ALLAN WILSON CENTRE
FOR MOLECULAR ECOLOGY AND EVOLUTION

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MATHEMATICS - BIOLOGY'S NEW MICROSCOPE

Allan Wilson pioneered the application of analytic techniques to genetic data to discover a new understanding of our ancestry. And today, in the Allan Wilson Centre, mathematicians work closely with biologists to provide analytical tools to study evolution. But the sort of maths being used is often quite different to that used in other sciences, like physics. Why is this? And what does it mean for Year 13 students, who have a choice of studying maths with calculus or maths with statistics?

Allan Wilson Centre mathematician and Deputy Director, Professor Mike Steel

In 2004 Joel Cohen wrote an essay entitled *Mathematics is biology's next microscope, only better; biology is mathematics' next physics, only better.* Cohen's point was that modern biology provides mathematicians with a huge array of fascinating questions requiring analysis, and that biologists can benefit in the same way that physicists once did from mathematics.

Historically, the main scientific partner for maths has been physics and associated fields such as engineering. As calculus is important for these, it has often been seen as the gold standard when it comes to studying maths in the final year at school. But the explosion of new and exciting DNA information in recent years means this idea might need re-thinking.

"For the work we do, and the work Allan Wilson did, calculus is usually not the main tool," says Allan Wilson Centre mathematician and Deputy Director, Professor Mike Steel from the University of Canterbury. "Statistics, particularly probability, is often more useful in modern genetics and evolutionary studies."

As a recent example, Mike has been using probability theory to discover some surprising new features about speciation, working with a biologist in Canada and a French mathematician. If each species gives rise to a new species randomly and on average once every million years, and if you examine an evolutionary tree that has 100 species at the tips, then you imagine that the average length of any branch in the tree should be 1 million years. "What we found is that it's not – it's exactly half that (500,000 years). It was as much a surprise to us as the reviewers of our paper," says Mike. The paper, published this month, uses these results to reach new conclusions about the likely loss of biodiversity due to current high rates of extinction.

To understand why the speciation result is even more surprising, consider the well-known 'bus paradox'. If buses arrive regularly at a bus stop every 20 minutes and you turn up at a random time, then you will expect to wait 10 minutes. But if the buses arrive *randomly* every 20 minutes, then you expect to wait the full 20 minutes from the time you show up. "This fact surprises some people, but it's just basic probability theory; what's interesting for our speciation problem is that it suggests branch lengths in a tree might average out at the full 1 million years, since the time to speciation follows the same exponential waiting time as random bus arrivals. But the branch lengths turn out to be shorter, and by a factor of 1/2."

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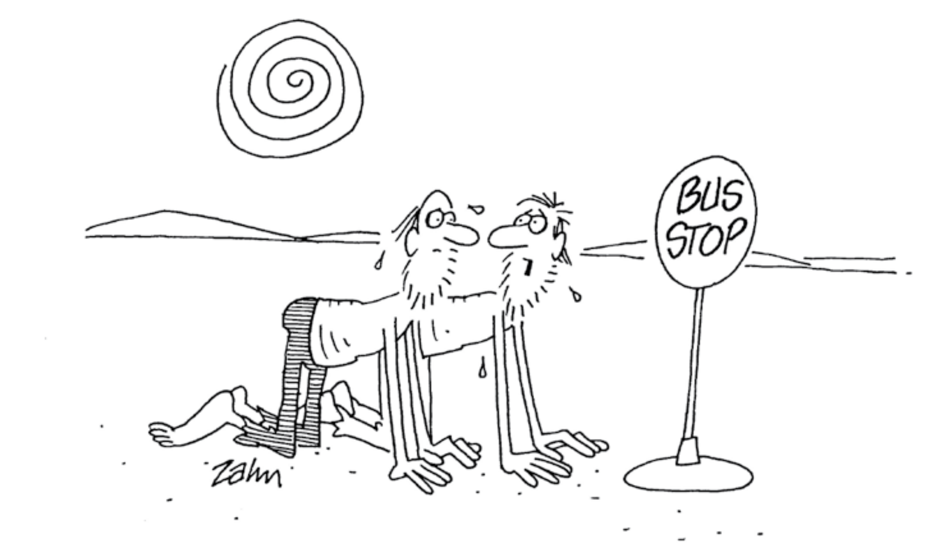


Bob Zahn, www.CartoonStock.com

Also important for evolutionary biology is an area known as discrete mathematics, which is at the intersection of maths and computer science. The study of algorithms is an important part of this. An algorithm is simply a method or procedure to help find patterns in complicated data. For example, an algorithm can be used to find common pieces of DNA that match exactly in a database of genetic information.

"Nearly all of the interesting questions that we'd like to answer are called intractable, in other words, extremely difficult to solve," says Mike. "If you look at short sequences of DNA and a handful of species, this is manageable. But in biology, sequences can be hugely long, and we often deal with hundreds or thousands of species at once. This is so much information that the only way to deal with it is to design clever shortcuts."

Discrete mathematics also includes the study of graphs and networks. One familiar example of a network is the Internet. Another is the set of links among people who know each other, leading to the famous 'six degrees of separation' idea, which, says Mike, is actually not far from the truth. Networks are widely used in biology, and particularly molecular biology, for studying interactions between proteins, and the patterns of lateral gene transfer during evolution – how genes were moved between species in the past. Importantly for the work of the Allan Wilson Centre, they are also used for drawing evolutionary trees and more complex evolutionary networks. One showcase example is the widely-used programme, *Neighbor-Net*, that was developed by Otago-based AWC investigator David Bryant with UK colleague Vincent Moulton. It has been applied to study the origin of mammals, the extent of hybrid species amongst alpine plants in New Zealand, and even to estimate the earliest forms of life on Earth.

> ***"...in biology, sequences can be hugely long, and we often deal with hundreds or thousands of species at once..." says Professor Mike Steel***

Calculus is still important in some areas of mathematical biology, such as ecological modelling of populations and how they change over time as a result of predator-prey interactions, or modelling how epidemics spread through a population. It is also relevant to evolution. It was a tool for proving the speciation times' result mentioned above, and it is central to related fields like population genetics. And calculus remains the foundation of physics. But for those who would like to be involved in the field of evolutionary biology, studying maths with statistics at Year 13 can be equally useful.

Following on from this is the choice of what maths to study at university. "At high school, we teach probability, which is great, but we don't yet teach a lot of discrete maths and algorithms," Mike explains. "But you can do these courses at university. So students shouldn't come with the preconception that if you want to do molecular biology, it's a science, and for science you need to concentrate just on calculus. They need to come with an appreciation that every science is different. If students want get into the area of evolutionary studies, I would encourage them, when they first come to university, to choose to study discrete maths and algorithms, as well as calculus."

Evolutionary biology, like all studies that involve the use of DNA, is a rapidly growing field, and there are many opportunities for those interested in working in it. Computing power and DNA sequencing technology, for example, are developing at an incredible rate. "When it comes to sequencing technology, the quantity of data that can be produced for a given amount of money has increased by an enormous amount in the last decade," says Mike. "When the human genome was sequenced for the first time ten years ago, it cost hundreds of millions of dollars. Now there's talk of the thousand dollar genome."

This huge increase in both the speed of production and the quantity of genetic data means that simply storing data is becoming a problem. Figuring out how to analyse it is also an area ripe for development. "There aren't the skills or the algorithms yet to make best use of all the DNA data," says Mike. "The data are just sitting there, and bits and pieces are being picked for analysis, while the rest is getting wasted. A lot more data are available, if one only knew how to extract these efficiently. So there's a job for those interested in mathematics, statistics, and computer science. Thanks to the advances that have already been made in the study of molecular biology and evolution, it's just phenomenal what has been discovered in the last 20 or 30 years. As Rebecca Cann says, it's a great time to be working in this field."

UK EXPERT ON HUMAN ORIGINS TO TOUR NEW ZEALAND IN FEBRUARY

In 1987, Allan Wilson sent a shockwave through the scientific world when he proposed that modern humans originated in Africa less than 200,000 years ago. Twenty-five years on, one of the leading modern advocates of Allan's 'Out of Africa' theory, Professor Chris Stringer, will visit New Zealand to talk about what we now know about human origins.

Professor Chris Stringer

Chris is the Research Leader in Human Origins at the Natural History Museum in London, and one of the world's foremost experts on human evolution. Through excavations of human remains in Ethiopia, Morocco, Gibraltar, and Turkey, Chris has traced the footsteps of the earliest modern humans as they emerged from Africa and spread through Europe. He also currently leads the Ancient Human Occupation of Britain project, which aims to reconstruct the pattern of the earliest human colonisations of Britain. His palaeontological research has filled in many of the missing pieces of the *Out of Africa* puzzle, refining and supporting Allan's original finding based on DNA evidence.

The advent of genomic data and several remarkable new fossil finds make this an exciting time to be studying human evolution. Particularly striking has been the finding that early modern humans interbred with Neanderthals as they first moved into Europe and Asia. Neanderthals were living across much of Europe between 150,000 and 40,000 years ago but, according to the *Out of Africa* model, were completely replaced by modern humans. However, comparison of the Neanderthal genome sequence, published in 2010, with our own revealed that Europeans and Asians (but not Africans) have around 2% Neanderthal DNA, suggesting interbreeding.

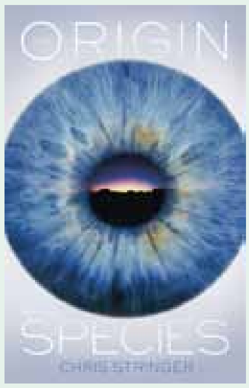
Much of Chris's early research focused on the interaction between Neanderthals and modern humans. As a graduate student he was fascinated by Neanderthals, and in 1971 drove through Europe in a battered old car visiting museums in search of Neanderthal skulls. He admits to being surprised by the extent of interbreeding suggested by the genomic data. "I had regarded Neanderthals as representing a separate lineage and most likely a separate species from us, and if there had been interbreeding I believed it to have been small and insignificant in the bigger picture of our evolution," he says.

Chris's visit is part of the Allan Wilson Centre's year-long "Africa to Aotearoa" programme commemorating the work of Allan Wilson.

Another surprise was provided by the recent find of a finger bone and tooth in a cave in southern Siberia. This proved to be from a previously unknown lineage of early humans, dubbed the Denisovans after the region where fossil was found. Denisovan DNA shows up in the genomes of modern Melanesians, again suggesting interbreeding. "The genomics work has made a huge impact," Chris says. He admits that while genomic results still largely confirm the *Out of Africa* model, it may not be as simple as Allan first proposed.

Chris describes many of these advances in his new book *Origin of Our Species*. The book summarizes the latest evidence from fossils, archaeology and genetics to answer some of the big questions in human evolution, explaining how these recent discoveries fit into our evolutionary history, how we can recognise our origins from the fossil record, and how climatic, dietary and social forces shaped our evolution.

Chris's visit is part of the Allan Wilson Centre's year-long "Africa to Aotearoa" programme commemorating the work of Allan Wilson. The Centre has an active research programme tracing the last part of the human journey through the Pacific to Aotearoa. Chris's work on the first part of the journey, as humans left Africa, forms the foundation on which the Centre's work builds. His talk promises to provide a fascinating insight into the origins of humanity and what it means to be human. He plans to visit New Zealand from 20-25th February, and will give talks in Auckland, Wellington, Christchurch and Dunedin.



The Origin of Our Species by Chris Stringer

OUT OF AFRICA AND THE LEGACY OF ALLAN WILSON

Allan Wilson, the Centre's namesake and inspiration, is one of New Zealand's greatest scientists. His former graduate student, Professor Rebecca Cann, visited New Zealand in August to give a series of six lectures around the country commemorating his life and work.

In front of capacity audiences in Dunedin, Nelson, Palmerston North, Wellington and Auckland, Rebecca talked about her experiences working with Allan, and how evolutionary biology has changed in the 20 years since his death. "Allan was an extraordinary teacher; he taught us to question what everybody said was the truth," she said. Rebecca's second Auckland lecture was held at King's College, where Allan went to high school, and attracted over 300 students from nine Auckland schools.

Rebecca is now a Professor of Cell and Molecular Biology at the University of Hawaii. She began a PhD in Allan's lab at the University of California, Berkeley, in the late 1970s, drawn to his idea that evolution could be studied by measuring the rate of changes in DNA. At the time, the tools to measure DNA changes directly were just being developed, and Allan was beginning to turn his attention to the DNA found in mitochondria. He recognised that this type of DNA could potentially be used as a molecular clock, as it is inherited only through the female line, and changes fast enough to be useful for investigating the evolutionary history of populations.

Along with co-worker Mark Stoneking, Rebecca measured mitochondrial DNA changes in women of different races and calculated that the modern human lineage can be traced back to one woman who lived in Africa less than 200,000 years ago – so-called 'Mitochondrial Eve'. This idea was revolutionary, challenging the prevailing view that modern humans had co-evolved on separate continents.

In her talk, Rebecca described the struggle they faced to publish the study: the paper went through 40 drafts, and then when it was submitted to the journal *Nature*, it came back with 18 pages of reviewers' comments. "One of the things that I learned from Allan was not to give up," she said.

> ***"I tell my students that this is the best time to be a biologist. We now have the tools to ask and answer the questions that you've been reading about for 30 to 40 years," says Professor Rebecca Cann***

Rebecca's lecture gave the audience an insight into what sort of man Allan Wilson was, describing how his openness to new ideas and technologies, and willingness to collaborate with a diverse array of scientists from other fields, made him a research innovator. She described what it was like to be a graduate student under Allan; how she would find handwritten notes from him in her lab-book in the mornings suggesting a new way of looking at her data, and how he taught her to challenge orthodoxy. "He was constantly sending you on a quest to learn a new technology, to bring it back to teach others in the lab."

"Wilson's influence on the field of evolutionary biology has been enormous," Rebecca emphasised. "His research challenged the existing dogma that evolution could only be studied using the fossil record. The idea that living organisms preserve their own evolutionary record that can be deciphered with cutting-edge technology became a really powerful change agent in evolutionary biology," said Rebecca. The methods that Allan and his students pioneered are now fundamental to modern-day research on evolution, conservation and systematics, and many of today's most prominent evolutionary biologists began their research careers in Allan's lab.

Rebecca stressed the importance of biomathematics for being able to correctly interpret DNA sequence data and the role of the Allan Wilson Centre in fostering connections between mathematicians and biologists. Rebecca and Allan's finding that the human lineage originated recently in Africa is now well accepted, but new tools for DNA sequencing and advanced biomathematics are still refining our ideas about human evolution and expanding the range of questions that can be answered. "I tell my students that this is the best time to be a biologist. We now have the tools to ask and answer the questions that you've been reading about for 30 to 40 years."

Professor Cann's talk in Wellington was recorded and may be viewed at *http://www.r2.co.nz/20110805/*. DVD copies are available on request from *j.r.wood@massey.ac.nz*.
Links to Professor Cann's interview with Kim Hill on Saturday 6 August, and the interview with Professor Charles Daugherty, Director of the Allan Wilson Centre, on Monday 1 August by Kathryn Ryan, Radio New Zealand National, can be found under the 'News & Events' tab on the Allan Wilson Centre website: *www.allanwilsoncentre.ac.nz*.

WAI262 BRINGS PARTNERSHIPS WITH MĀORI TO THE FORE

A landmark report released by the Waitangi Tribunal in July may result in Allan Wilson Centre researchers strengthening their links with Māori. The report on the Wai262 claim – also known as the indigenous flora and fauna claim – found that no-one should own our flora and fauna, but the role of Māori as guardians, or kaitiaki, of native species should be protected.

The Wai262 claim was lodged by six Iwi over 20 years ago in response to the fear that their language, symbols and rituals were being taken out of their control. Central to the claim is the question of who owns or controls Māori culture, identity, and the things that identity is built on, like indigenous flora, fauna and the natural environment. Many of our native species are inextricably linked with Māori culture and are regarded as taonga, or treasures, by Māori, who in turn regard themselves as guardians of those species.

Of particular interest to Allan Wilson Centre scientists are the Tribunal's recommendations on use of genetic and biological resources of taonga species, and management of the conservation estate. The claimants' concerns centre around commercial exploitation of native species, including intellectual property rights (patents), genetic modification and bioprospecting. The Tribunal found that Māori should not be entitled to veto scientific research or commercial ventures using taonga species, and that they should not have exclusive ownership of the genetic and biological material of those species. However, the special relationship that Māori have with these species should be protected, and they should be given a greater say in how they are used. The Tribunal also recommends a reform of conservation laws to enable Māori to co-manage protected wildlife in partnership with the Department of Conservation.

It remains to be seen what the Wai262 report will mean for Allan Wilson Centre researchers. The Centre's research concentrates on improving basic knowledge of the evolution and conservation of native species rather than commercial exploitation of those species. The Tribunal did consider such "public good" research, stating that the interests of Māori must be balanced against the interests of such research and the interests of the species themselves. If these interests conflict, there should be a mechanism for determining priority.

The Centre's research concentrates on improving basic knowledge of the evolution and conservation of native species rather than commercial exploitation of those species.

Much of the Allan Wilson Centre's research is subject to permits from the Department of Conservation and the Environmental Protection Authority and already requires consultation, but not permission or partnership, with Māori. A reform of laws governing science and conservation may require researchers to develop closer relationships with Māori. However, many Allan Wilson Centre researchers who work on taonga species already have strong, ongoing relationships with the Iwi who are kaitiaki of those species, and any changes in legislation will likely have little effect on those relationships in practice.

The recommendations of the Waitangi Tribunal are non-binding, and the government is currently considering whether these recommendations will be incorporated into New Zealand law.

A Tuatara

REPTILE ECOLOGY AND CONSERVATION RESEARCH IN THE ALLAN WILSON CENTRE AT VICTORIA UNIVERSITY OF WELLINGTON

Allan Wilson Centre Principal Investigator, Dr Nicola Nelson, leads a research group focused on reptile biology and conservation at Victoria University. Their research interests range from community interactions and disease in wild populations of reptiles to molecular aspects of sex determination. They study how incubation conditions affect sex determination and fitness of egg-laying reptiles, how climate change will affect distribution and survival of reptiles, and techniques for the conservation of reptile populations. In this article, three of Nicola's students tell us more about their work:

Helen Taylor

What is your research about?

The little spotted kiwi was reduced to just five individuals in the early 1900s and has very low genetic diversity. Despite this, the population has grown significantly and now numbers around 1600. My research investigates the relationship between inbreeding and fitness in two populations of this species. I have fitted male birds (who are the sole providers of parental care) with radio tags that collect information on activity patterns. This allows me to gather data on activity as well as nest site selection, territory sizes and, ultimately, reproductive success. I am also collecting genetic data to investigate mating systems, parentage and inbreeding.

What do you like about working in this area?

The main appeal for me is the combination of field and lab work coupled with the opportunity to work with a unique and charismatic species. I feel privileged to have the opportunity to get up close and personal with a bird that many people, even here in New Zealand, may never see. It's also satisfying to be able to see how my work might actually make a difference. I'm hopeful that the results of my research will prove useful for the future management of little spotted kiwi and potentially for other species too.

How did you get into this field?

I've been passionate about the natural world from an early age, but it's taken me a while to find my way into conservation work. When I completed my undergraduate degree, I moved from science into public relations. However, I realised that conservation would be a far more interesting and rewarding career path. I wanted to be able to make a genuinely positive impact on the world around me. I found my way back to conservation via a variety of voluntary field worker positions. I also undertook a Masters in conservation science in the UK, where I came to understand the importance of genetic work in maintaining viable populations of species and effective conservation management. As a result, shortly before completing my masters, I applied for the PhD scholarship I currently hold and was delighted to be accepted.

What would you like to find out?

I'd like to know how inbred little spotted kiwi are, whether they have any mechanisms to avoid inbreeding and how inbreeding might impact on their future survival as a species. I'm also interested in conservation prioritisation and decision making and how fields such as genetics and behavioural ecology can feed into that for more effective conservation management.

Lindsay Mickelson

What is your research about?

Corticosterone is a steroid hormone that can indicate condition and level of stress. Short-term, or 'stress response' increases in corticosterone levels help individuals cope with environmental challenges such as predators, food shortages, habitat changes, humans and pollution. Long-term elevations in corticosterone levels are, however, harmful. I am investigating factors affecting patterns of corticosterone release in tuatara, the effects on their performance, and implications for future population performance and viability.

What do you like about working in this area?

I am attracted towards research that incorporates both evolutionary biology and conservation biology. Specifically, I am interested in how environmental change affects the development, physiology, behaviour and fitness of species. The combination of collecting data in the field and continuing work in the laboratory is a nice balance, and the chance to study tuatara in New Zealand is a wonderful opportunity.

How did you get into this field?

After earning my undergraduate degree in biology, I was awarded a wildlife conservation internship at the Devonian Wildlife Conservation Centre in Calgary, Canada. There, I analysed the egg management and chick-rearing of the whooping crane. I learned about captive breeding, and my interests steered towards learning more about conservation of endangered species and their habitat. My master's degree focussed on the influence of incubation temperature on leatherback turtle hatchlings, which inspired me to continue with research in reptiles.

What would you like to find out?

I hope to identify factors that affect corticosterone release in natural populations of tuatara and how release varies with specific stressors. I also hope to determine maternal transfer of corticosterone to egg yolk and effects on hatchling development and future performance. This will contribute to our understanding of reptiles and is applicable to captive breeding programmes and translocation of eggs and juveniles from stressed populations.

Anna Carter

What is your research about?

I am studying how female reproductive behaviour interacts with the environment to affect offspring sex ratios in tuatara, a species with temperature-dependent sex determination. I am integrating tuatara behavioural data at the individual and population levels into a physiological model to look at the implications of behaviour for the evolution of temperature-dependent sex determination and the fitness and conservation of modern tuatara populations.

What do you like about working in this area?

I particularly enjoy using different computer-based modeling tools and geographic information systems in ecologically relevant ways. Combining traditional field ecology with remotely-sensed high resolution geospatial information, for example, allows me to ask research questions within a timeframe that would be impossible without decades of additional field work.

How did you get into this field?

My research background is in marine ecology, but after coming to New Zealand to do my PhD, I became interested in the behavioural ecology of tuatara and implications for evolution. Research in land-based ecology is not a great departure from my previous experience. I am interested in the evolution and ecology of individual species and of biodiversity, rather than in working primarily with a particular favourite species or in one particular habitat.

What would you like to find out?

I am interested in the effects of evolved behavioural traits within rapidly varying environments. How do millions of years of evolutionary adaptations 'show up' in our modern climate? How can we use that behavioural information to examine the evolution of species? Importantly, how do evolutionary and behavioural data inform our efforts at species conservation?

Photo By Stefan Philippsen

INTRODUCING HUMAN EVOLUTION TO YEAR 10

How did humans evolve from ape-like ancestors in Africa to the modern species occupying every part of the globe? The Allan Wilson Centre has developed a PowerPoint presentation aimed at introducing evolutionary concepts to Year 10 students, using the story of human evolution as an example. It also highlights the contributions that Allan Wilson made to our understanding of human evolution.

Dr Azra Moeed

The presentation comes in two parts, each of which has accompanying notes for teachers. In Part 1, students learn how scientists study our evolutionary history, using evidence such as fossil remains and genetics to form theories about evolution, and how these theories may change as new evidence is found. Part two covers adaptation and evolution in modern humans, discussing how natural selection acts on genetic variation with examples such as eye colour and disease resistance, and answering questions such as 'why do we look the way we do?' and 'are we still evolving?'.

Azra's research has shown that students often make the decision whether or not to carry on with science at Year 10, so the presentation was targeted at this level.

The presentation was created by Allan Wilson Centre researcher, Dr Hilary Miller, in collaboration with biology teacher, Dr Azra Moeed, from Victoria University's Faculty of Education. The pair held a workshop at the BioLive conference in July to demonstrate the presentation, which was very well received by teachers. Azra's research has shown that students often make the decision whether or not to carry on with science at Year 10, so the presentation was targeted at this level.

Dr Hilary Miller

The aim is to inspire students to learn more, rather than just imparting the facts, and to clear up misconceptions they may have about evolution. It shows how scientists gather evidence and come up with theories based on this evidence, making it useful for the Nature of Science curriculum objectives.

The PowerPoint presentation and accompanying notes pages are available for download from the 'Teachers & Students' tab on the Allan Wilson Centre website, *http://www.allanwilsoncentre.ac.nz*. Each part is around 20 minutes long and can be edited if teachers wish to customise it for their class. Although the two-part presentation is aimed at Year 10 students, it may also be useful for teachers and senior biology students, indeed anyone wanting an interesting introduction to human evolution and the work of Allan Wilson.

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