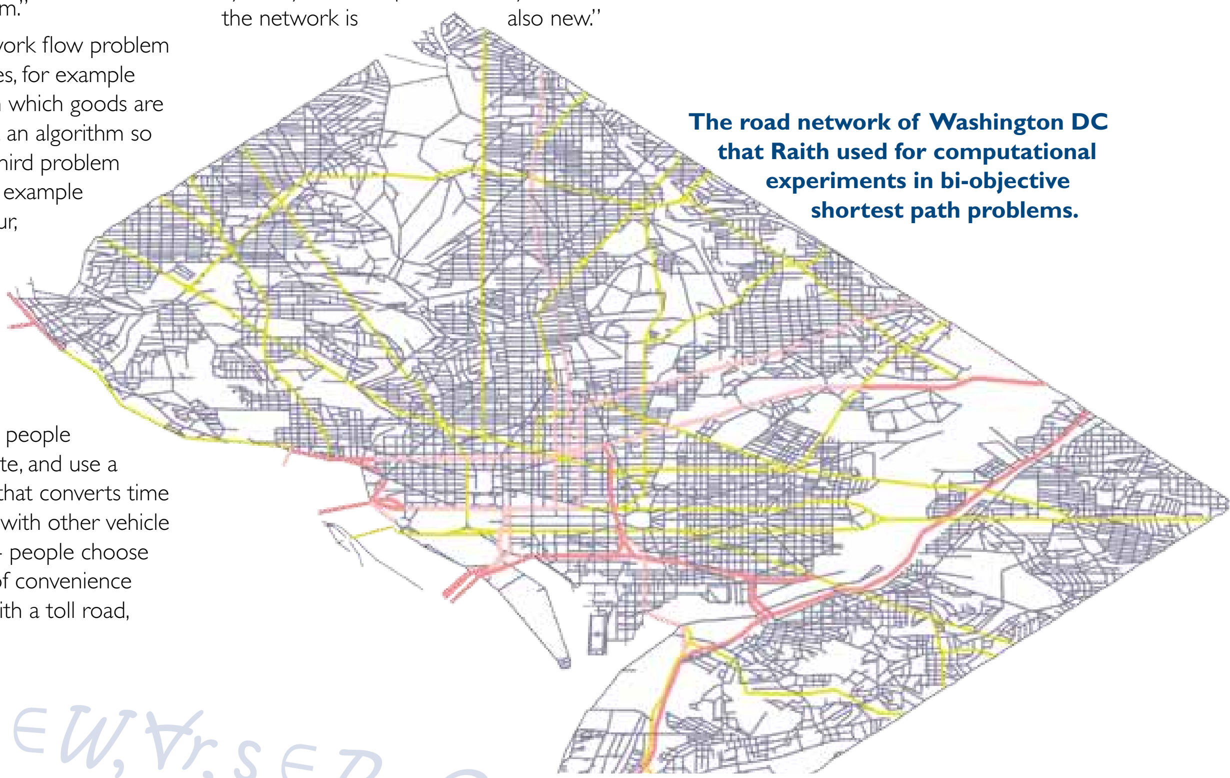
She and her two PhD supervisors, Matthias Ehrgott and Judith Wang, were awarded a Marsden grant to find better ways of solving this multi-objective traffic assignment problem.

She is involved in a project applying a similar theory to Auckland's cycling network. "Cyclists want to minimize their time and maximize the suitability of the path - this includes 20 factors, such as road gradient, traffic volume and speed, road surface and width, combined into a score."

She found that new cycling paths are often decided on in isolation, rather than on how they fit into routes that people want to follow. "We thought it was important to capture that. The route choice idea is new for cycling, and integrating an assignment approach that determines how many cyclists you can expect on every road in the network is also new."

However, convincing, or even contacting the Council decision-makers isn't so easy.

She's also using optimization to manage water assets and solve factory production problems. "That's the interesting part of the job - you can link with the real world and help them solve problems."



The road network of Washington DC that Raith used for computational experiments in bi-objective shortest path problems.

$$\forall w \in W, \forall r,s \in R_w \; C_{\cdot s}(f^*) \geq C_{\cdot r}(f^*) \Rightarrow f_s^* = 0$$

Finding the underlying patterns

Former NZIMA PhD scholarship holder Dion O'Neale enjoys seeing the same mathematical patterns in completely unrelated fields.

O'Neale has applied mathematical modelling methods to fields as different as astronomy (Saturn's rings), electricity generation (geothermal reservoirs), physics (laser light oscillation), chemistry (nano crystals), and economics (research investment).

He didn't expect to specialize in mathematics, but got hooked by a university research project that used maths to solve an astronomy problem. "I looked at whether sunlight hitting the particles in Saturn's rings affects their position, and it does!" He majored in maths and physics for his BSc, and for his MSc at Düsseldorf in Germany he developed numerical integrators to solve differential equations describing relativistic interactions between lasers and charged particles.

The scholarship from the NZ Institute of Mathematics and its Applications meant "not having to use tutoring to get by at Massey, otherwise I would have taken much longer to do the PhD". He was also awarded NZIMA travel funding to attend part of the six-month programme on highly oscillatory problems at the Newton Institute in Cambridge, and the International Conference on Scientific Computation and Differential Equations in France.

Highly oscillatory problems involve light, sound or other elements that oscillate very quickly. "If you're doing a laser experiment, you want a simulation to predict what might happen over longer periods without having to worry about every little wavelength."

This background in geometrical numerical integration, Hamiltonian systems and differential equations enabled him to develop mathematical models for many different fields as a research scientist at Industrial Research Ltd. "If an electricity company wants to set up a new geothermal power station and has reports of what's under the ground, a mathematical model tells them they're likely to be able to make this much electricity for this many years before the field stops being viable, as well as how much water they have to re-inject into the ground to avoid subsidence."

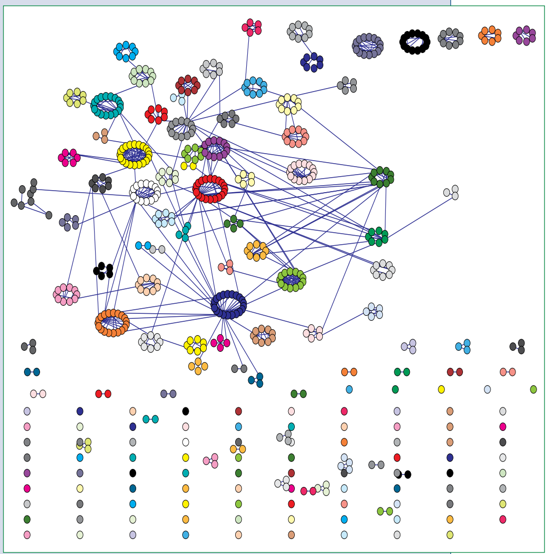
His latest project attempts to "bring some hard numbers to the innovation ecosystem". He has examined how patents are distributed between companies in New Zealand and overseas and the relationships of research and development funding to patents, as part of an IRL project led by Professor Shaun Hendy.

"We found that the model followed a power law, and could describe the relationship of the spread of patents in a population of companies with a single number. The more you spend on R&D, the higher your rate of return in patents up to a threshold of about three percent of GDP. New Zealand only spends about 1.3 percent, so there's plenty of room for improvement."

Government innovation policies and the level of collaboration among scientists also affect the rate of return on R&D. The major difference between New Zealand and other OECD countries is the low investment by New Zealand businesses – they contribute 0.5% of GDP in R&D investment, 38 percent of the total, compared to two-thirds of the total in other OECD countries.

O'Neale borrowed this model from biology, where it described the spread of species in different genera. "I like being able to take the same piece of computer programme and use it in an entirely unrelated area; seeing the underlying patterns in things, looking a little deeper into the world than you could without the mathematics."

See also: http://frontlawn.blogspot.co.nz/



A detail from a patent network for some companies in Denmark; companies are dots and lines are shared patents or inventions.

O'Neale rock climbing at Mt Arapiles in Victoria in 2009. Photo: Chris Tuffley.

Tracing the body electric

Andrew Pullan was an outstanding bioengineering scientist who died in March 2012 in the middle of a stellar research and teaching career in the Auckland Bioengineering Institute and the Department of Engineering Science (DES) at the University of Auckland.

See also

The Next Top Engineering Scientist competition - www.des.auckland.ac.nz/uoa/home/for/secondarystudentsandschools/nztescompetition

Mathematics and the human stomach - www.math.auckland.ac.nz/CULMS/wp-content/uploads/2010/08/Maths-and-the-Human-Stomach.pdf

Pullan grew up in South Auckland and was dux of Aorere College, where he later donated (and regularly presented) the Pullan Cup for Dux. His research ranged from theoretical aspects of the microscopic function of stomach cells, to computer models of the electrical function of the heart, gastro-intestinal system and other body areas, to developing measuring devices and analysis techniques for improved health care.

Says a friend Professor Ron Paterson: "He was fascinated with the human body and loved thinking about anatomy and physiology". After a PhD modelling groundwater, he found his career focus when he started modelling electrocardiography. Says Professor Martyn Nash: "The standard 12-lead ECG provides sparse measurements, and doctors largely use pattern recognition and educated guesswork to infer what is wrong with the heart."

Pullan and his team designed a vest with several hundred ECG electrodes, and developed numerical methods to infer heart health from this dense array of surface signals. For these inverse problems, he solved partial differential equations using detailed computer models to investigate the relationship between the two. He attracted large research grants, teams and collaborators in three universities in the USA, eventually writing a textbook on mathematical modelling of the heart. Pullan become a professor in 2006 and was elected a Fellow of the Royal Society of New Zealand in 2009.

He used the same ideas to model skeletal and smooth muscle, more recently in the gastrointestinal system. Our digestion operates on small electrical signals - slow waves - that push the food through the stomach and intestines. Signal abnormalities can create chronic indigestion, reflux and other problems. Members of Pullan's team designed electrodes that could be inserted down the throat to measure signals directly from the stomach, and are working out how to record them.

Pullan saw this as leading to the development of pacemaker devices for the stomach. This work was recognised with a James Cook Research Fellowship in 2003. His team of 14, now led by Dr Leo Cheng, is well-established, with different projects building on aspects of gastrointestinal function that he initiated.

Pullan was hugely supportive of his students; Associate Professor Rosalind Archer says "He had a knack of knowing when someone could do better or extend themselves". He was also known as an inspiring teacher, full of boundless and infectious energy. He opened his inaugural professorial public lecture in fluent Māori verses which he had spent a month memorising, and a large monitor displayed the electrical activity of his body in real time as he paced.

He was also famous for his shorts and polo shirt dress code, at Auckland Grammar School Board meetings and university lectures, and for his intense competitiveness in any physical activity. He established the highly successful Next Top Engineering Scientist problem-solving competition for secondary school students in 2009, which now offers the Pullan Prize, and the DES Christmas lunch for families and children. His love of chocolate meant he was a regular judge of the annual student maths-themed baking competition, and many of his postgraduate students have vivid memories of their labour on his extensive house renovations.

Says colleague Professor Bruce Smaill: "He was fearsomely bright, extraordinarily energetic, and he cared intensely about everything that he did."

$$\nabla(\sigma_e \nabla \phi) = \nabla . J$$