Changing the scientific paradigm

The era of the algorithm is upon us, says Bernard Chazelle, and it "promises to be the most disruptive scientific development since quantum mechanics". Chazelle is a Professor of Computer Science at the Ivy League Princeton University in New Jersey, USA, and made this claim in March during public lectures in Auckland, Wellington, Christchurch and Dunedin as part of the NZIMA Programme in Algorithmics. He talked with Jenny Rankine.

Bernard Chazelle advocates radical change. When asked how algorithmics can become not just a body but a *way* of thinking, he focuses first on maths and science. "Traditional maths focused on symmetries. You could write on one page math equations from physics that explain 99% of everything that happens around you in the physical world. The reason is that the natural world has so much symmetry."

"But the 21st century is looking very different; the problems are economic, technological, the behaviour of complex organisms, ecologies and social groups. The traditional tools of maths are not going to be as efficient to handle these new problems, because they don't hold the same symmetries."

An algorithmic way of thinking is pretty much the only candidate, he says. "If you squint hard enough, a network of autonomous agents interacting together will begin to look like a giant distributed algorithm in action." Algorithms may not be as successful as equations, but there is no plan B; "it's becoming the central scientific paradigm of the 21st century."

Then he focuses on education: "The way teaching is done in the USA and Europe, if I say the algorithmics toolkit is going to unleash a new world, it makes no sense. The curriculum will have to change."

University departments and curricula, and by implication those in secondary schools as well, are based on 19th century classifications, he says. "Algorithms and information science are becoming an integral part of how scientists think about their science. The biology part of the Human Genome Project was not the most important - the hard part was algorithmic, computer science."

He gives an integrated first-year biology course at Princeton as an example of how science and maths could be taught. He and another computer scientist taught the course with two biologists, a chemist and a physicist, aiming to show the relationships between the deepest concepts in these disciplines. "I talked about the algorithm behind Google, the chemist talked about the fundamental chemical process of diffusion; we taught together so students would understand that these are the same processes."

Chazelle's enthusiasm for integration may relate to his own abilities in multiple fields; he blogs regularly about politics and music, and draws cartoons.

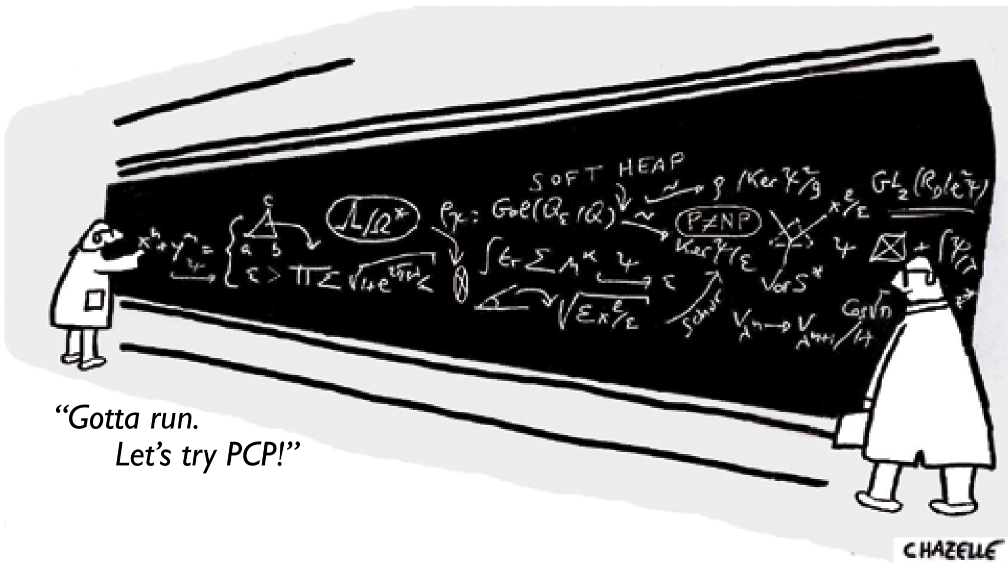
Chazelle argues that the field of algorithmics has been limited by its use only as a problem solver; publications systems have discouraged exploratory and theoretical work. He gets quite literary. "There are simple, zinger-like algorithms; local rules that produce complex systems." An illustration is an algorithm about bird behaviour that models migrating geese as well as undirected flocking networks.

Then there are algorithmic novels, which allow multiple levels of abstraction. Chazelle gives the example of war, which at its most basic "is a soldier valiantly following combat rules on the battlefield. At a higher level of abstraction, it is a clash of warfare strategies." These epics of the algorithmic world "devote most of their energies to servicing their constituent parts via swarms of intricate data structures."

Chazelle looks forward to the time when the ability of maths to modify, combine, harmonise and generalise equations is applied to algorithms, enabling us to knead them like dough to form new algorithmic shapes.

See also

Chazelle's home page: www.cs.princeton.edu/~chazelle/



"Gotta run. Let's try PCP!"

Harnessing the **waves** and tides

New Zealand is rich in potential sources of wave and tidal energy according Margot Gerritsen, who spoke at the NZIMA Energy, Wind and Water programme workshop earlier this year. She discussed her work with Jenny Rankine.

Tory Strait and French Pass in the Marlborough Sounds and the Hokianga and Kaipara Harbours are all potential energy sites, says Gerritsen, a professor in the Department of Energy Resources Engineering at Stanford University in California.

A tidal power generation project has been proposed for the Kaipara, where currents move at up to three metres per second in a deep channel. Full tidal assessments involve radar observations, two-dimensional computer modelling to rank sites, three-dimensional modelling for design optimisation and risk analysis, as well as studies of possible effects on marine life and harbour floors. This has yet to be completed for the other sites.

Gerritsen has helped develop a computer model exploring the impact of tidal turbines, and hopes to extend it to their design. "They look just like a beefed-up wind turbine: the drag and friction forces are much larger in water and so they need to be a lot stronger." Cavitation, the formation and collapse of vapour bubbles in water with pressure changes, is also a problem for tidal turbines.

Gerritsen's computational mathematics has several other applications. She has developed a computer model of coastal erosion, for example the way in which sand in the Kaipara and Hokianga Harbours moves from the harbour to the ever-changing sandbar in the estuary. "I'm also interested in the transport of nutrients, which is very important for fishing. Nutrients may well up from the bottom to the top layers of the sea; this can show fishing boats when they should fish where, and when they should not, because they may be overfishing."

When she worked at the University of Auckland in New Zealand in the late 1990s, Gerritsen used computer modelling to help design spinnakers, mainsails and jibs for Team New Zealand's America's Cup yacht. "It requires a lot of mathematics; like turbine design you need to understand how air flows past a sail." She is now collaborating with international sail making company Doyle Sails and has worked on the unique no-rigging design of the 88m luxury clipper yacht, the *Maltese Falcon*.

Another application is the application of efficient numerical schemes to the recovery of oil from existing fields. "Pumping is not efficient for very long. You can inject carbon dioxide or other gases to increase the pressure in the reservoir, which helps get more oil out. A lot of the oil being produced now is very, very sticky, like peanut butter in the rock, and very hard to extract. One method is to burn some of the oil to heat and "soften" the oil. It's an optimisation problem working out where to inject the gas or where to burn. We build computer models to simulate the flow of gas and oil through the reservoir."

She and more than six other researchers have been working with multinational oilfield services corporation Schlumberger. "We use laboratory experimentation to validate the model. You can mimic a rock using very small glass beads, for example, and observe the flows." The team also uses CT scanners to look inside rock cores from the actual field.

In 2007 Gerritsen started Smart Energy, a podcast blog site that discusses energy issues and policies for the public and policy makers. "A lot of people don't like having new energy systems built close to where they live; NIMBY (not in my back yard) is very strong. It's hard to convince people that we always have to choose between the lesser of several evils, and that energy has to be paid for in different ways."

See also

- Gerritsen's blog site - www.smartenergyshow.com
- The no-rigging yacht - www.symaltesefalcon.com/about.asp

Top: Wave power buoy. Above: Gerritsen on her Triumph Bonneville with students in her department.

$$P=\left(\frac{15^2 20}{2}\right)=112.5MW$$

> **"There is an eternality about math questions, a feeling that you're really getting to the bottom of something."** *John Conway*

Analysing earthquake signals

Statistical analysis of a well in China by a PhD student in Palmerston North has developed diagnostics for seismic activity that are being used in Taupo and Southern California. Jenny Rankine reports.

Ting Wang at the Forbidden City in Beijing.

The Tangshan Well (above) is about 100km north-east of Beijing, in an area which has had many small earthquakes since 1976, when a magnitude 7.8 earthquake directly under the city killed about 240,000 people and flattened most of the city's buildings.

Chinese seismologists have known for years that the water level in this well is very sensitive to earthquakes. The level has been recorded daily since 1974, hourly since 1981 and digitally every minute since 2001.

Chinese student Ting Wang has studied in Beijing and is now doing her PhD at the Institute of Fundamental Sciences at Massey University, supervised by Associate Professor Mark Bebbington, Dr David Harte of Statistics Research Associates and Victoria University Emeritus Professor David Vere-Jones. She has analysed well level records since 2002, supplied by the Tangshan Earthquake Administration (TEA).

"Most fluctuations in water level register for about a half an hour to an hour, so hourly data is not useful for extracting well signals," she says. Her data set is two million measurement points, one minute apart, over four years, and a catalogue of global earthquakes from the USA Geological Survey's National Earthquake Information Center.

From this she extracted the arrival times of different earthquake waves - the primary and secondary waves, which travel through the earth, and the Rayleigh and Love waves, which travel along the earth's surface.

The amplitude of well level fluctuations increases after earthquakes. "We extract signals from the well data using a moving average filter method over a 10-minute window, and move that window along one minute at a time." She has used skill score and Poisson process tests to choose well signal filter parameters and magnitude thresholds for earthquake series.

"From the well point of view, there is a lot of movement and you don't know the cause. We've identified what is an earthquake response and what isn't," says Wang. About 40 percent - 237 of the 600 earthquakes above magnitude 6 - appeared to trigger identifiable fluctuations in the Tangshan Well. "We also found a threshold in the relationship between the magnitude of the earthquake and the well's distance from the epicentre, above which earthquake-related changes in well level are most likely."

The existing theory is that changes in water level are caused by Rayleigh waves, but in Tangshan arrivals from earlier waves, particularly primary waves, are often noticeable, although the Rayleigh waves do amplify movement in the well level.

Wang then turned her attention to analysing New Zealand earthquake data. "GNS Science has over 100 GPS receivers, which measure east-west, north-south and up-down position in each site each day, but only about 12 were in place around Taupo before 2004." The standard wisdom was that GPS signals measure only deformation after earthquakes. Using a lot of the same techniques, Wang was trying to find if any pattern of GPS movements from around Taupo preceded earthquakes.

"We used a hidden Markov model to filter the data from the noise, then used mutual information to analyse which kind of movement is related to earthquakes. We found pre-seismic signals but they need more analysis; seismologists are very cautious."

While the Taupo analysis may provide some precursory information, there is not a risk to life or property. Wang moved her attention to GPS data and earthquakes in Southern California, which has more than 10 years of GPS data. "We needed a place with good GPS records and lots of earthquakes." There she found pre-seismic signals similar to what have been found at Taupo. With more testing and longer data sequences, Wang hopes that GPS measurements may be able to provide probability forecasts for large earthquakes.

$$V_t = \frac{1}{10}\sum_{s=t-9}^{t}\left(e^{-a(t-s)}d_s - \frac{1}{10}\sum_{s=t-9}^{t} e^{-a(t-s)}d_s\right)^2$$

Awards and honours

Professor **ROD DOWNEY** (Victoria University of Wellington) has been appointed to the Marsden Fund Council.

Professor **VAUGHAN JONES** was made a Knight Companion of the New Zealand Order of Merit (KNZM).

Professor **GAVEN MARTIN** (Massey University) and **DR ANDRE NIES** (University of Auckland) were invited to give lectures at the International Congress of Mathematicians in India in 2010

Emeritus Professor **DAVID VERE-JONES** (Victoria University of Wellington) was awarded the Campbell Award by the NZ Statistical Association.

VICKY WANG (NZIMA scholar, University of Auckland) won the best paper award at the MICCAI Society Conference (for medical image computing and computer-assisted technology), jointly with Hoileng Lam.