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Editorial: Dirac, Moyal, and von Neumann

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What is the most significant scientific event of the past six months? The COVID-19 pandemic continues to throw up mutations of the virus, most recently the Omicron "scariant" or "variant of concern." We can only hope that Omicron is more infectious and less severe, so that it drives out any worse variants, such as Delta. If so, then this might be how the pandemic ends, with an endemic coronavirus that we might all expect to contract at some time (or perhaps every year), but with little serious effect for most of us, dosed with our annual vaccinations. Apparently, past pandemics have spluttered out in this fashion.

Meanwhile, I have prevailed upon Eddie Holmes FRSN to allow me to publish in this issue a paper based on a talk he gave last March, which includes a Q and A. I also include a recent short interview he gave to Fran Kelly of the ABC's RN Breakfast after he had won the 2021 Prime Minister's Prize for Science. I fear that any hope Eddie might have harboured of avoiding further publicity after his bold action in publishing the genome of SARS-CoV-2 online almost two years ago was illusory.

A most important paper in this issue is by Basil Hiley, professor emeritus of physics at University College, London; the title of this editorial refers to lead actors of this significant paper. As regular readers will recall, the late Ann Moyal published a paper (Moyal, 2017)[1] on the exchange of letters eighty years ago between her late husband, Joe Moyal, and the Nobel laureate physicist, P. A. M. Dirac, in which Moyal was arguing for a statistical approach to quantum mechanics, in contrast to Dirac's preferred approach for, roughly, an algebraic formulation. In my editorial in that issue (Marks, 2017), I referred to an email from Professor Hiley which confirmed that Moyal's phase space approach had anticipated Richard Feynman's propagator approach (Feynman, 1948) by a decade or more. Professor Hiley now adds to that insight.

As I understand the paper in this issue, Hiley recounts how he realised that the polymath John von Neumann had published an earlier paper (in German, apparently unknown to either Moyal or Dirac), which provides a foundation (and tools) for Moyal's statistical approach. That Dirac appears to have remained ignorant of von Neumann's approach, not referring to it in any publications, is strange, as many have remarked. I'd like to thank correspondent Douglas Roger for bringing Professor Hiley and the Society together again, four years later.[2]

Ian Sloan stood down as President of the Royal Society earlier this year, but following past precedent he has written a Presidential

1 This paper won the Ollé Award for best paper earlier this year.

2 A good summary introduction to pioneers of quantum mechanics is Physics History (2021). An amusing, non-mathematical account of the development of quantum mechanics is James (2019).

Paper, which begins this issue. As a highly cited mathematician, Ian's technical work would be beyond almost all of the Society's Fellow and Members, but he has written a non-technical paper outlining the increasing ways in which the evolution of computers and computing, over the past sixty years of his career, have affected the modelling of issues of interest to us all: weather forecasting, computing rocket and spacecraft trajectories, climate change, extreme bushfires, and quantum physics.

Following Ian Sloan's insights, we have learnt this year of two scientific breakthroughs achieved using tools of Artificial Intelligence (AI): a team led by scientists at the London-based AI company DeepMind has developed a machine-learning model that suggests a molecule's characteristics by predicting the distribution of electrons within it (Kirkpatrick et al., 1921). Earlier, DeepMind had developed an AI tool called AlphaFold, which has predicted the structure of nearly the entire human proteome (the full complement of proteins expressed by an organism). In addition, the tool has predicted almost complete proteomes for various other organisms, ranging from mice and maize to the malaria parasite (Jumper et al., 2021). Stand by for more AI accomplishments.

And with two papers in the issue concerned with quantum phenomena, there is word of detection of a "wet" quantum phenomenon breakthrough: Researchers (Xu et al., 2021) have isolated a molecule in birds' eyes that might act as a compass thanks to a quantum-mechanical mechanism called "radical pairs." The idea is that a light-sensitive molecule called a cryptochrome absorbs light and produces a pair of electrons. The quantum-mechanical spins of those electrons are influenced by Earth's magnetic field, showing the bird the way. This is the kind of biological quantum phenomenon predicted by McFadden and Al-Khalili (2014).

Earlier this year, the inaugural Warren Prize was awarded to Simon Devitt FRSN of UTS, and he has contributed a long paper based on his work with others on the architectures being explored for building quantum computers. The sensitivity of the set-up (the risk of decoherence due to thermal noise etc.) means that much thought and effort must go in to designing these platforms.

Devitt's paper follows two earlier published papers by authors who wished to be considered for the Warren Prize: Holman (2019) and Li et al. (2021). The application process has changed and no longer requires submission of a paper, but I hope that future prize-winners will continue to submit papers outlining their work.[3]

"Stop laughing, this is serious," the caption to a classic Australian cartoon by Stan Cross, could also be applied to a talk and following paper that Dr Jessica Milner Davis FRSN has produced on the multidisciplinary field of humour studies. This refereed paper started life as an address to the Society.

In his recent book, *Revivalistics*, Professor Zuckermann recounts arriving in Australia, deciding to stay here, and to help redress "the injustice done to the Aboriginal people." But how? As an Israeli linguist, he had written on the revival of Hebrew and the emergence of what he titles the Israeli language (from the ancient liturgical and

3 Because of its length, Devitt's paper has been held over to the June 2022 issue.

literary language, Hebrew — not spoken as a living language for over 1900 years — and Yiddish, with secondary contributions). He tells us he decided to use his linguistic skills for the "reclamation, revitalisation, and reinvigoration" of Aboriginal languages in Australia, bringing his competence and global perspectives to the task, building on preceding work, especially by Aboriginal communities. I approached Professor Zuckermann and asked whether he would write a paper outlining his approach. His paper is below. I thank Peter Keeda for introducing me to this work.

The Society was very pleased when Professor Stan Grant FRSN agreed to give the first address to the newly formed Western NSW branch of the Society. The address, "With the falling of the dusk," also available on-line, has been turned into a paper. It apparently reflects the conclusions of his 2021 book. The paper includes a Q and A.

Although the grand synthesis of relativity (and gravity) with quantum physics remains elusive, seventy years ago, after the first nuclear bombs had been exploded and nuclear power was to herald a new world, there was a palpable interest in how gravity would be incorporated into physics, and perhaps might result in anti-gravity devices. Dean Rickles has been interested in the ideas and people that emerged at this time, and his paper gives a summary of a 1957 conference on these issues.

At my request, Malte Ebach FRSN and Patrick Smith have written a personal account of their satisfaction at finding and discovering fossils — no, finding and discovering are not the same — a good introduction to paleontology for the rest of us.

Soon after becoming the Editor in 2016, I set to work to produce the Contents pages for the Journal, by searching through the NLA's Trove database of newspaper articles, as well as the U.S. Biodiversity Library, where almost all papers since 1867 had been scanned and made available on-line. But there were no listings of papers within issues. I extracted the URLs of the individual papers and constructed the Contents pages. I had hoped that the Google bots would index these pages and so make the *Journal* and its articles accessible for anyone on the Internet to find a particular author or paper. I also hoped that someone would make an alphabetical bibliography by author of the complete collection. I'd like to thank Councillor Davina Jackson FRSN for undertaking this task, which will mean that a researcher could easily find all papers that we have published with the word, say, "meterorite" in their titles. At the moment, there is such a bibliography for all publications from 1822 to 1900 on-line,[4] and Davina continues the extend the bibliography.

Geoff Harcourt AC FRSN died earlier this month. In a future *Journal* we shall include an obituary to this outstanding economist and man.

Important note for member subscribers

We have moved to a new database that members and fellows access when renewing their memberships. Previously, if you were a subscriber to the paper copy of the *Journal*, this subscription and its cost were rolled over to the new year, unless you opted out. I fear that the new system is an "opt-in" system: unless you specifically ask to subscribe, you won't receive a paper copy of the *Journal*.

4 https://royalsoc.org.au/images/pdf/journal/Biblios1822-1900.pdf

If you discover too late that you no longer subscribe to the paper copies, it might be too late after the print run: we will not print extra copies on the off-chance that some members have not opted-in.

Housekeeping

As always, I'd like to thank Jason Antony for his thorough help in producing the *Journal*.

December 10, 2021.

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A marriage made in heaven — mathematics and computers

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Abstract

Professor Ian Sloan AO PhD FAA FRSN is the immediate past President of the Royal Society of New South Wales. This is his presidential paper.

Introduction

In this non-technical article I celebrate the extraordinary contribution to the world made by mathematics in combination with modern computing over the past six decades or more. Because my working career as a research mathematician and physicist has spanned roughly the same period, I have experienced many of these extraordinary developments at first hand, and can share some of those experiences with you.

Of course, mathematics itself traces back millennia rather than decades, and indeed was used to create computational tools, even by the ancient Greeks.[1] But until the coming of electronic computers all calculations were extraordinarily arduous, time consuming, and prone to error.

As an undergraduate student at the University of Melbourne in the late 1950s, I recall a take-home assignment on "numerical mathematics," for which we were to do the calculations on a hand-operated calculating machine, the famous "Brunsviga." These machines were engineering masterpieces, with ten or so levers on the front and a solid handle at the end for turning a cylinder. Let me explain how to multiply two decimal numbers, say 1.2468 by 5.234: one would enter the first number by setting five levers to the appropriate level 1, 2, 4, 6, 8 respectively (that's the easy part), and then rotate the handle 5 times for the leading digit of the multiplier, then shift something and rotate the handle 2 times for the next digit, then shift and rotate 3 times for the next digit, then finally shift and rotate 4 times for the last digit. (You can forget about the decimal point: you can see easily where it should go in the product.) If the number of turns was to be more than five, say 7, to save time one would rotate backwards 3 turns. All of this you could learn to do in maybe 10 seconds, but you certainly had to concentrate.

A more substantial criticism was that the methods used, and the problems tackled, were inevitably extremely limited, and restricted to simple and frankly boring problems. The typical problem was to compute the value of a certain function for some given input number (to be definite, let's say the logarithm to the base 10 of the given input number; but if you don't remember what a logarithm is, it doesn't matter in the slightest). In those days every school and university had many tables of logarithms of numbers, given at equally spaced inter-

1 https://en.wikipedia.org/wiki/Antikythera_mechanism [Ed.]

vals. But what about if you wanted the logarithm of a number (such as 1.2468) that was in between two entries in the table? In that case one would need to "interpolate" to obtain the number. That would require (depending on the accuracy you want, and the spacing used in the table) some number of additions and multiplications on your Brunsviga calculator.

Thank goodness, all that pain has gone. Every scientific calculator these days has logarithms (and many other functions) built in — all that underlying mathematical work is now built into the software. Now we can focus on more interesting problems.

In this article I concentrate on problems in just five areas of application; but, believe me, there are a multitude of others.

Weather forecasting

Have you noticed that the quality of the weather forecasts we look at each day has improved greatly over recent years? In part this is because of better observational data over land and over oceans. But it is also because of better mathematical models, better mathematical techniques, and of course better computers.

The scientific approach to weather forecasting is often attributed to Lewis Fry Richardson, a British applied mathematician working in the 1920s.[2] Our weather is determined by the physics and chemistry of what happens in the atmosphere, which is the thin film of oxygen, nitrogen, water vapour, carbon dioxide and other gases that covers the first few tens of kilometres above us. The temperature, wind, humidity and other quantities within this zone are governed by mathematical equations. (I hope that this is known to all, but I suspect not.) It is the working out of the physical systems described by these equations that determines the weather. What makes it all so difficult is that what happens at one point (say a pressure or temperature change) affects what happens at nearby places, and at adjacent times. And the pressure and temperature vary not only at places on the ground, but also at different heights above the ground. Everything is connected. To work out the consequences of those equations, and all that connectivity, supercomputers are needed.

I was struck by this sentence from the NASA website mentioned above: "Despite the advances made by Richardson, it took him, working alone, several months to produce a wildly inaccurate six-hour forecast for an area near Munich, Germany." Several months of computation to produce an unusable 6-hour forecast. That's exactly the point: that with the equipment he had available at the time (perhaps a Brunsviga calculator) there was absolutely no way of obtaining a useful forecast in real time. That's what has changed: not only has forecasting improved enormously, but also a forecast can be provided speedily enough to be useful.

In his book *Weather Prediction by Numerical Process*, published in 1922, Richardson evidently realised that real-time forecasting would require more resources: he estimated that the job could be done if he could have 64,000 assistants all in the one room.

Nowadays the Australian Bureau of Meteorology owns immensely powerful supercomputers, used every day for its forecasts. It also employs many scientists, who work continually to improve the models and the

2 See https://earthobservatory.nasa.gov/features/WxForecasting/wx3.php

science incorporated in those models. Some also work to improve the approximation schemes needed to restrict the mathematical equations (which are about continuous temperature or wind fields) to the discrete space and time grids used on the computer.

Statistics (another branch of the mathematical sciences) also plays a big role at the Bureau. One aspect of forecasting with strong statistical implications is what is known as "data assimilation." This describes the process of revising a forecast to take account of new information: perhaps rain was predicted at noon at a certain spot, but in fact it has already rained at 8 AM; how should the forecast be revised? And what is the uncertainty in the revised forecast? (Have you noticed that BoM forecasts now come with probabilities, for example the probability of rain over successive three-hour periods?) And of course all must be done quickly, and automatically, or else the forecast (like Richardson's) will be unuseable.

Computing rocket and spacecraft trajectories

The story of the computation of trajectories of rockets, like weather forecasting, traces back well before the age of electronic computers. Indeed, the first "computers" were not electronic, but human. The early history of the Jet Propulsion Laboratory (which later morphed into NASA) is told in Lutz (2016).

From that source, "What's often not known is that all the early rocket experiments and later missions to the moon and beyond wouldn't have been possible without a team at JPL known as the human 'computers.' Most of these human computers were women, who either had degrees in mathematics or were simply very good at mathematics. Over the course of time, these women not only performed hundreds of thousands of mathematical calculations crucial to the U.S. space program, but also eventually became some of the first computer programmers at NASA." The recent movie "Hidden Figures" is a dramatic representation of the contribution of these early "computers."

It is said that the human computers worked with pencil and paper. I suspect they also had the benefit of Brunsviga calculators and early electro-mechanical computers. But however they did it, they did remarkably well with old technology, and old mathematical tools.

This is perhaps a good moment for me to mention the importance in the old days of error control. When every calculation (and every single addition, multiplication or division) was done by the fallible hand of a single human, the possibilities of error were immense. For that reason, much of the literature in those days was devoted to the detection and correction of errors. As a young researcher I used to look regularly at the journal *Mathematical Tables and Other Aids to Computation* because its main role was to report errors in published tables. That was important in case one had to rely on a table that might contain errors. That's another painful task that has disappeared. (Some of those "errors" in tables were said to be deliberate, designed to flush out plagiarists.)

But I want to emphasise that error control in the broader sense is still very important. In my early days in research, working in physics, I came to the sad conclusion that around half the published papers contained significant errors, either mathematical or

computational (the latter meaning that the published numbers were not correct, the former that even the formulas were not correct). If this is less true now that I work mainly in mathematics, it is possibly because publication in mathematics is so slow that there is more time to correct errors.

Climate change

The Royal Society of London, the world's oldest scientific body, recently issued a call[3] for the creation of a multinational supercomputer centre, to provide climate modelling facilities beyond the capacity of any one nation to sustain, which will develop models on an unprecedentedly fine scale. The call notes that to double the precision of present modelling, a tenfold increase in computing power is required. This makes sense if you consider that to improve the resolution from 20 km to 10 km on the earth's surface requires four times (or 2 squared) as much data (because the surface is 2-dimensional); and to improve the resolution also in the vertical direction by a factor of two requires a further factor or two; and to halve the time step needs yet another factor of two. And that does not consider the extra processing power required for that much connectivity and so much more data.

Interestingly, the Royal Society does not say much about mathematics in its document. Why not? Because the writers of the document along with the earth scientists know full well that every aspect of the underlying models is expressed in terms of mathematics. Here is one quote: "These laws, represented by mathematical equations, have to be solved using sophisticated numerical techniques." Yes indeed.

Extreme bushfires

In a recent lecture at the Royal Society of NSW I learnt about "Extreme Bushfires and the Age of Violent Pyroconvection."[4] In brief, extreme bushfires (such as those we saw in 2019–20 in Eastern Australia) are bushfires that are violent enough to create their own weather. The reason we are coming into the age of extreme bushfires and "violent pyroconvection" is of course climate change.

I learnt that most bushfires are not in this sense extreme, and for those that become extreme the damage often happens during very short but violent episodes. Extreme bushfires are hard to predict, and even harder to manage. For an insight into how such events can be modelled and understood, see the excellent lecture by Jason Sharples FRSN in the YouTube video recording.[5]

My interest here is in an aspect little mentioned in the lecture, the hidden cooperating giant fields of mathematics and computing. As before, mathematics is everywhere when the physics and chemistry of the atmosphere and the environment are involved, and under extreme conditions they make a highly challenging and volatile cocktail. What about computers? The website of National Computational Infrastructure (which is Australia's national supercomputing centre) describes a ten-year partnership on Extreme Bushfires between Sharples'

3 https://policycommons.net/artifacts/1724705/next-generation-climate-models/2456354/

4 A paper based on this talk is in preparation for publishing here. [Ed.]

5 https://www.youtube.com/watch?v=cTRXkM_z-S8

group and NCI, reported in "Protecting lives and property from extreme bushfire."[6] This website describes supercomputer modelling that has the ultimate aim of being able to predict extreme bushfire events.

But prediction is not the end of the game, not if (like Lewis Richardson's weather forecasting efforts a century ago) the result arrives after the crisis has passed. The key to achieving the necessary "faster-than-real-time modelling" has many facets. As explained to me by Professor Sharples: the need is for

1. Understanding the fundamental processes driving extreme bushfire development
2. Computational models ... [that] inform ... the development of simplified "proxy" mathematical models
3. "Simplified" mathematical models sometimes require specific computational methods to deal with sources of numerical instability
4. Drawing upon fundamental mathematical theorems
5. The potential for Artificial Intelligence to support prediction of extreme bushfires.

These headings are perhaps enough to hint at the many challenges involved in the future design of an "app" that will give an authentic prediction in real time of an extreme bushfire event. Mathematics and computers need to work together!

Quantum physics

Never fear: I am not about to teach you about quantum physics. But I do want to say that the computations that are trying to explore the fundamental nature of matter (for example under such headings as string theory and lattice gauge theory) are some of the most challenging computations undertaken anywhere. It is common worldwide that non-military supercomputers spend much of their time doing lightning-fast calculations of enormous complexity on problems coming from quantum physics. Often the underlying approximation scheme (necessary to convert the mathematical equations to computer code) uses the so-called Monte Carlo method,[7] which as the name suggests relies on choosing numbers randomly. With colleagues in Germany and Australia I have had some recent involvement in this quantum physics activity, the key being a large interest in my group at UNSW in methods similar to Monte Carlo (so-called Quasi Monte Carlo methods), which however aim to be "better than random." This is one way of trying to achieve ever faster solutions of ever larger problems.

At the beginning of my research career, as a PhD student at the University of London, my project involved working out new ideas for calculating how a beam of electrons would be scattered by a collection of hydrogen atoms — an important question for astrophysics, and one not accessible to earthbound experiments (because on earth hydrogen atoms are invariably joined to other atoms to form molecules).

If I had arrived in London much earlier, then I would have spent perhaps six months sitting with a Brunsviga calculator (I don't remember seeing any electric calculators), doing unbelievably repetitive and tedious calculations every day. By the greatest good

6 https://nci.org.au/research/research-highlights/protecting-lives-and-property-extreme-bushfire

7 See Marks R.E. (2014) "Monte Carlo," in *The Palgrave Encyclopædia of Strategic Management*, edited by David Teece and Mie Augier, London: Palgrave. [Ed.]

fortune, I happened to arrive when the University of London was soon to have access to an advanced electronic computer. This was the "Atlas" computer built by the Ferranti company and Manchester University, said to be the fastest computer in the world when it came online in 1962.[8] I suppose that it had roughly the capacity and computational power of a modern smart phone, but at time the advance was tremendous. The Atlas wasn't so easy to use: the Autocode program had to be typed on easily torn paper tape, so one became an expert at splicing paper tape. But at least I was saved (by not being in Manchester) from the fate of many beginning PhD students in the early days of electronic computers, of having to nurse the computer overnight, in case of a "bug" in the program or the machinery.

I count it as the greatest of good fortune that I came online at more or less at the same time as modern computers.

Conclusion

In the modern world of science and technology, mathematics in a marriage with computers is so often providing the answer. The role of mathematics is very often unmentioned: mathematics is often the hidden secret agent. Do please remember that "computer model" almost always means "mathematical model captured in computer code."

8 See https://en.wikipedia.org/wiki/Atlas_(computer)

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The Moyal-Dirac controversy revisited

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Abstract

In this paper we revisit the controversy that arose between Paul Dirac and Joe Moyal. Our motivation is provided by the fact that the algebraic aspects of both their approaches are becoming more appreciated as interest in the development of non-commutative geometry's attempt to "geometrise" quantum mechanics grows. Both were seeking to understand the role of non-commutativity, Moyal from a consideration of the differences between classical and quantum statistics, while Dirac was exploring its implications for the dynamics. The disagreement arose essentially over which should be given priority, the dynamics or the statistics. We will provide the background to show that both are essential aspects of the same overall mathematical structure.

1. Introduction

IN this paper I want to focus on the controversy that arose between Paul Dirac and Joe Moyal as a consequence of their different proposals for developing a phase space approach to quantum theory. This controversy gets to the heart of the fundamental problems in the description of quantum phenomena. Interestingly Dirac and Moyal were both "outsiders" in the sense that they started out as engineers, more so Moyal because of the way he entered academia, a story beautifully told in a biography penned by his wife Ann Moyal (2006).[1]

We pick up the story when Moyal was working in the Meteorological branch of the Ministère de l'Air in Paris at the outbreak of World War II. In the ensuing chaos, he managed to escape to England and was eventually given a job at the de Havilland Aircraft Company where he became the Assistant Director of the wartime Vibrations Department.

After the war Moyal wanted to work in quantum physics when fortunately an opportunity arose for him to enter academia by becoming an assistant lecturer in the Department of Mathematical Physics at Queen's University Belfast. It was there in 1949 that he published his classic paper which is the focus of his disagreement with Dirac.

This disagreement involves the question as how best to develop a (p, x, t) phase space formulation for quantum phenomena, the well-recognised difficulty arising from the non-commutativity of the quantum observables for momentum and position. In other words, if we replace the classical variables, (p, x), by operators, or rather

1. See also Moyal (2017). [Ed.]

elements of a non-commuting algebra, can we develop a coherent mathematical structure to describe quantum phenomena? Or must we simply use the wave theory as mathematically refined by the Hilbert space formalism with its interpretational difficulties?

Dirac showed how this phase space approach was possible by specifically developing his bra-ket notation for the purpose (Dirac 1939). In doing this, he showed that one had to introduce a special symbol, the standard ket, often overlooked, but necessary to distinguish algebraically specific representations in a Hilbert space. In the immensely fruitful Schrödinger approach one avoids any question about the standard kets by normalising the wave function at every stage. However, as Dirac (1965) himself points out, one can find situations where the Schrödinger picture fails because the state vector does not even remain in the same Hilbert space.

Moyal's approach was to use the structure of the algebra of functions on (p, x) phase space to compare a classical statistical theory with a quantum statistical theory. In doing so, he revealed the importance of a new bracket, the Moyal bracket, that replaced the quantum commutator bracket. Naturally, Moyal's (1949) paper focusses on *statistics* but he chose to discuss the relation between the algebraic approach, the wave function and the Schrödinger equation in an appendix at the end of the paper, giving the impression that statistics was more important than the dynamics. Dirac (1927, p. 641) on the other hand, did not think probability should be given priority over the dynamics. He writes:

> The notion of probabilities does not enter into the ultimate description of mechanical processes; only when one is given some information that involves a probability (e.g., that all points in η-space [η is a space of commuting variables] are equally probable for representing the system) can one deduce results that involve probabilities.

So already a misunderstanding began to arise fuelling a dispute. What neither of them had realised was that von Neumann (1931) had already created the algebra that Moyal developed in order to prove what became known as the Stone-von Neumann theorem, namely that the Schrödinger picture was unique, but only up to a unitary transformation. The theorem itself gave the impression that one need only work in this picture, so the wave function became *the way* of talking about non-relativistic quantum mechanics. The alternative Heisenberg picture, often called matrix mechanics, was thought only to be of importance for the relativistic domain and quantum field theory.

In this paper I want to bring out this historical background so that we see how the differences between Dirac and Moyal can be resolved. I will also show how other unitarily equivalent pictures arise and how they help to clarify a different overview of what both Dirac and Moyal were pioneering.

2. A Brief Historical Background to the Controversy

Mathematically, quantum theory had effectively two very different births. One in the mathematical work of Born and Jordan (1925) which was developed out of the physical insight of Heisenberg (1925) as he studied the emission of light quanta from accelerating electrons. This approach is generally known as matrix mechanics. The second approach emerged from Schrödinger's work using de Broglie's proposals that electrons should show the same interference effects as photons when they pass through two slits. This approach led to wave mechanics and the Schrödinger picture. Physically these two approaches looked very different. Schrödinger (1926) showed how they could be related mathematically, a relation that was later formalised in the Stone-von Neumann theorem. This mathematical fact still leaves open the question as to whether the Heisenberg and Schrödinger pictures are physically equivalent.

Wave mechanics used mathematical techniques that were very familiar to physicists at the time. Matrix mechanics, on the other hand, involved the new and unfamiliar mathematics of non-commutative structures — so much so that Heisenberg had to be told that he was using matrix multiplication.[2]

However, it was not that the general notion of non-commutativity was unfamiliar. For example, one must open the door before we can pass through; turn a book first through 90 degrees about the x-axis and then through 90 degrees about the y-axis and note its final orientation. Do the same thing in reverse order and you will obtain a different orientation. Again, measure the phase of a wave before measuring its amplitude and you will obtain a different result if you reverse the order of measurements. All very familiar. But what do we make of the non-commutability of position and momentum? The last example provides a simple answer, it is *all* to do with measurement. Hence *the* interpretation becomes *what we do*, rather than *what happens*.

Surely what happens naturally should not depend on what we do or don't do. The cosmos evolved before humans came into existence, so how do we understand the basic notion of movement, or of change? This was probably the most fundamental aspect of the disagreement between Dirac and Moyal, namely what was the best way to develop an ontology of quantum movement?

The classical ontology of movement asserted that a particle could be at position x and have momentum p simultaneously, so that a trajectory could be given a well-defined meaning. All this takes place in what is called a *phase space*. What happens when x and p become elements of a matrix algebra where they no longer commute and therefore cannot be given simultaneous meaning? Could they be given meaning without resorting to interpreting the symbols as describing our actions on the unfolding process?

Dirac (1945) certainly did believe that we could develop a theory that would provide us with a rather more definite picture of the motion of a quantum particle and

2. By Max Born, in July 1925. See van der Waerden (1968), Introduction, p. 35. [Ed.]

indeed did make a specific proposal. The disagreement was not about developing a phase space approach to quantum phenomena but in the details of how we should construct such a theory. Indeed Dirac did make such a proposal but it turned out that the probabilities in his approach were, in general, complex numbers. In a comparison with the probabilities in the Moyal approach, Dirac (1945) concluded:

> Moyal's probability is always real, though not always positive, and is thus one step more physical than the probability of the present paper, but its region of applicability is rather restricted, as it does not seem to be connected with a general theory of functions like the present one.

Later in his classic textbook, Dirac (1947) made his overall position on probabilities in phase space very clear. After a discussion of the use of a probability density distribution, ρ, in a Gibbs ensemble in classical phase space he writes:

> We shall now see that there exists a corresponding density ρ in quantum mechanics having properties analogous to the above. It was first introduced by von Neumann. Its existence is rather surprising in view of the fact that phase space has no meaning in quantum mechanics, there being no possibility of assigning numerical values simultaneously to the q's and p's.

It should be noted that Moyal (1949) did not start from the dynamics, rather he focussed on the statistical aspects of the theory. His key question was "What are the similarities and differences between the statistical concepts used in quantum mechanics and those used in classical statistics?" He treated the time evolution of the statistics by starting from the Heisenberg equation of motion. As is made clear in the first quotation, it was the emphasis Moyal placed on the statistics, rather than the dynamics, that was the source of Dirac's objection.

As previously mentioned, both had overlooked a (1931) paper by von Neumann where he had developed the same non-commutative algebra that Moyal was exploring in his classic (1949) paper. Von Neumann's paper was the source of what became known as the Stone-von Neumann theorem which proves that the Schrödinger picture is unique up to a unitary transformation. It is remarkable that von Neumann used the algebra of the non-commutative phase space to reaffirm the Hilbert space structure he had set down in his classic (1932) book. The irony being that the Hilbert space formalism became so entrenched that those who tried to develop the algebraic approach, such as those using the $\star$-algebra, were generally ignored. We will discuss the details of the von Neumann approach later in section 3.

2.1 The Mathematical Structure of the Moyal Approach

Let us start as Moyal (1949) did by comparing quantum statistics with the techniques used in classical statistics. In classical statistics, it is the *characteristic function* that plays a key role so Moyal set about constructing an analogous *quantum characteristic function* for a quantum system in a state ψ. This he did by first forming the operator

$$\widehat{M}(\tau, \theta) = \exp\,[i(\tau \hat{P} + \theta \hat{X})]. \tag{1}$$

Here $(\hat{P}, \hat{X})$ are elements in the operator algebra satisfying the usual commutation relation

$$[\hat{X}, \hat{P}] = i\hbar$$

and (τ, θ) are two commuting classical parameters (c-numbers).[3] Then the characteristic function in the state ψ is given by the scalar product

$$M_\psi(\tau, \theta) = \langle \psi \,|\, e^{i(\tau \hat{P} + \theta \hat{X})} \,|\, \psi \rangle. \tag{2}$$

Taking its Fourier inverse, we obtain the probability distribution function $F_\psi(p, x)$ so that

$$F_\psi(p, x) = \frac{1}{4\pi^2} \int\int \langle \psi \,|\, e^{i(\tau \hat{P} + \theta \hat{X})} \,|\, \psi \rangle \; e^{-i(\tau p + \theta x)} d\tau d\theta.$$

In this way Moyal arrived at the Wigner (1932) distribution function

$$F_\psi(p, x) = \frac{1}{2\pi} \int \psi^*(x - \tfrac{1}{2}\hbar\tau) \; e^{-i\tau p} \psi(x + \tfrac{1}{2}\hbar\tau) \, d\tau. \tag{3}$$

This shows that the variables (p, x) were actually the variables used in the Wigner distribution, so confirming that the variables are the elements in some non-commutative phase space.

What Moyal then shows is that the expectation value of any bounded operator, $\hat{A}$, can be simply found using the relation

$$\langle \hat{A} \rangle = \int\int \mathbf{a}(p, x) F_\psi(p, x, t) \, dx \, dp, \tag{4}$$

where $\mathbf{a}(p, x)$ is a function on the symplectic phase space. Moyal has implicitly assumed that the non-commuting operator algebra has been replaced by an algebra of C^∞-functions on a phase space. Thus the expectation value $\langle \psi_j | A | \psi_k \rangle$ can be obtained by integration of the ordinary function $\mathbf{a}(p, x)$ with respect to the corresponding phase space matrix $F_{jk}(p, x)$. Thus

$$\begin{aligned} \langle \psi_j \,|\, A \,|\, \psi_k \rangle &= \int\int A(p, x) F_{jk}(p, x) \, dp \, dx \\ &= \int\int\int\int \mathbf{a}(p, x) \, \langle \psi_j \,|\, e^{i(\tau \hat{P} + \theta \hat{X})} \,|\, \psi_k \rangle \, dp \, dx \, d\tau \, d\theta. \end{aligned}$$

The first surprise for Dirac (1947, p. 132) was that the (p, x) phase space appeared to be commutative and therefore the Heisenberg uncertainty principle would be violated. However, this turns out not to be the case provided we replace the commutator bracket, $i\hbar[\hat{R}\hat{G} - \hat{G}\hat{R}]$, by a new bracket, the Moyal bracket defined by

3. The reduced Planck's constant, $\hbar$, is Planck's constant h divided by 2π. The angular momentum of any electron is an integral multiple of $\hbar$. [Ed.]

$$\frac{2}{\hbar}\sin\frac{\hbar}{2}\left[\frac{\partial}{\partial p_g}\frac{\partial}{\partial x_r}-\frac{\partial}{\partial p_r}\frac{\partial}{\partial x_g}\right]\mathbf{r}(p,x)\;\mathbf{g}(p,x) \tag{5}$$

where $\mathbf{r}(p,x)$ and $\mathbf{g}(p,x)$ are the phase space C^∞-functions that replace the two operators, $\hat{R}$ and $\hat{G}$. Notice even at this stage that the differential operator inside the square bracket has the same form as the classical Poisson bracket, a relation which we will develop further in section 3.3.

3. The von Neumann 1931 Paper

In the same year that his classic text appeared, von Neumann (1931) published the paper which formed the basis of the important Stone-von Neumann theorem. This paper is central to our discussion of the Moyal algebra. The importance of this theorem is that it proves that the Schrödinger picture is unique up to a unitary transformation. Thus it has provided the justification, quite rightly, for many physical situations, for the dominant use of the Schrödinger wave function picture, in spite of the well-known paradoxes and the unresolved "problem" of the collapse of the wave function.

It is interesting to take note, in passing, of von Neumann's confession to Birkhoff (Rédei 1996), saying that he no longer believed that the wave function should be regarded as an adequate description of the state of a quantum system. As a consequence Birkhoff and von Neumann (1936) developed a notion of what they called "Quantum Logic" to provide a different way of looking at quantum phenomena. As an algorithm, the Schrödinger picture has not been surpassed in the non-relativistic domain.

What is not generally realised is that the mathematical techniques that von Neumann used to prove his theorem are of major significance to Moyal's work. Indeed, what we will now show is that the mathematical structure developed by von Neumann is identical to the one that appeared in Moyal's classic paper (1949). In other words, the Moyal algebra is isomorphic to the standard operator algebra of quantum mechanics. This in turn implies that a *non-commutative phase space* can be regarded as lying at the heart of quantum theory.

Rather than starting with the well-known relation[4] $[\hat{X},\hat{P}]=i$, von Neumann, following Weyl (1927), introduces a pair of bounded operators, $U(\alpha)=e^{i\alpha\hat{P}}$ and $V(\beta)=e^{i\beta\hat{X}}$ so that the non-commutative multiplication can be written in the form

$$U(\alpha)V(\beta)=e^{i\alpha\beta}\,V(\beta)\,U(\alpha), \tag{6}$$

together with the relations,

$$U(\alpha)\,U(\beta)=U(\alpha+\beta);\quad V(\alpha)\,V(\beta)=V(\alpha+\beta).$$

One can now define an operator

4. We will for convenience put $\hbar=1$ in this section.

$$\hat{S}(\alpha,\beta) = e^{-i\alpha\beta/2}\, U(\alpha)\, V(\beta) = e^{i\alpha\beta/2}\, V(\beta)\, U(\alpha)$$

which can also be written in the form

$$\hat{S}(\alpha,\beta) = e^{i(\alpha\hat{P}+\beta\hat{X})}. \tag{7}$$

This is exactly the operator $\widehat{M}(\tau,\theta)$ introduced by Moyal in his equation (1), provided we identify (τ,θ) with (α,β). Thus Moyal's mathematical starting point is exactly the same as that of von Neumann but is motivated from a very different standpoint.

Let us go further. Von Neumann then proves that the operator $\hat{S}(\alpha,\beta)$ can be used to define any bounded operator $\hat{A}$ on a Hilbert space through the relation

$$\hat{A} = \int\int \mathbf{a}(\alpha,\beta)\, \hat{S}(\alpha,\beta)\, d\alpha d\beta, \tag{8}$$

where $\mathbf{a}(\alpha,\beta)$ is the kernel of the operator.

To proceed further, von Neumann defines the expectation value of the operator $\hat{A}$ as

$$\langle\psi\,|\,\hat{A}\,|\,\psi\rangle = \int\int \mathbf{a}(\alpha,\beta)\, \langle\psi\,|\,\hat{S}(\alpha,\beta)\,|\,\psi\rangle\, d\alpha\, d\beta. \tag{9}$$

Here

$$\langle\psi\,|\,\hat{S}(\alpha,\beta)\,|\,\psi\rangle = \langle\psi\,|\,e^{i(\alpha\hat{P}+\beta\hat{X})}\,|\,\psi\rangle$$

so that

$$\langle\psi\,|\,\hat{S}(\alpha,\beta)\,|\,\psi\rangle = \langle\psi\,|\,\widehat{M}(\alpha=\tau,\beta=\theta)\,|\,\psi\rangle,$$

which, apart from a change of variables, is identical to the expression used by Moyal in equation (2). If we now use the Fourier transformation of $M_\psi(\tau,\theta)$ in equation (9), we find it immediately gives the Moyal equation (4) for the expectation value. Including the time dependence, the expectation values of the two approaches give

$$\langle\psi\,|\,\hat{A}(t)\,|\,\psi\rangle = \int\int \mathbf{a}(p,x,t) F_\psi(p,x,t)\, dp\, dx. \tag{10}$$

Here $\mathbf{a}(p,x,t)$ is called the *Weyl symbol* (de Gosson 2016), its Fourier transform being $\mathbf{a}(\tau,\theta,t)$.

Thus Moyal has chosen to label the parameters in the Fourier inversion (p,x) because he is anticipating a generalised phase space. Von Neumann, on the other hand, attaches no specific physical meaning to the parameters (α,β).

3.1 The Relationship Between Quantum Operators and Weyl Symbols

Looking at equation (8) we see that there is a well-defined relationship between an operator, $\hat{A}$, and its corresponding symbol, $\mathbf{a}(\alpha,\beta)$. If the algebraic structure of the quantum operators is to be made isomorphic to the algebraic structure inherited by the

symbols, we must find the nature of the two defining binary relations between the symbols.

Clearly addition, being abelian, is straightforward so that

$$\hat{A} + \hat{B} \rightarrow \mathbf{a}(\alpha, \beta) + \mathbf{b}(\alpha, \beta) \, .$$

The product, being non-commutative, is more difficult and we must find how the product $\hat{A}\hat{B} = \hat{C}$ translates into the product $\mathbf{a}(\alpha, \beta) \odot \mathbf{b}(\alpha, \beta) = \mathbf{c}(\alpha, \beta)$ so that the expectation value for the product is the same in both cases. To show how this is possible, we follow von Neumann and write

$$\begin{aligned}
\langle g \,|\, \hat{A}\hat{B} \,|\, f \rangle = \langle \hat{A}^* g \,|\, \hat{B} f \rangle &= \int\int \mathbf{b}(\alpha, \beta) \, \langle \hat{A}^* g \,|\, \hat{S}(\alpha, \beta) f \rangle \, d\alpha d\beta \\
&= \int\int \mathbf{b}(\alpha, \beta) \, \langle g \,|\, \hat{A}\hat{S}(\alpha, \beta) f \rangle \, d\alpha d\beta \\
&= \int\int\int\int \mathbf{b}(\alpha, \beta) \, e^{\frac{1}{2}i(\gamma\beta = \delta\alpha)} \, \mathbf{a}(\gamma - \alpha, \delta - \beta) \, \langle g \,|\, \hat{S}(\gamma, \delta) f \rangle \, d\alpha d\beta d\gamma d\delta \\
&= \int\int \Big[\int\int e^{\frac{1}{2}i(\gamma\beta - \delta\alpha)} \, \mathbf{a}(\gamma - \alpha, \delta - \beta) \, \mathbf{b}(\alpha, \beta) \, d\alpha \, d\beta \Big] \langle g \,|\, \hat{S}(\gamma, \delta) f \rangle \, d\gamma \, d\beta .
\end{aligned}$$

The kernel of $\hat{A}\hat{B}$ is thus $\int\int e^{\frac{1}{2}i(\gamma\beta - \delta\alpha)} \mathbf{a}(\gamma - \alpha, \delta - \beta) \, \mathbf{b}(\alpha, \beta) d\alpha d\beta$. (The absolute integrability of this expression follows from the deduction.) Von Neumann's product can be transformed into one given in terms of the variables (p, x). We thereby arrive at the ★-product which can be written in a geometrically illuminating form (Hirshfeld and Henselder 2002a)

$$\begin{aligned}
&\mathbf{a}(p, x) \bigstar \mathbf{b}(p, x) \\
&\qquad = (\pi\hbar)^{-2} \int\int\int\int \exp\left[\left(\frac{2}{i} \hbar \right) (p(x_1 - x_{2)} + x(p_2 - p_1) + (x_2 p_1 - x_1 p_2)) \right] \qquad (11) \\
&\qquad\qquad \times \mathbf{a}(p_1, x_1) \, \mathbf{b}(p_2, x_2) \, dp_1 dp_2 dx_1 dx_2 .
\end{aligned}$$

The exponent can then be simplified by writing $z = (p, x)$ to give

$$\frac{1}{2} \left[p(x_2 - x_1) + x(p_1 - p_{2)} + (x_1 p_2 - x_2 p_1) \right] = \frac{1}{2} (z - z_1) \wedge (z - z_2) = A(z, z_1, z_2)$$

where $A(z, z_1, z_2)$ is an area, a symplectic area in phase space (see Figure 1).

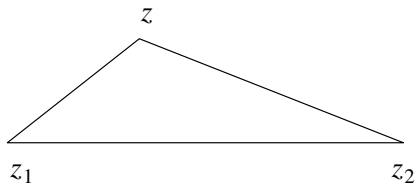

Figure 1: Symplectic area $A(z, z_1, z_2)$

We then find that the ★-product can be written in the form

$$(\mathbf{a}\bigstar\mathbf{b})(z) = \int\int \exp\left[\frac{4i}{\hbar}A(z, z_1, z_2)\right]\mathbf{a}(z_1)\,\mathbf{b}(z_2)\,dz_1 dz_2.$$

Thus the ★-product is non-local in that it involves integrating over a non-local region in the non-commutative phase space. It is this product that is used in M-theory. Notice that when the area $A(z, z_1, z_2)$ is zero, the multiplication is commutative and we return to the classical domain. For an excellent and more extensive discussion of the ★-product and the implications of its non-local nature see Zachos (2000, and 2002) and Zachos, Fairlie and Curtright (2005, and 2014).

3.2 The Non-local ★-Product

In an analysis that focusses on the *non-local* nature of the ★-product, Hiley (2015) shows that the (p, x) should be identified with the mean position of a "blob" in phase space (de Gosson 2013). To motivate this suggestion we follow the work of Berezin and Shubin (2012) who show that there is a relation between propagators in space-time and phase space kernels. A similar result was proposed by Bohm and Hiley (1981, and 1983), who worked from a different perspective.

If $K(y, y')$ is the propagator linking two points, (y, y'), in configuration space and $F(p, x)$ is the corresponding phase space kernel, which Moyal calls the "phase space distribution," we have the relations

$$K(y, y') = \int\int L^*(y, y' \mid p, q)F(p, q)dpdq$$

and

$$F(p, x) = \int\int L(p, x \mid y, y')K(y, y')\,dyd\,y'.$$

After some detailed work that can be found in Berezin and Shubin (2012), we find the function $L(p, x|y, y')$ and obtain the relations in their final form

$$K(x, y) = (2\pi\hbar)^{-n}\int F(p, x)e^{-ip.(y-x)/\hbar}dp$$

and

$$F(p, x) = \int K(x, y)e^{ip.(y-x)/\hbar}dy.$$

Rather than following von Neumann to arrive at (11), we can obtain the formula for the product of kernels by considering the succession of propagators which form a groupoid defined by

$$K(y, y') = \int K_1(y, z)K_2(z, y')\,dz.$$

In this way we arrive at an expression for the product of kernels (11), again confirming the isomorphism between the operator algebra and the non-commutative algebra formed by functions on a quantum phase space.

Remember that (y, y') are the coordinates of two separate points in configuration

space which means we are also considering two points in phase space, (p, y) and (p', y'). In $2n$-dimensional phase space we have what de Gosson (22) calls a "blob." The main measure of such a blob is its symplectic capacity or phase space area (in two-dimensional phase space). These are the type of object that lie at the heart of M-theory (Steinacker 2011).

Now we make the coordinate transformations

$$p \to P = (p + p')/2 \quad \text{and} \quad x \to X = (y + y')/2$$

while

$$\tau = y - y' \quad \text{and} \quad \theta = p - p'.$$

The important conclusion we then arrive at is that the Moyal algebra is describing extended objects in phase space. In other words, the quantum formalism translates to something *non-local* on a phase space. This is a key point that will come up again and again. For now we will simply treat it as a mathematical consequence of the Moyal formalism. However, it should already be noted that Dirac's criticism was based on the implicit assumption of a local description in phase space. This then surely resolves one difficulty that Dirac anticipated because he assumed a local phase space description whereas we are concerned with "areas" or "regions" of phase space.

3.3 More on the ★-Product

The fact that Moyal can use C^∞-functions to describe quantum phenomena will generate, as our own experience shows, disbelief so we feel it is necessary to go into a few more details concerning the ★-product and the implications of the formalism. This radical change in the algebraic structure becomes more compelling once we realise that the ★-product can be written as

$$\mathbf{a}(p,x) \bigstar \mathbf{b}(p,x) = \mathbf{a}(p,x) \exp\left[\frac{i\hbar}{2}\left(\frac{\overleftarrow{\partial}}{\partial x}\frac{\overrightarrow{\partial}}{\partial p} - \frac{\overleftarrow{\partial}}{\partial p}\frac{\overrightarrow{\partial}}{\partial x}\right)\right]\mathbf{b}(p,x) \tag{12}$$

which is just the complex exponential of the classical Poisson bracket (Groenewold 1946). Quantum mechanics is not "another world," as the "classical world" actually emerges from the underlying quantum processes. Thus while classical mechanics involves the representations of the symplectic and orthogonal groups, quantum mechanics exploits the representations of their covering groups, explaining the appearance of the orthogonal and symplectic spinors.

Moyal only considered the symplectic aspects of the symmetries in his investigations, so his results were pertinent to the double cover of the symplectic group, namely, the metaplectic group and its non-linear generalisation (Guillemin and Sternberg 1984).

It was Groenewold (1946) who first wrote down equation (12) in terms of its trigonometric expansion. He writes

$$\mathbf{a}(p,x)\frac{2}{\hbar}\sin\frac{\hbar}{2}\left(\frac{\overleftarrow{\partial}}{\partial x}\frac{\overrightarrow{\partial}}{\partial p}-\frac{\overleftarrow{\partial}}{\partial p}\frac{\overrightarrow{\partial}}{\partial x}\right)\mathbf{b}(p,x)\leftrightarrow\frac{i(\mathbf{ab}-\mathbf{ba})}{2}$$

which was used by Moyal in the form of equation (5). The remaining cosine term

$$\mathbf{a}(p,x)\frac{2}{\hbar}\cos\frac{\hbar}{2}\left(\frac{\overleftarrow{\partial}}{\partial x}\frac{\overrightarrow{\partial}}{\partial p}-\frac{\overleftarrow{\partial}}{\partial p}\frac{\overrightarrow{\partial}}{\partial x}\right)\mathbf{b}(p,x)\leftrightarrow\frac{\mathbf{ab}+\mathbf{ba}}{2}\tag{13}$$

was not used by Moyal.

An exponential form is extremely useful for cases where the $\mathbf{a}(p,x)$ and $\mathbf{b}(p,x)$ are finite polynomials. For example, it is trivial to show that

$$x\bigstar p-p\bigstar x=i\hbar.$$

This demonstrates that a form of the Heisenberg commutator also appears in the algebra as it must. It is often convenient to write the $\bigstar$-product in terms of two types of bracket. The first is the Moyal bracket defined by

$$\{\mathbf{a},\mathbf{b}\}_{MB}=\frac{\mathbf{a}\bigstar\mathbf{b}-\mathbf{b}\bigstar\mathbf{a}}{i}\hbar.\tag{14}$$

The second is a Jordan product, which we have elsewhere called the Baker bracket (Baker 1958) for historical reasons. It is defined by

$$\{\mathbf{a},\mathbf{b}\}_{BB}=\frac{\mathbf{a}\bigstar\mathbf{b}+\mathbf{b}\bigstar\mathbf{a}}{2}.\tag{15}$$

A series expansion of the $\bigstar$-product will produce a power series in $\hbar$ which forms the basis for *deformation quantum mechanics* (Hirshfeld and Henselder 2002a). A more mathematically advanced treatment will be found in Khalkhali (2009). If we retain only the terms to $O(\hbar)$, we find

$$\text{Moyal bracket}\rightarrow\text{Poisson bracket to }O(\hbar)\,.$$

This bracket is defined in equation (7.8) of Moyal's (1949) paper. Thus classical mechanics emerges from this structure if we only retain terms to $O(\hbar)$. While in the case of the Baker bracket, we find

$$\text{Baker bracket}\rightarrow\text{commutative bracket to }O(\hbar)\,.$$

Hence it is only when going to $O(\hbar^2)$ and above that quantum effects emerge from the Jordan product.

Moyal makes no use of the Baker bracket, but Baker (1958) shows that for a pure state, the Green's function is degenerate and can be written in the form $K(y,y')=g^*(y)g(y')$. Thus the wave function appears only when the propagator is degenerate. It was from this form that Baker showed that we could write

$$F(p,x) = \hbar\left(\frac{i}{2}\,[F,F]_{MB} + [F,F]_{BB}\right)$$

where $[F,F]_{MB}$ is the Moyal bracket and $[F,F]_{BB}$ is the Baker bracket.

Clearly the Moyal bracket replaces the quantum operator commutation relations $[\hat{A},\hat{B}]$. It is this bracket that was used by Moyal in deriving the continuity equation which we will use in section 5.1. On the other hand if the expansion of the Baker bracket is limited to $O(\hbar)$ then it reduces to the usual commutative product. It was for this reason that Dirac (1947) missed the appearance of the quantum potential energy. Whereas it appears in the appendix of Moyal's classic (1949) paper, as we will show in section 5.1.

To repeat, it is only when we go to order $O(\hbar^2)$ and above that the Baker bracket does not reduce to the usual commutative product. Generally terms of $O(\hbar^2)$ are assumed to be negligible and therefore are not discussed, but the bracket plays an important role when energy (Hiley 2015) is involved. A careful study of Pauli's (1926) application of the algebraic approach to the energy level structure of the hydrogen atom shows how a Jordan product enters into the calculation.

As we have already pointed out, one of the advantages of the Moyal approach is that it contains classical physics as a limiting case as is clearly seen from equation (12). There is no need to look for a one-to-one correspondence between commutator brackets and Poisson brackets, a process which fails as was demonstrated by the well-known Groenewold-van Hove "no-go" theorem (Guillemin and Sternberg 1984). Furthermore, it is not necessary to introduce the notion of decoherence as a fundamental process in order to obtain the classical limit. This does not mean that decoherence has no role to play in quantum physics. It plays a vital role in real experiments where noise and other thermal processes enter to destroy quantum interference. However, destroying the interference does not necessarily return us to the classical formalism involving Poisson brackets. It merely destroys coherence.

3.4 The Physical Meaning of the Weyl Symbol

To complete this section, let us examine the physical meaning of the Weyl symbol $\mathbf{a}(p,x,t)$ introduced in equation (10) in more detail. We start with the standard definition of the mean value of the operator $\hat{A}$,

$$\begin{aligned}\langle\hat{A}\rangle = \langle\psi(t)\,|\,\hat{A}\,|\,\psi(t)\rangle &= \int\int \langle\psi(t)\,|\,x'\rangle\ \langle x'\,|\,\hat{A}\,|\,x''\rangle\ \langle ix''\,|\,\psi(t)\rangle\,dx'dx''.\\ &= \int\int \langle x'\,|\,\hat{A}\,|\,x''\rangle\ \rho\,(x',x'',t)\,dx'dx''.\end{aligned}$$

Let us now change coordinates using $x' = x - \tau/2$ and $x'' = x + \tau/2$, then

$$\langle\hat{A}\rangle = \int\int \langle x-\tau/2\,|\,\hat{A}\,|\,x+\tau/2\rangle\ \rho(x-\tau/2, x+\tau/2, t)\,dx\,d\tau.$$

Now write $\rho\,(x-\tau/2, x+\tau/2, t) = \int F_\psi(p,x,t)e^{ip\tau}\,dp$, and we find

$$\langle \hat{A} \rangle = \int\int\int \langle x - \tau/2 \,|\, \hat{A} \,|\, x + \tau/2 \rangle \, e^{-ip\tau} \, d\tau [F_\psi(p, x, t) \, dp \, dx]$$

which becomes equation (10) if we identify

$$\mathbf{a}(p, x, t) = \int \langle x - \tau/2 \,|\, \hat{A}(t) \,|\, x + \tau/2 \rangle \, e^{-ip\tau} \, d\tau .$$

Thus we see that $\mathbf{a}(p, x, t)$ is derived from a transition probability amplitude integrated over the "blob" at the mean position x when the blob is moving with mean momentum p. The Weyl symbol $\mathbf{a}(p, x, t)$ is sometimes called the "classical observable" associated with the observable $\hat{A}$, but I find that association misleading since there is very little that is classical about $\mathbf{a}(p, x, t)$.

Moyal noticed that if $\mathbf{a}(p, x, t)$ could be regarded as one of the possible values of $\hat{A}$ and if we could regard $F_\psi(p, x, t)$ as a probability distribution, then the RHS of (10) has exactly the form of a classical expectation value where $F_\psi(p, x, t)$ is a weighting function. So why not treat $F_\psi(p, x, t)$ as a probability distribution? After all, we can write equation (3) in a slightly different form

$$F_\psi(p, x, t) = \frac{1}{2\pi} \int e^{-ip\tau} \langle x - \tau/2, t \,|\, (\,|\psi\rangle \, \langle\psi\,|\,) \,|\, x + \tau/2, t) \, d\tau .$$

Notice $(|\psi\rangle \, \langle\psi|)$ is just the density operator, $\hat{\rho}$, for a pure state, so that we can write

$$\rho_\psi(p, x, t) = \frac{1}{2\pi} \int e^{-ip\tau} \, \langle x - \tau/2, t \,|\, \hat{\rho} \,|\, x + \tau/2, t \rangle \, d\tau . \tag{16}$$

Thus clearly demonstrating that the probability distribution $F_\psi(p, x, t)[:= \rho_\psi(p, x, t)]$ is simply the Weyl symbol of the density matrix for a pure state in the (p, x, t) representation.

This has then been used to argue against the whole approach because $F_\psi(p, x, t)$ will always be negative somewhere in phase space when quantum effects show up. Moreover this has generated much debate with Bartlett (1945) and even Feynman (1987) feeling it necessary to defend the use of Wigner functions which may be negative. But we should not even be having the argument because $\mathbf{a}(p, x, t)$ is not a "classical observable." It is an average over a region in phase space. Note there is no reason why a density matrix (16) should stay positive. The positivity condition is only desirable if $F_\psi(p, x, t)$ is to be regarded as a probability density.

4 The Bohm approach

The Bohm (1952) approach has a deep connection with Moyal's work. This is highlighted by the fact that the two key equations of Bohm's theory already appear in the appendix of Moyal's (1949) paper. Moreover, Dirac's classic (1947) book also contains a harbinger of the Bohm approach.[5] Dirac obtains the quantum Liouville equation but does not exploit the quantum Hamilton-Jacobi equation, the real part of the Schrödinger equation. Subsequently Dirac only explored his version of the algebraic approach by expanding the formalism to $O(\hbar)$ and so only recovered the

classical Hamilton-Jacobi equation. Why he did not explore terms of $O(\hbar^2)$ when the quantum Hamilton-Jacobi [QHJ] equation appears is not clear. He simply writes (1947):

> By a more accurate solution of the wave equation one can show that the accuracy with which the coordinates and momenta simultaneously have numerical values cannot remain permanently as favourable as the limit allowed by Heisenberg's principle of uncertainty ⋯, but if it is initially so it will become less favourable, the wave packet undergoing a spreading.

Later Bohm showed that, by using the Schrödinger picture, there was no conflict with the uncertainty principle.

Because of the title Bohm chose for his (1952) paper, his work became entangled in the "hidden variable" controversy, which is unfortunate, as no new variables were added to the standard formalism and this old controversy has deflected attention away from the real implications of the physics lying behind the Bohm method.

As far as the mathematical structure is concerned, the only novelty Bohm introduces is in the *interpretation* of the mathematical symbols used in the Schrödinger picture. Mathematically, the approach simply uses the Schrödinger equation and separates it into its real and imaginary parts under polar decomposition of the wave function.[6]

Bohm's paper focusses attention on the ideas already presented in Schrödinger's (1952) paper "Are there quantum jumps?" Schrödinger argues that a description in terms of a continuous evolution should be possible "without losing either the precious results of Planck and Einstein on the equilibrium of (macroscopic) energy between radiation and matter, or any other understanding of phenomena that the parcel-theory [sic quanta] affords."

For the purposes of this paper we need only know that the real part of the Schrödinger equation under the polar decomposition of the wave function can be written in the form

$$\frac{\partial S(x,t)}{\partial t} + \frac{1}{2m}(\nabla S(x,t) - e\mathbf{A})^2 + \hbar^2 Q_\psi(x,t) + V(x,t) = 0 \tag{17}$$

where $Q_\psi(x,t) = -\nabla^2 R(x,t)/2mR(x,t)$. Bohm (and also de Broglie (1960)) called this term the "quantum potential energy." This new quality of energy enters as the coefficient of $\hbar^2$ and this is why Dirac missed the QHJ equation. Its appearance is intimately connected with the Baker bracket (Jordan product) and therefore the non-

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5. The specific section in Dirac (1947) we are referring to here is §21, entitled "The motion of wave packets." A more detailed discussion of this relationship will be found in Hiley and Dennis (2018, 2019).

6. A first draft of Bohm's paper has recently come to light in the Archive Louis de Briglie at the French Academy of Science. The original title of the paper was "A Causal and Continuous Interpretation of the Quantum Theory," a title which more accuractely reflects the conetnt of the paper (Drezet and Stock 2021).

commutativity of $(x \bigstar p)$.

To understand the meaning of this equation, recall that in classical physics the canonical energy is given by $E = -\frac{\partial S}{\partial t}$ while the canonical momentum is given by $p = \nabla S$, so that equation (17) can be regarded as the quantum equivalent of an energy conservation equation. This means that in the quantum domain a new quality of energy appears, namely, the quantum potential energy.

We should not be surprised that a new quality of energy is involved because the quantum vacuum is a sea of virtual particle-antiparticle pairs. At higher energies these virtual particles emerge as real particle-antiparticle pairs. In this case we are in exactly the same situation that chemists find themselves in when having to deal with a many-particle system. Here thermodynamics with its various qualities of energy such as Helmholtz free energy, Gibbs free energy and even heat energy have to be distinguished and accounted for. In this context it seems eminently sensible to take the possibility of a new quality of energy seriously in the quantum domain.

5 Back to Moyal

It may seem that we have strayed from the Moyal-Dirac disagreement over a phase space description by bringing in a discussion of the Bohm model. However, the main equations that Bohm used appear already in the appendices A1 and A2 of Moyal's 1949 paper. This naturally raises the question as to the nature of the relation between the two approaches.

In appendix A1, Moyal (1949) introduces the space-conditional average of the momentum and obtains the relation, $\overline{\overline{p}} = \nabla S$ where S is the phase of the wave function. This is identical to the momentum, $p_B = \nabla S$, introduced in the de Broglie-Bohm approach.

To show this we use the distribution function, $F_\psi(p, x, t)$, to construct the space-conditional moments of the momentum. These are written as $\overline{\overline{p^n}}$ and defined through the general formula

$$\rho(x)\,\overline{\overline{p^n}}(x) = \int p^n F_\psi(p, x, t)\, dp. \tag{18}$$

This can then be written in the form

$$\rho(x)\,\overline{\overline{p^n}}(x) = \left(\frac{\hbar}{2i}\right)^n \left[\left(\frac{\partial}{\partial x^1} - \frac{\partial}{\partial x_2}\right)^n \psi(x_1)\,\psi^*(x_2)\right]_{x_1=x_2=x} \tag{19}$$

where $\rho(x) = \int F_\psi(p, x, t)\, dp = \psi^*(x)\,\psi(x)$. If we now write

$$\psi(x) = \rho^{1/2}(x)\, e^{iS(x)/\hbar} \tag{20}$$

we find for $n = 1$

$$\overline{\overline{p}} = \nabla S. \tag{21}$$

This is equation (A 1.6) in the appendix of the Moyal 1949 paper. Note that this

means $\overline{\overline{p}}$ is dependent on the wave function ψ as is the de Broglie-Bohm momentum. Please also note we are not interpreting this as a "guidance condition"; it was de Broglie who later regretted introducing such a concept.

5.1 The Transport of $\overline{\overline{p}}$

Now we are in a position to show how Moyal described the dynamics. To obtain a transport equation for $\overline{\overline{p}}$, we need the equation for the time development of the quasi-probability distribution. This is written in the form

$$\frac{\partial F(p,x,t)}{\partial t} + \{F(p,x,t), H(p,x)\}_{M\,B} = 0 \tag{22}$$

where $\{F(p,x,t), H(p,x)\}_{MB}$ is the Moyal bracket defined in equation (14). We have omitted the subscript ψ on $F(p,x,t)$ because this equation is valid for all wave functions. In the limit to $O(\hbar)$, equation (22) becomes the classical Liouville equation.

With a specific Hamiltonian, $H(p,x) = p^2/2m + V(x)$, we can show that equation (22) leads to the real part of the Schrödinger equation (17) used in the Bohm approach. To do this we write equation (22) in the form

$$\frac{\partial F(p,x,t)}{\partial t} + \frac{p}{m}.\nabla F(p,x,t) = \int J(p-p',x)F((p',x,t)\,dp' \tag{23}$$

where

$$J(p-p',x) = -i\int [V(x-y/2) - V(x+y/2)]e^{i(p-p')y}dy. \tag{24}$$

The full details of the derivation of this result can be found in Takabayasi (1954).

To obtain the expression for the transport equation for $\overline{\overline{p}}$, we must multiply equation (23) by p_k to obtain

$$\frac{\partial p_k F(x,p,t)}{\partial t} + \sum \frac{p_k p_i}{m}\frac{\partial F(x,p,t)}{\partial x_i} = \int p_k J(x,p-p')F(x,p',t)dp'. \tag{25}$$

By introducing a wave function, $\psi(x,t) = R(x,t)\exp(iS(x,t)/\hbar)$, and then integrating over p, we find the RHS of equation (23) reduces to $-\rho\,\partial V/\partial x_k$ where $\rho = R^2$. Then equation (25) becomes

$$\frac{\partial(\rho\,\overline{\overline{p^k}})}{\partial t} + \frac{1}{m}\sum_i \frac{\partial}{\partial x_i}(\rho\,\overline{\overline{p_i p_k}}) = -\rho\,\frac{\partial V}{\partial x_k}\,. \tag{26}$$

We can also show that the dispersion in momentum becomes

$$\frac{1}{m}\sum_i \frac{\partial}{\partial x_i}[(\rho\,\overline{\overline{p_i p_k}}) - (\rho\,\overline{\overline{p_i}}.\,\overline{\overline{p_k}})] = -\frac{\hbar^2}{4m}\sum_i \frac{\partial}{\partial x_i}\left[\rho\,\frac{\partial^2 \ln\rho}{\partial x_i \partial x_k}\right]. \tag{27}$$

This result may now be used in equation (26) so that it can be written in the form

$$\frac{\partial(\rho\,\overline{\overline{p_k}})}{\partial t}+\frac{1}{m}\sum_i\frac{\partial(\rho\,\overline{\overline{p_i}}.\,\overline{\overline{p_k}})}{\partial x_k}=-\rho\,\frac{\partial V}{\partial x_k}-\frac{\hbar^2}{4m}\sum_i\frac{\partial}{\partial x_i}\left[\rho\,\frac{\partial^2\ln\rho}{\partial x_i\partial x_k}\right]. \tag{28}$$

Differentiating the first term in equation (28) and using equation (21) we find

$$\rho\,\frac{\partial}{\partial x_k}\left[\frac{\partial S}{\partial t}+\frac{1}{2m}\sum_i\left(\frac{\partial S}{\partial x_i}\right)^2+V\right]=\frac{\hbar^2}{4m}\sum_i\frac{\partial}{\partial x_i}\left[\rho\,\frac{\partial^2\ln\rho}{\partial x_i\partial x_k}\right]. \tag{29}$$

In order to bring the RHS of equation (29) into a recognisable form let us write $\rho = R^2$. Then it is straightforward to show

$$\frac{1}{4m}\sum_i\frac{\partial}{\partial x_i}\left[\rho\,\frac{\partial^2\ln\rho}{\partial x_i\partial x_k}\right]=\frac{1}{2m}\,\rho\,\frac{\partial}{\partial x_k}\sum_i\left[\frac{\partial^2 R}{\partial x_i^2}/R\right] \tag{30}$$

so that equation (28) becomes

$$\rho\,\frac{\partial}{\partial x_k}\left[\frac{\partial S}{\partial t}+\frac{1}{2m}(\nabla S)^2+V-\frac{\hbar^2}{2m}\nabla^2 R/R\right]=0. \tag{31}$$

Thus we arrive at the connection between the Moyal approach and the Bohm formalism as expressed through equation (17). Equation (31) is essentially equation (A 4.4) in Moyal's 1949 paper, the difference being that the equation (A 4.4) is derived for a charged particle moving in an electromagnetic field using the more general Hamiltonian $H(p_i, x_i) = \frac{1}{2m}\sum_i(p_i - eA_i)^2 + V(x_i)$. This reduces to equation (31) in the absence of the vector potential.

Hence the two essential equations that form the basis of the Bohm interpretation already appear in the appendix of Moyal's classic paper; Bohm providing a description of the individual, while the Moyal approach provides a description of the collective.

In passing it should be noted that by combining equations (27) and (28) we have

$$(\rho\,\overline{\overline{p_i p_k}})-(\rho\,\overline{\overline{p_i}}.\,\overline{\overline{p_k}})=-\frac{\hbar^2}{2}\,\frac{\partial}{\partial x_k}\left[\frac{\partial R}{\partial x_i}/R\right]. \tag{32}$$

Thus we see that, mathematically, the quantum potential arises as a consequence of the difference between the mean of the square of the momentum and the mean momentum squared. All this implies that the dispersion in the momentum for a single particle in quantum mechanics will, in general, be nonzero. For the single particle in classical physics the momentum is always dispersion free. In this way we see that the ★-product contains the structure that guarantees the existence of the uncertainty principle, contrary to what Dirac claims.

The connection with the quantum potential is made even clearer when one realises that the LHS of equation (28) is the total derivative of the mean momentum $\overline{\overline{p}}$, so that using equation (30) in equation (28) we find

$$m\frac{d\overline{\overline{v}}}{dt} = -\nabla[V + \hbar^2 Q_\psi] \tag{33}$$

where the quantum potential $\hbar^2 Q_\psi = -\frac{\hbar^2}{2m}\nabla^2 R/R$. Equation (33) explains the origin of the name since a force is derived from the quantum potential. Notice, once again, that $d\overline{\overline{v}}$ depends on the state ψ.

6 Conclusion

We have given a detailed account of the background to the problem of developing a theory involving a non-commutative phase space structure, showing exactly how the Moyal approach, generalised to include the Jordan product, fits into this theory. Because Moyal was concentrating on the statistical aspects he was led to the conservation of probability in the form of the quantum Liouville equation. Consequently he only produced half of the ★-product necessary for a complete description of quantum phenomena.

On the other hand, Dirac was concentrating on the dynamical aspects of quantum phenomena and then seeing how the statistics arose. At that stage it was not clear how to bring these two aspects together, or even if that were possible. If this analysis is correct then one can begin to see how disagreements could arise.

The implications of von Neumann's approach to establishing the uniqueness of the Schrödinger picture are crucial here. It is not generally realised that von Neumann had shown it is possible to reproduce the expectation value of all functions of observables such as $g(\hat{P}, \hat{X}, t)$ by the method that Moyal was proposing. That is, simply by replacing them with functions of c-numbers, $g(p, x, t)$, and using the "distribution" function $F(p, x, t)$.

Unfortunately, this function has properties that disqualify it from being regarded as a probability because it takes on negative values when quantum effects arise. Rather than try to accommodate negative values into a theory about probabilities (Bartlett 1945, Feynman 1987), we need to focus on the meaning of the term "distribution" function when applied to $F(p, x, t)$.

In Dirac's (1945) own approach to developing a theory of the non-commutative phase space, he ended up with a distribution that was even worse because it gave complex probabilities. As Dirac remarked in his 1945 paper, at least the Moyal function was real but not positive. However, we can link the distribution $F(p, x, t)$ with the quantum density matrix through the relation

$$\rho(x, t) = \int F(x, p, t)\, dp = \psi(x, t)\, \psi^*(x, t) \tag{34}$$

and its generalisation. $\rho(x, t)$ is then identified as the density matrix of a pure state. This will always give a positive value and so can be used legitimately as a probability.

The reason why equation (34) works was pointed out by Baker (1958), who introduced the Jordan product in the form of what we have called the Baker bracket. If we form the Baker bracket with $\mathbf{a} = \mathbf{b}$ then the bracket simply becomes

$$\{\mathbf{a},\mathbf{b}\}_{BB} = \mathbf{a}\bigstar\mathbf{a} = \mathbf{a}^2$$

so that an idempotent element produces the result $\{\mathbf{a},\mathbf{a}\}_{BB} = \mathbf{a}$. Baker shows that the kernel, or propagator, is degenerate in the pure state, i.e. $K(x, y) = g^*(x)g(y)$. Recall the Baker bracket is simply the part of the $\bigstar$-product that Moyal does not consider in his discussion. My own research shows that the cosine bracket (13) leads to the conservation of energy. So ignoring this term will lead to nonphysical results.

In his attempt to show that Moyal's approach will not work, Dirac considers the problem that arises when converting a classical polynomial function of (p, x, t) into an operator; this is the well-known ordering problem. It is a difficulty that occurs in all approaches to quantum theory (see de Gosson (2016)). It arises because, in the Schrödinger picture, we have the replacement $\hat{X} \to x$, but $\hat{P}_x \to -i\hbar\partial/\partial x$, so clearly $\hat{X}\hat{P}$ will differ from $\hat{P}\hat{X}$ by a factor $\hbar$.

However, this can be taken care of by choosing the appropriate standard ket introduced by Dirac himself. This special ket plays the role of a vacuum state, so by choosing the vacuum state correctly, we find the ordering problem disappears. For example the normal ordering chosen in the Heisenberg picture starts with no energy in the vacuum state, whereas in the Weyl ordering, the energy in the vacuum state is $\hbar\nu/2$. Thus the zero-point energy is correctly specified by the Weyl ordering (Hirshfeld and Henselder 2002b).

In one final attempt to show that the Moyal approach will not work, Dirac (in Dirac and Moyal 1944–1946, p.147) writes: "Your theory gives correctly the average energy when the system is in a given state (i.e. represented by a given wave function) but not when the system is at a given temperature." He then proceeds in the letter to show that it gives $\bar{E} = kT$ which is, unfortunately, the wrong result. It should be

$$\bar{E} = \hbar\nu(e^{\hbar\nu/kT} - 1)^{-1} + \hbar\nu/2.$$

The full treatment of this problem appears in Bartlett and Moyal (1949).

Unfortunately, in his reply to Dirac's letter, Moyal refers to an early draft of the Bartlett and Moyal paper of which I have no copy. Dirac's response (Dirac and Moyal 1944–1946, p.147) to the draft of that paper is that "the quantum values for the energy of the harmonic oscillator are *assumed* and the correct value for $\bar{E}$ was obtained because of this assumption." Here Dirac seems to have misunderstood the argument proposed by Bartlett and Moyal (1949) and all the correct results emerge directly from the theory proposed by Moyal. An independent and simple verification of this result can be found in Case (2008). Unfortunately, Dirac got this one wrong, as shown in the comprehensive work of Curtright, Fairlie and Zachos (2014).

I do not want to give the impression that I am trying to identify the hero and the villain in this controversy. Both Moyal and Dirac were working outside the box of "orthodoxy," grappling with the deep implications of a new non-commutative dynamics. Both were pioneers and I have certainly learned a lot by studying their disagreements. Dirac is, of course, a giant in physics and his work has been indispensable in the development of quantum theory. I have a great empathy for Moyal, given the turmoil of his life in the nineteen-forties, a turmoil I experienced

making one of the last crossings of France while travelling to meet up with my father.

While Dirac's work was taken up by Feynman and developed into a very successful quantum electrodynamics, the importance of Moyal's work in laying the foundations of the ★-algebras has been slowly gathering pace (Curtright, Fairlie and Zachos 2014). The growing interest has coincided with the ongoing development of non-commutative geometries as demonstrated in the books of Connes (1994) and Madore (1995). One particular use of Moyal's work in non-commutative quantum field theory has been discussed in Gayral et al. (2004).

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The discovery, origins and evolution of SARS-CoV-2 (COVID-19)

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Abstract

This transcript comes from a presentation Professor Holmes gave on 31 March 2021, at the NSW Science & Research Breakfast Seminar Series, hosted by Hugh Durrant-Whyte, FRSN. See https://attend.mediahouse.com.au/breakfast-series/view/Professor-Edward-Holmes

Introduction

Introduced by Professor Hugh Durrant-Whyte, NSW Chief Scientist and Engineer.

Hugh Durrant-Whyte: We are all acutely aware of the COVID-19 pandemic that has prevented us holding a large in-person seminar for the last 13 months, and perhaps none more so than today's speaker, the 2020 New South Wales Scientist of the Year Professor Eddie Holmes. Eddie is a global leader in research on the emergence, evolution, and spread of viruses.

He has a particular interest in investigating how viruses are able to jump species boundaries, occasionally causing disease, epidemics and pandemics. In January 2020, Eddie became the first person in the world to publish the genomic sequence of SARS-CoV-2, enabling urgent work to commence globally on both virus detection tests and vaccine development. He followed this with fundamental research into the animal origin of SARS-CoV-2 helping to demonstrate the presence of related viruses in bats and pangolins and showed that coronavirus can jump species boundaries and emerge in new hosts.

It's no exaggeration to say that Eddie's work has been instrumental in helping the world get to the point where vaccines are now being rolled out and the future can be viewed with a degree of optimism. In Eddie's career, he has made major contributions to our understanding of the fundamental mechanisms by which viruses evolve and helped to pioneer the use of phylogenetic methods to track the spread of viruses within populations. His other major research themes are using genomics to understand the epidemiology of major human and animal pathogens and revealing the extent and structure of global virus diversity, the so-called virosphere. His work has led to fundamental insights into the origin and spread of numerous viruses that have had a major impact on human and animal health, including hepatitis C, HIV, influenza, West Nile, dengue, Zika, and Ebola.

Befitting his achievements, Eddie has received numerous accolades. In 2003 he was awarded a Scientific Medal by the Zoological Society of London. In 2008 he became a Fellow of the National Academy of Sciences,

USA. In 2010 he won the Faculty Scholars Medal in the Life and Health Sciences at Pennsylvania State University. In 2015 he was elected a Fellow of the Australian Academy of Science, in 2017 he was elected a Fellow of the Royal Society of London and won the New South Wales Premiers Prize for Science and Engineering in the Biological Sciences, as I mentioned in 2020. He was also honoured as the New South Wales Scientist of the Year at the New South Wales Premier's Prizes for Science and Engineering. Now I will be joining the seminar online, but I would like all of you in person, please join me in welcoming Professor Eddie Holmes from the University of Sydney as he presents the discovery and origins of SARS-CoV-2.

Smallpox

EH: Good morning. As Hugh said, we've all been giving virtual seminars over the last year. This is the first I've given in person for over a year, so I may be a bit rusty. What am I going to do today? I want to talk a bit about how we found this virus and where it may have come from. I added the words "and evolution" to my title, because I'll also talk a little about where we are now as we're hearing about how the virus is evolving, and new variants are appearing. I want to discuss what that means for how we might handle this virus.

Before I get to SARS-CoV-2. I want to give another story, that sets up some of the key topics. It's a different virus, and I wind the clock back to 1978. I have a page from the London *Daily Mirror* newspaper. The top two stories are discussing the sad tale of a person who's just died. There's a photo of her in a wedding dress. At the top it talks about the mystery of the smallpox leak, which is referring to the very last case of smallpox ever recorded anywhere on Earth.

Bizarrely, that occurred in Birmingham, UK.

It's a very sad story of a person called Janet Parker. She was a medical photographer at the University of Birmingham, and she was exposed somehow to a smallpox virus that they were working with on the floor below hers. Somehow the virus got onto her floor, she got infected and she died on September 11, 1978, in a quite miserable place, the Catherine-de-Barnes Isolation Hospital. It's a very sad story. There's a very good book you can read by Mark Palin called *The Last Days of Smallpox*.

I have discussed smallpox very briefly because it is an extremely important virus in terms of human history for a number of reasons. And it's the only human virus that we've eradicated from our species. It was eradicated by vaccination.

Everyone knows the story of vaccination for smallpox. It was first developed by Edward Jenner in 1796. And you all know the story of cowpox and the milkmaids. There's a Hogarth painting of Jenner vaccinating someone: it's an 18th century celebrity thing. The terms vaccine and vaccination actually come from the phrase *Variola vaccinae*, or smallpox of the cow. That's the history of vaccination.

I've worked with my colleagues for many years, trying to understand the origin and evolution of smallpox. We've gone to various locations globally to try and find old smallpox samples. So, for example, we went to Vilnius in Lithuania. In Vilnius, there's an old church, the Dominican Church of the Holy Spirit of Vilnius, and in that church there's a crypt, and in that crypt, there are coffins, and in those coffins, there are mum-

mies. Some of those mummies are child mummies. And some of those children died of smallpox. What we dis was sample the lesions of smallpox from these mummies, to extract any nucleic acid, and sequence it. We managed to sequence the complete genome of variola virus from a sample that's from 1650. 400 years ago. At the time, that was the oldest known smallpox strain.

That's what we can do with genomics. Once we've got that genome, we can then start to look at its evolutionary history. That's what we've done for SARS-CoV-2. Now, the way we look at evolutionary history is we draw things called evolutionary trees, or phylogenic trees. They are exactly the same as family trees. We all know family trees and pedigrees. You can easily track the lines of ancestors and descendants in a family pedigree. Evolutionary trees are exactly the same. They're stretched in time. There are hundreds or thousands of years, but exactly the same principle. Figure 1 is such a tree. I've spun the tree on its side so

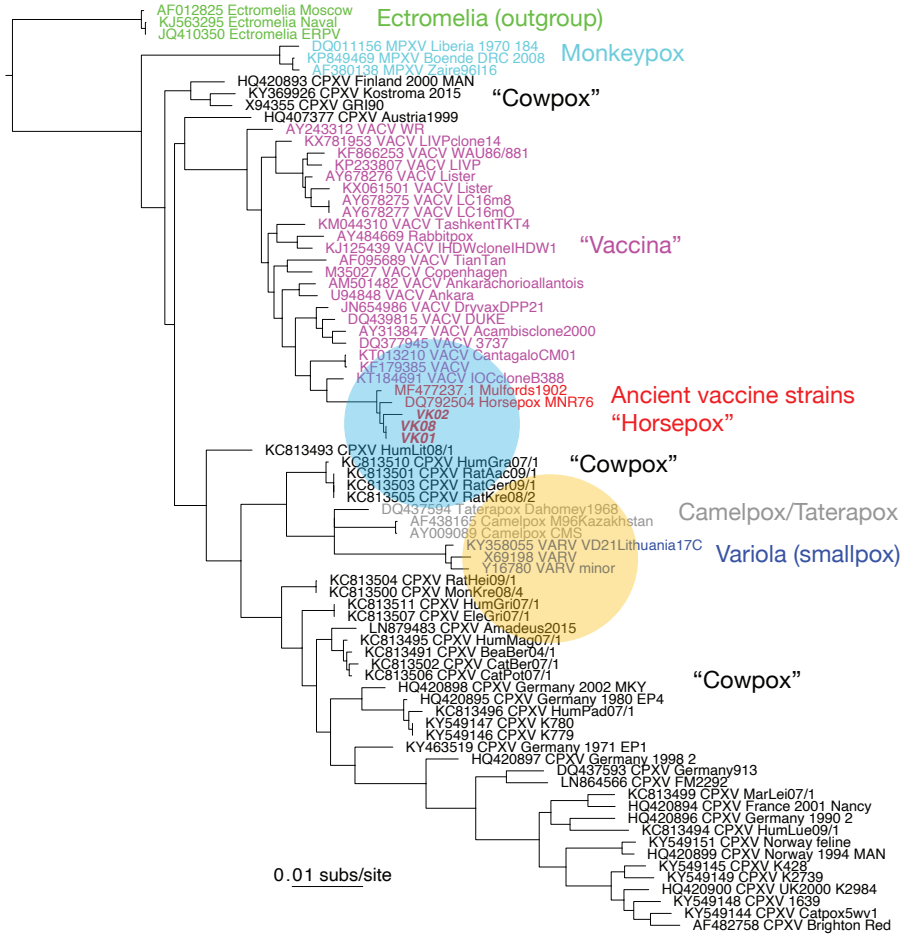

Figure 1: Evolutionary tree. Adapted from Fig. S5 in Lu et al. (2020), published under Creative Commons.

you can't really see so the base of the tree on the left. This tree is not a random tree: it's a tree of the pox viruses that includes smallpox. There a yellow circle, the smallpox virus. That little cluster of brothers and sisters is smallpox. It is labelled Lithuania since my Lithuanian strain falls in that little cluster.

And the idea is, these are all animal viruses. Jenner very famously used cowpox. Now, one of the questions we were interested in is what did Jenner actually use when he started vaccinating. During the 19th century, there was a big vaccination campaign against smallpox, like the campaign which we're now entering for SARS-CoV-2.

What vaccine strain did they actually use when they vaccinated people with smallpox back in the 19th century, and late 18th century? From a museum in the US, from the US Civil War, about 1860, we managed to find some old vaccination kits. In those days, there wasn't a needle. Instead there was a little pad and a little knife. Basically they cut you and they rubbed in the vaccine. That would be your vaccination.

We took those pads, washed them in water and residual comes off, which actually contains the vaccine strain that they used in 1860. We sequenced that. And that is where the blue circle is in Figure 1. It turns out the vaccine that they used was not cowpox or vaccinia. It's a thing called horsepox. All these names are actually very misleading. Horsepox is not from horses. It was found once in a horse from Mongolia. But we don't know where it comes from. Cowpox is not from cows, either. It was once in a cow, in Gloucestershire in 1798. But it does not necessarily come from cows.

Figure 1 shows all these pox viruses. They are animal viruses. We don't know exactly where they come from. It's the same story as with SARS-CoV-2. Are they bats? Are they rodents? The animal kingdom carries lots of viruses, and occasionally they jump into humans with disease, like smallpox did back then.

So we're now actually going to try and find more about the origins of smallpox. Jenner had a very famous cow that he used to get the first cowpox extract. That cow was called Blossom, a celebrity cow. There is a painting by Hogarth of Blossom. And amazingly, Blossom's hide is still around. If you go to St. George's Hospital in London, in their library, there's an exhibit about smallpox vaccination. And behind the glass cabinet is Blossom's hide, or supposedly Blossom's hide. The hide looks a little bit like the painting. It may or may not be Blossom. We've actually managed to take a swab of Blossom — this hide — to see if we can sequence it, to see whether it actually has a virus in it that might be like cowpox.

We've also been trying to get hold of an even earlier celebrity smallpox victim. And that's the Pharoah Ramesses V, from the Twentieth Dynasty in Egypt.[1] A very famous textbook says Ramesses V may have died of smallpox. And we've actually got samples we think are from Ramesses to try and see whether he really died of smallpox.

Emergent diseases

I have mentioned smallpox for a couple of reasons. First, it's a classic case of emerging disease. And it's one that's come from animals to humans. And all examples of disease emergence like smallpox or flu or

1 Ramesses V died in 1145 BC. [Ed.]

COVID-19 are about pathogens jumping from animals to humans. I also mentioned smallpox because, as you would have been aware, the Janet Parker story is also a story about a virus and laboratory escape, which I'll get to with SARS-CoV-2. Smallpox and COVID-19 are actually examples of these emergent diseases.

You can find online maps of the world that show you where these jumps of a pathogen for animal diseases have occurred in recent years. And there are a myriad of these. In Australia we've had Hendra. We've had Ebola in Africa, Zika in the Americas. Flu comes from Asia. We had the movie "Contagion." There's a book called *Spillover*, by David Quammen. If you actually want a good general book about disease emergence, it's very good.

And what I do for a living is try to understand how diseases emerge. So I take the natural world, and I look at the places where humans and animals interact, because that's the fault line. It's a very simple analogy from earthquakes. The tension point where jumps occur are where people interact with wildlife. That's where viruses can jump. So what we try and do is sample across that natural space.

For example, where people work with livestock or where humans have encroached into green belts and they're exposed to animals, what's jumping between humans and animals? What's in the animals and what's in the humans? What moves across? That's where we sample. And then we use genetics to work out what viruses are there. I won't go into the genetics in any great detail. Suffice to say, we use a very simple technique, with a fancy name. It's called meta-transcriptomics.

Let's, for example, take one thing I'm working on with which you are familiar — tick-borne disease. In New South Wales, people get bitten by ticks. Ticks sometimes cause disease. There's been a big question: what's the causative pathogen? What's doing this? What we do is take blood sample, skin biopsies at the lesion when we have been bitten by a tick. And then we can sequence all the RNA — not the DNA — RNA is the kind of information molecule in the sample. So we can sequence all the genes expressed in that tick bite. And the genes that are expressed come from the host, like our immune genes, for example, or from the bacteria or from the virus or fungus or parasite. We sequence all that. Then we try and work out what can we see. Can we see a pathogen in there? Can we see a new virus or bacteria? That's the technique.

And that's the technique that we used to discover SARS-CoV-2. Meta-transcriptomics is just basically sequencing all the RNA and using computers to work at what it means. One thing you realise from doing that is that the number of viruses out there is just absolutely astronomical.

The number of human viruses that are known is about 200, 250 or so. The number of viruses that have been classified is now about 6000 or 7000. But it's estimated that 99.995% (or about 87 million) viruses are unknown. We have basically scratched a tiny, tiny fraction of the virosphere. Viruses are absolutely everywhere. If you go and sample wildlife in Sydney; you go to a food market; the plants that you buy; the food that you buy will have viruses, they're everywhere.

So that's the kind of background I want to get onto SARS-CoV-2. So for a number of years, when I do this, the core of my work is going out there and looking at places

where humans and animals interact to see what viruses are there and what could jump species, and a lot of work I do is in China, which is actually a very good place to work on this.

Bat viruses in China

For example, I went to Zhejiang Province in south-eastern China a few years ago. There are very old villages and you walk around a mountain for a couple of hours and you get to a cave and then people have to put their PPE on. There's a cavern and in these caverns there are bats, lots and lots of bats. Our group and many others, for a number of years, have been sampling bats in China and other locations too — I've done it in Australia as well. And then you use meta-transcriptomics to sequence sometimes faecal samples, sometimes tissue samples. Bats carry one hell of a lot of viruses. They're absolutely full of viruses, partly because their immune systems may be different, partly because there's a lot of bats.

There's a paper we wrote in 2017, showing the diversity of bat viruses in China. And there's lots. We were already sampling these bat viruses from China. In that paper we wrote prophetically that these things can and will emerge: "The ongoing emergence of these CoVs in humans means that CoVs will likely remain a key public health threat for the foreseeable future." There's a lot of viruses in bats, a lot of viruses that look potentially dangerous, like coronaviruses. So there's a chance that this could happen. We could get an epidemic.

And so COVID-19 was of absolutely no surprise me whatsoever. It was clearly going to happen because we could see the viruses out there. We knew they were jumping. It was an accident waiting to happen. As well as Zhejiang Province, we've been doing a lot of work in other parts of China, and over the years, one of the locations we'd also sample a lot in was Hubei Province in the middle of China where the Yellow River runs. We'd sample lots of wildlife around the city of Wuhan in Hubei. We've sampled lots of bats and insects and mice around Hubei.

But we'd also sampled patients in the city of Wuhan. And in particular, we went to a hospital called Wuhan Central Hospital. This is the hospital you saw in Wuhan last January. This is the epicentre of the epidemic. Wuhan Central Hospital became very famous. And I was there in 2016 when I gave a talk. What we, in fact, were doing sounds quite prophetic. We were taking people who had pneumonia and acute respiratory disease to see what microbes could be infecting them. This is two years before COVID. We wanted to know what was there. People get pneumonia very often and it's often undiagnosed. It's a very common disease.

The question we were trying to answer is what was responsible for pneumonia. It's an acute respiratory disease in Wuhan. We were doing this two years prior to the outbreak. We had about 408 patients plus loads of controls. And we took a sample called bronchoalveolar lavage, a lung wash. That's quite a good sample for looking for respiratory disease. We took these lung wash samples and then used meta-transcriptomics to see what these patients had, in this hospital in Wuhan a couple of years ago.

This is a bit technical, but basically they had a ton of stuff, as you might expect. There's bacteria, there's fungi, there's viruses. There was nothing novel. This is 2016, 2017. Basically, they had lots of common cold coronaviruses, influenza, parrot influenza,

respiratory viruses, a whole bunch of the standard stuff you'd expect. They had a whole bunch of bacteria you'd expect. There was nothing novel at all.

Critically, there was no SARS-CoV-2. Or the first SARS virus. That wasn't there at all. That's two years prior to the outbreak. We stopped sampling in December 2017. And the evolutionary trees show the viruses that we discovered and where they fit. They're linked to global sequences. Wuhan is a really global place, a big city, in the middle of China, very well connected. And so it's getting a global mix of viruses. Because it's a hub, a real big hub.

In fact, the only thing that was unusual we found is a zoonotic pathogen. It's a bacteria (*Chlamydia psittaci*) that causes psittacosis, often called parrot fever. People who work with birds sometimes get psittacosis. We had one person who had pneumonia because they got this parrot fever, which is kind of strange. That was the only thing that was unusual. There was nothing else there. But the key thing was we were on site in Wuhan collecting these respiratory samples in the hospital prior to the outbreak. So by chance, we were on site.

COVID appears

The end of 2019. The first I heard about this outbreak was on a website called ProMED, a really great free tool. You can download it on your phone, it's on Twitter, it's on the web.[2] It provides a daily update of outbreaks of disease globally. It could be animal disease or human disease, anything. Figure 2 is the actual original ProMED post. I saw this on New Year's Eve, 2019. It basically says there are four cases of pneumonia in China associated in Wuhan with the South China Seafood Market. Now I'd been to that market. I'll discuss that below. But I was immediately interested because it's pneumonia in Wuhan that I was working on and a market that I've been to. So I thought, okay, this is really cool. So at that point, we were not worried. So then I contacted my friend and colleague, Professor Zhang in Shanghai, to see whether he was going to work on this.

And a few days later, on January 3, Professor Zhang, at Fudan University, was sent seven lung wash samples to sequence in his lab. These seven samples were all people presenting with pneumonia. And they were all people associated with the Wuhan seafood market. That's on January the third. On January the fifth, 40 hours later, he managed to sequence all those samples using meta-transcriptomics. Of those seven, one of them had really lots and lots of matches of a sequence of SARS-CoV-2. So it took 40 hours from the virus sample arriving in his lab to us sequencing the virus. 40 hours. To put this in context, it took two years to find that HIV caused AIDS. So it is quite extraordinary what we can now do with modern genomics.

That sequence was finished on January 5, 2020. Zhang and I were talking on the phone that day, and, on the same day, he wrote to the Ministry of Health in China and said, basically, this is what it is. It's a new coronavirus. It looks like the first SARS coronavirus, very similar to the one of 2000 to 2003. And because it looks like that, we knew automatically it was going to be respiratory. Because coronaviruses are respiratory. That absolutely is their defining feature. So, Zhang and I discussed it. He wrote

2 https://promedmail.org/about-promed/

ProMED
INTERNATIONAL SOCIETY
FOR INFECTIOUS DISEASES

Published Date: 2019-12-30 23:59:00
Subject: PRO/AH/EDR> Undiagnosed pneumonia - China (HU): RFI
Archive Number: 20191230.6864153

UNDIAGNOSED PNEUMONIA - CHINA (HUBEI): REQUEST FOR INFORMATION
****
A ProMED-mail post
http://www.promedmail.org
ProMED-mail is a program of the
International Society for Infectious Diseases
http://www.isid.org

[1]
Date: 30 Dec 2019
Source: Finance Sina [machine translation]
https://finance.sina.cn/2019-12-31/detail-iihnzahk1074832.d.html?from=wap

Wuhan unexplained pneumonia has been isolated test results will be announced [as soon as available]

On the evening of [30 Dec 2019], an "urgent notice on the treatment of pneumonia of unknown cause" was issued, which was widely distributed on the Internet by the red-headed document of the Medical Administration and Medical Administration of Wuhan Municipal Health Committee.

On the morning of [31 Dec 2019], China Business News reporter called the official hotline of Wuhan Municipal Health and Health Committee 12320 and learned that the content of the document is true.

12320 hotline staff said that what type of pneumonia of unknown cause appeared in Wuhan this time remains to be determined.

Figure 2: The original ProMED post announcing the four "pneumonia of unknown cause" cases in Wuhan.

a letter to the Ministry of Health saying this is likely a respiratory pathogen. It's likely to be dangerous. People should take precautions. That was the same day.

Now, one of the unfortunate things that was not done was that human-to-human transmission was not officially recognised until about January 20. A two-week gap between the virus being sequenced by us and the authorities realising that there was human-to-human transmission. But, to Zhang and me, it was obvious from day one.

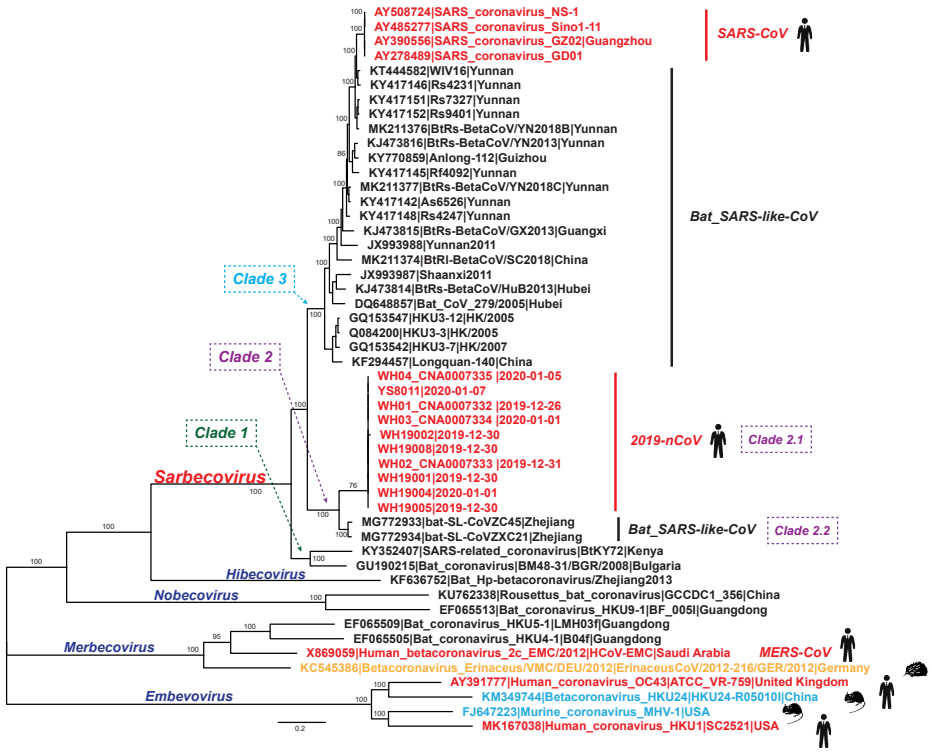

Figure 3: SARS coronavirus tree. Reprinted from *The Lancet*, Vol. 395, Duggan et al. (2020), pp. 565–574, Copyright (2020), with permission from Elsevier.

In fact, we have emails, and we're asking is the transmission asymptomatic or symptomatic, because it's a coronavirus. Coronavirus is respiratory. So unfortunately, the ball was dropped for a bit there.

Yes, we were the first people to release the sequence. But we were not actually the first people to sequence it. Prior to us, there were a number of other groups — you can find this online. Other groups had been sequencing the virus. The first actual sequence came from a company called Vision Medicals on 25 December. These doctors in Wuhan saw they had something. Their diagnostic tests weren't working. They didn't know what it was. They sent it quite reasonably to a local sequencing company and asked, Can you figure out what this is?

And that company first saw the data and they sequenced it on 25 December, and they got hits for SARS virus, and they basically went, oh dear, it's SARS back again. And that SARS was back went all over social media in China. Of course, that was a toxic thing. People didn't want to have SARS back. All it did was cause pandemonium. Then a second company confirmed that and re-sequenced it. But when they said SARS was back, what they couldn't see was that it wasn't exactly SARS. It was related to SARS, but it's a different virus. There was some confusion early on, a lot of toing and froing in late December. The last week in December is when people really started getting a number of groups of sequencing. We were one of them.

But as soon as we had the first sequence in detail we knew exactly what it was. It was pretty obvious this was a coronavirus related to SARS. Figure 3 is one of the first trees that we did. At the top in red, that's the first SARS coronavirus, and a bit further down in red, that's the new one. Halfway down, it says 2019 human symbol nCoV. That's what we called it then. You can see that the two red bits are quite similar. So we knew right from day one, it was closely related to SARS virus. And that's what we said. It's respiratory. Also the bottom shows other coronaviruses that infect humans.[3] We knew it was a kind of human coronavirus. Critically, the branches in black, they're all from bats. So we knew right from the start it was like the first SARS virus, only a bit different. It was related in evolutionary terms. Its family tree had bats very close. I won't talk about the gene structure in any great detail.

Now the virus looks like a big ball. On the ball outside there's a protein called the spike protein. That's the bit that attaches to the host cell. And there was lots and lots of interest about the spike protein. In particular, the spike protein had some little bits of sequence that looked quite unusual. The sequence is called a polybasic or a furin cleavage site. It's actually four amino acids, four bits of sequence that are unusual in SARS-CoV-2. Again, it's a standard coronavirus. We could see it was like the first coronavirus and a bit like bat viruses.

The big question is, where does it come from and what's the animal reservoir? I've already noted that, from day one, we could see it was closely related to viruses in bats. That was very obvious. And not just any old bats. It's particularly horseshoe bats. Their nasal structure looks like a horseshoe, so it's obvious why they're called horseshoe bats.

They're from a genus called *Rhinolophus*. And it turns out that horseshoe bats are very common reservoirs for coronaviruses in China. They are full of coronavirus very, very commonly. So that was not a surprise. What was a surprise is that pangolins also have a related virus. No one was expecting pangolins to have a virus. No one had worked on pangolin viruses ever previously. Pangolins (*Manis* sp.) are nocturnal solitary animals, massively endangered because they're trafficked all the time for their scales, used in folk medicine.

What happened was the customs authority in China, in two provinces, Guangdong and Guangxi, had confiscated pangolins that had been smuggled in for their scales. And these pangolins were sick. They were not healthy pangolins. So the customs authorities alerted the vets to say there's something wrong with these pangolins. And so my colleagues then did genomic sequencing on the pangolins. And, bizarrely, they have a virus that's very closely related to SARS-CoV-2. You would not have predicted that.

There's one bit of sequence called the receptor binding domain. That's the bit of the virus that attaches to the host cell. The virus binds the cell to get in. Where it attaches, that bit of sequence, bizarrely, in the Guangdong pangolins confiscated by Guangdong customs, is almost identical to the human sequence. It's very strange. So bats have it. Pangolins have it. But there's a gap. There's an evolutionary gap. In evolutionary terms, it's about 20 years or so of missing evolution. So you have the human virus, the animal viruses. And there's some-

3 SARS-CoV-2 is the seventh documented human coronavirus; four cause common colds, three cause severe disease (SAR-CoV, MERS-CoV, SARS-CoV-2); bats are involved with the emergence of five.

thing in the middle we haven't sampled yet. And we don't know what that is. I'll come back to that.

Bats carry an awful lot of viruses. It is quite startling to see how many viruses they carry. We just did another study. My colleagues went to the Xishuangbanna Tropical Botanical Garden in Yunnan in southwestern China. And in this garden the bats are not in caves, they're in trees. They managed to sample 26 new bat coronaviruses, novel, completely new, in a 1000 hectare area. So you can just imagine the number of viruses that are out there in nature. The number of coronaviruses is absolutely astronomical. In fact, *Rhinolophus* horseshoe bats are widely distributed across all over Southeast Asia, and this part of the world has lots of horseshoe bats. And they're going to have absolutely buckets of virus. There's an amazing diversity of viruses out there.

One thing people haven't really cottoned on to about the pangolins is they were ill. They were not healthy animals at all. They were diseased. Basically, when a human has COVID-19, various immune genes are turned. The same genes are turned on in pangolins. It turns out it's a very similar disease presentation. So pangolins get a very similar kind of COVID thing as do humans. But, to repeat, there's a gap between the human ones and the closest animal ones.

And the question is what goes in that gap? And what the WHO have just announced in yesterday's report is they think the most likely scenario for how this virus emerged is it comes from bats through an intermediate host to humans. So the question is what's that intermediate host? And the animals that I think are most likely are mink and raccoon dogs (*Nyctereutes procyonoides*). Mink you all know. These animals are fur farmed in large quantities in China. They're wildlife that are farmed. And I think they're pretty likely to be the intermediate host. We know mink carry the virus. The virus in Europe has gone from humans to mink, and then from mink back to humans. So mink are a really good source of virus. The other animals, I think, are very likely raccoon dogs. They're my personal favourite. And I say that because, in 2014, I went to the Wuhan seafood market.

It's a pretty confronting place. It's kind of sweaty, it's steamy. There's lots of internal roads. There are lots and lots of animal stores. In their recent report the WHO have produced a map of the market and the different stores. They swabbed the surfaces, be it a wall or a bench or the floor or a grate. And they found virus on those surfaces. And they're all clustered on one side of the market, on the west side of the market. And that's the side where the animal traders were. The fruit and veg people are on the east. The animal people are on the west and it is the west side that has the virus. There is clearly mass transmission going on in that market.

Now we don't know whether it's going from just between humans or whether animals are involved. But there were lots of transmission. When I was there in 2014, I took photographs of wildlife in that market, including raccoon dogs. They're very strange. They're kind of photoshopped animals, but they really do exist. And the raccoon dogs were in cages stacked up in the west side of the market.

And that's where most of the positive environmental samples were. I suspect that's a really important avenue for this virus. My bet is on the wildlife, farmed wildlife trade being brought into this market. That, to me, is the most likely scenario. And that's

what WHO have decided. We're lacking the smoking gun, or smoking raccoon dog. We don't quite have it yet. But I think, tellingly, these animals have not been tested in China, nor have mink, and I suspect they're the most likely intermediate.

Lab escape or wild transmission?

So now the million dollar question. Did this virus escape from a lab? It's something that I thought about immediately, as well. It's not a strange question: in the middle of Wuhan is a very big virus lab called the Institute of Virology. And they were working on bat viruses in that lab. And one of the closest relatives to SARS-CoV-2, called RaTG13, is from that lab, which has led to an enormous amount of debate. But here are a few facts.

First, there is no evidence that SARS-CoV-2 is engineered (and no reason to bioengineer a random bat virus). Any talk of covert military operations is rubbish.

Second, bat virus RaTG13 is not the direct ancestor of SARS-CoV-2, it's a relative, but not that close, and all the components of the SARS-CoV-2 virus exist in nature, including the furin cleavage. There is nothing unusual in the SARS-CoV-2 sequence at all.

Third, there is no evidence of a secret SARS-CoV-2-like virus (closer to SARS-CoV-2 than to RaTG13) kept at the Wuhan Institute (and no reason to keep it secret before the pandemic) — they have previously published all their viruses.

Fourth, SARS-CoV-2 is not necessarily from bats and not necessarily from Yunnan Province. It's just that Yunnan is a great place to go and sample bats. Indeed, bats are probably an intermediate species.

Fifth, SARS-CoV-2 was not perfectly adapted to humans on first emergence and appears to be a "generalist" virus: it does well in humans but it does well in other species too. Indeed, a paper in *Nature* reports that the pangolin virus itself works really well in humans. So you didn't need to adapt this virus for humans: it was going to work already. The ones from nature are very, very good human viruses.

Sixth, cases near the Wuhan Institute only appeared later in the outbreak, cases appeared near the seafood market earlier. So the spatial distribution fits the market first, then the lab quite clearly later.

Seventh, there is no evidence of SARS-CoV-2 infection at the Wuhan Institute: they claim their staff were PCR- and antibody-negative, so no one is infected. And, if that's true, that rules it out automatically.

So either this is the biggest cover up in history and they're all lying. Or there is no evidence at all. I'm very prepared to believe it's out of a lab. But give me the evidence. At the moment, there is absolutely none. This is going to go on for a very long time.

The virus mutates

So the virus has then emerged. We're now sequencing it frantically. You've heard about that. We have now sequenced something like 900,000 genomes globally. Just extraordinary. Soon, within the next couple of weeks, we'll have a million genomes sequenced. And the virus is gradually evolving. It's actually picking up about two mutations a month, on average, as it evolves through populations. What we've been doing is trying to classify the virus as it spreads globally. And we developed a very simple online tool where you can take your sequence, your virus, and you can work out what lineage it is. You take the tree of the virus, you can divide it into lineages. I'm using very technical names: A-B-C, things like that. And A1, B1.

It's very simple lineage classification system. There is a little tool called Pangolin[4] that allows you to find out what lineage your virus is. We have classified something like 887 lineages so far, but there are three of them you're hearing a lot about in the news at the moment. And they are the so-called lineage "variants of concern."

There are three that you want to know about. One is called B.1.1.7.[5] And it's often called the UK variant, because it was found first in the UK. The outbreak in Queensland is B.1.1.7. One's called B.1351.[6] That's the one that's found in South Africa. And there's one called P.1 and that's from Brazil.[7] They're the three that people are most worried about because they're spreading very quickly.[8]

The mutations in those three variants are mainly clustered in the spike protein. Now, the key thing is all those variants are characterised by lots and lots of mutations, which is very unusual. And you've heard about these mutations. And the key thing is the same mutations are appearing in all these different variants.

And to make it easy because they're so complicated, we've given them stupid nicknames in the group. So, for example, the first mutation we saw was amino acid 614 in the spike protein. It's a D amino acid to a G, so asparagine to a glycine change. D614G. So we called it Doug. We've also got an N501Y — we called it Nelly. I apologise if you're one of these names. The mutation that looks worse is one called E484K. Originally we called it Eric. We now think it's actually the worst one. We call it EEK.

And the key thing is that the same mutations are appearing independently in these different lineages. And so the big question is, what's driving this? There are a variety of theories on why suddenly all these variants of concern are appearing. Is it increased transmissibility? Is it immune escape or evasion? Is it mounting interferon resistance (evasion of innate immunity)? Is it the impact of population lockdown? Is it because people have chronic infections so they don't shed, don't clear the virus? Are they generating the virus? I suspect it's the top two. It's immune evasion. So as the virus is spreading globally, people are gradually getting vaccinated and gaining immunity. And that's putting selection pressure on the virus. And I suspect all these variants are actually in some way immune escape. I suspect that's what's going on. This is going to happen. The more immunity rises, the greater the selective pressure on the virus. It's going to happen. And we will likely have to update the vaccines.

Now, of those three lineages of concern, the one that's most concerning is B.1.1.7. That's the one that's in the UK, and that's the one that's now broken out in Queensland. And it's concerning for two reasons. First, it does appear to have an increased transmissibility compared to the other variants. There's a 43% to 90% increase in transmissibility of this variant compared to

4 https://virological.org/t/pangolin-web-application-release/482

5 The Alpha variant, also known as lineage B.1.1.7. [Ed.]

6 The Beta variant, also known as lineage B.1.351. [Ed.]

7 The Gamma variant, also known as lineage P.1. [Ed.]

8 The Delta variant, first seen in India, also known as lineage B.1.617.2, was named on 31 May 2021. The Omicron variant, also known as lineage B.1.1.529. was named on 26 November 2021. [Ed.]

the original. So it's much more infectious. Even more of a concern is the hazard of death, which is a nice way of saying mortality rate. It's between 42% to 80% higher if you have this variant. So it spreads faster and it's more serious. Actually for people over 80, the mortality rates are really high, over 15%. This is a concern. The good news is, as far as I'm aware, the vaccines that we have, although they don't always protect against transmission, are very good at stopping death and serious disease against all the variants, including the UK one, B.1.1.7.

So the vaccine is critical. It should massively reduce the mortality. It may not stop transmission, but it will definitely reduce mortality. It's not just the UK variant. This variant is spreading, and there's absolutely no surprise it's spreading all over the place. It will become the dominant strain globally. And I'd say, luckily, we can vaccinate against this strain pretty well. People in hotel quarantine that come into Australia are now very commonly B.1.1.7. It's no surprise that's the one that's escaped because that's the one that's spreading all over the place globally. But the vaccine should control it.

Future prevention?

So how can we stop this happening again? I think there are three things you need to do. First, emergence. I have tried to show it is all about human-wildlife interaction. Somehow we need to stop emergence happening again by monitoring, reducing our exposure to the wildlife trade, live animal markets, with better zoning. That's the fault line. That's where we get viruses from. So not building on areas where bats live, for example, like councils tend to allow. We need to stop doing that.

Second, we need to have much better surveillance mechanisms. We should establish global genomic, serological and social media surveillance of people at risk: those living and working at the human-animal interface. People who work at the human-animal interface, whether an abattoir or an animal market, and in animal trade need to be screened absolutely regularly, because they're on the front line. They're being exposed. If we can survey them and detect any disease early, then we can stop the next thing happening. But that also requires data sharing, and politics to get out of the way. And unfortunately, politics is undermining this at the moment.

Third, finally, the kind of critical thing is we need to develop and stockpile universal vaccines or cost-effective vaccines and antivirals that recognise all the viruses out there. There are certain viruses that always jump. Coronaviruses jump, influenza viruses jump. There are other families that jump all the time. We need to make new vaccines and antivirals that can protect against a broad range of those. I've been trying for a few years to make a universal flu vaccine. The same thing needs to happen for lots of other viruses, too. That's the kind of Apollo Project for virology. That's what we need to do. Massive investment. That's where science needs to be.

I'm going to stop there. Lots of people have been involved. Thank you.

Q and A

Q: With these new viruses, can sewage testing be used to detect new crossovers, new pathogens, which crossover to humans from animals, since not everyone is going to get tested or going to be eligible for tests?

EH: It's a good idea. The question is, can you do sewage testing, waste water testing? You can if you know what you're looking for. The problem with sewage testing is the virus is very, very fragmented when you get there. So doing a simple PCR test, that's what you use now to test whether you're coronavirus infected or not. That works. To do the genomics that I do to find unknown viruses, it won't be as good because the material is so complicated and broken up. So I think it's definitely a useful thing. But if we know something's there, we can track it. Finding a completely novel thing, at the moment, things are a bit harder.

Q: I guess the simple question to me is, where does it end? Fauci tells us that the only way out of all this is the vaccine. We have to build up herd immunity, but we isolate. So we're not building up herd immunity, but we need the vaccine. But you look at the Spanish flu. You look at the Hong Kong flu. They eventually burn themselves out. But everything we hear indicates that this is going to go on forever. What's your opinion?

EH: Yes. I think this will become an endemic human virus. There's no doubt whatsoever. And flu has never died out. I mean, flu is an endemic thing, we've had it for years. My guess is the virus will gradually evolve into a seasonal respiratory infection, and that we'll need to vaccinate every year or every two years, as we do for flu. There's no way — eradication is impossible since not every country is going to roll the vaccine out, it's not going to happen and the virus will evolve around it. So I think it will be an everyday part of our lives, and we'll just have to get used to being vaccinated.

Luckily, like I said, those variants, or "scariants" as they're often called now, are coming up all the time, and the vaccines have different efficacy against them. The good news is they all seem to control mortality pretty well. So you get vaccinated, you might get a bit ill, but you should stop getting the lung and serious lung infection. So it's going to be part of our lives.

Q: Look, I was just wondering, could you give us an indication of what your feelings are on the apparent claim of the Chinese government that there only have been about 4300 deaths due to COVID-19 in China?

EH: There's a lot of politics in this thing. I think there's a number of countries where the numbers claimed may actually not be real. In Wuhan, the modelling suggested very early on the number of cases was far higher than reported, potentially hundreds of thousands of people in Wuhan were infected. So I don't know the data, but I think a lot of these things you need to be very careful about.

Q: Thank you. I'm enjoying the splendid isolation of Australia, and it seems that we have zero tolerance to COVID coming into the country. This is great, short term, but, long term, I can't see that it's a feasible position to take. What do you think it will take for that position to change politically?

EH: Yes. At some point, the federal government will decide enough people have been vaccinated and they will open up the borders. We can't be an isolate like this. We've done extraordinarily well: I think there's a case that New South Wales has done better than any place in the world, because we've had 56 deaths from COVID in New South Wales. Extraordinary. And we've not had a really hard lockdown. So I think we've done better than anywhere. But it won't continue.

My guess is once we've reached the level when most of the adults over a certain age have been vaccinated, I think that that's when they'll start to open up. The kids, I don't think, will come into it. I think they might leave those alone a little bit. I think they're looking for a portion of the adult population to be vaccinated. What proportion is that going to be? I don't know. Unfortunately, the vaccine roll-out's not going as quickly as I hoped it would. I think they've been too slow. I was hoping by the end of October, but they're now kind of hedging their bets, so it's hard to tell. It really is hard to tell, but I think they'll have to come out, certainly by the start of next year, if not this year. It has to happen.

Q: What is the evolutionary role of the furin cleavage site? How did it get inserted into the SARS-CoV-2 virus?

EH: This furin cleavage site has been contentious — four amino acids of such absolute contention. And so there's been an argument that it's been deliberately inserted. If you look at viruses, lots of them have furin cleavage sites. It's very, very common. Serious influenza viruses have them. In coronaviruses, they are all over the place. They come and go all the time in evolution. We've actually found some bat viruses that have quite similar sites, so I think it's a hot spot in evolution. It changes all the time. In itself it means absolutely nothing. It appears to increase transmission of the virus, but I think no more than that. One more thing. If you use cell culture, if you try to grow in the lab in cell lines, you only ever lose the site. You don't gain it. So if it's engineered in the lab, the result you're getting is the opposite you actually get because you tend lose the furin cleavage in the lab. So I think it's a natural piece of coronavirus and virus evolution. And no more than that, there's no engineering going. On that I'm pretty sure enough.

Q: Why did you and Professor Zhang not release the genome on January 8th, 2021? GenBank had already processed it.

EH: We got the sequence on the 5th of January, and I released it on the 11th. Over that week, I didn't have the sequence myself until about less than an hour before I released it. I was trying to get Professor Zhang to release it, but they were under great pressure in China not to release any data. Other groups had the sequence as well, and essentially, there were instructions that there should be no publicising of the outbreak. So we kept it to ourselves. But we told the key people in China — people actually on the ground during the outbreak, but we were told not to release the data. As that week wore on — and I said other groups had it as well — as that week wore on it became untenable to keep it to ourselves. As soon as they said it was a coronavirus and the pressure grew online to release it. So it got to kind of breaking point.

And I then persuaded Zhang to give me the sequence, and I released it. I think it's very hard to judge these people because the politics are very complicated there. It's not a simple thing. If it's a Western thing, it'd be different. It's not so easy dealing with China.

Q: Have we understood the long-term impact of the virus infection?

EH: No. In terms of disease, no, I don't think we do. I think there'll be this long-COVID phenomenon. I think there are long-term implications of this that we don't know. We've learned an awful lot. I mean, the number of papers on COVID-19 is just unbelievable, right. My citations did really

well last year, but there's clearly a lot more work needs to be done on that. I think it'll take years to kind of really come out, unfortunately.

Q: Can you treat coronavirus by using the inhibitor of the protein that it binds to?

EH: Yes. There's a lot of work on antivirals for coronaviruses using drugs. I don't think they've got one yet that works that way. Most of the drugs that we've got — and then none of them are actually that good at the moment — they're all old drugs have been repurposed. They're drugs they had lying around. They've been used against coronaviruses, and sometimes they said they worked okay. At the moment, I don't think we have a really good antiviral that works. People have touted hydroxychloroquine and ivermectin. They just do not hold up at all in clinical trials.

People are trying to do what you say. At the moment, the drug research hasn't really been as successful as the vaccine research, and the vaccine research has been spectacularly successful. We do need an antiviral, like you say, but unfortunately, at the moment, we haven't quite got there.

Q: My question is with the history of the wet markets, how did it take so long for it to spring over to humans? I mean, the last big dynamic that we can think of, that I can think of, is the Spanish flu. How did it take so long to kind of come over to humans?

EH: No, people are exposed all the time. They've tested people working in the market trade in southern China, and I think like 3% of them have antibodies to SARS-like coronaviruses. So people have been challenged all the time. 99 times out of 100, these things go nowhere. They go absolutely nowhere. But that one time they don't. SARS-CoV-2 is the seventh human coronavirus. Five of those have appeared in the last 20 years. And some of them have very similar stories to SARS-CoV-2. We have no idea where they come from.

There's one called HKU1. That was discovered in Hong Kong/Shenzhen from an animal reservoir that's unknown, initially associated with pneumonia. And it has a furin cleavage site in the sequence. That's now spreading. Luckily, now it turns out to be similar to the common cold virus. So this emergence process is happening all the time. Absolutely all the time. Luckily, most of them don't go anywhere.

Unfortunately, SARS-CoV-2 — the problem was it's pretty transmissible, also it emerges in a big city in China just before Lunar New Year, which is the worst possible situation. And then you get millions of people moving literally the week after. It's all over China very quickly. And because Wuhan is an international hub, it's out of Wuhan very quickly. That was a problem. So it's the worst possible place for it to happen. Unfortunately, it happened.

Q: Why were the four studies on pangolins all released within the same two- to three-day period?

EH: I can only speak from our study. We had our paper published. We were working on pangolins. And then as our paper was being written, we heard that there was a press release by another group claiming they had a pangolin virus as well. I can't say anymore. I wasn't involved in the other studies.

Q: You showed a lot of data about the virosphere and how many viruses are out there. So can we actually prevent the next pandemic? What do we need to do to be able to do so?

EH: The number one thing, I think, is better surveillance. Absolutely better surveillance. And then data sharing. And unfortunately, those things didn't happen in this particular circumstance. It's become overtly political. All those sorts of things have meant that we've not been able to share data under political pressure now: Zhang has been under huge political pressure in China, and I don't think people really appreciate what it was like. And so the number one thing we need to do is to build data-sharing mechanisms. We have surveillance and that data is shared globally.

That's the number one thing to do. But we've got to cut through the politics, right?

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Postscript

Professor Eddie Holmes FRSN on ABC's Radio National Breakfast on 4 November 2021, with Fran Kelly.

Fran Kelly: The sequencing of the COVID-19 genome in March last year was a critical breakthrough in the fight to contain the virus. Australian scientist Professor Eddie Holmes' work and the decision to share that research with the world allowed labs around the globe to start work on a vaccine. It's been described as one of the most important acts of data sharing in human history, saving millions of lives. Last night, Eddie Holmes was honoured for his work and awarded the 2021 Prime Minister's Prize for Science.

Professor Eddie Holmes, welcome back to RN Breakfast, and congratulations.

Eddie Holmes: Thank you, Fran. It's nice to be here.

FK: Described as one of the most important acts of data sharing in human history, when you cracked the code and decided to share it with the world, did you know that you were doing something that could set us on a path to the quickest sort of development of vaccines ever? Why did you decide to do this?

EH: No. That actually was a big surprise. If you wind your mental clock back to January last year — it seems like a long way back — at that point, this outbreak was in Wuhan. There weren't that many cases. It was localized around this market. It was growing. It was clear we had to get the data out there. And that's why I shared the data at that point. But the fact that then it turned into this horrendous pandemic, I didn't see that coming at that particular point. So that's all been a bit of a surprise.

FK: You were on it pretty quickly. The genetic code you published just barely months, hardly months after the virus really emerged and came into our consciousness. Does the fact that you decoded it and shared it with the world does that also mean you were the first to decode it?

EH: No. What actually happened was — it's quite a complicated story that's gone on — the first people actually to sequence the genomic sequence of the virus was actually a biotech company in China. What happened was some of the doctors in Wuhan noticed that they had these patients with pneumonia. They couldn't figure out what it was. Their standard tests weren't working. They sent their samples to a local biotech company, and they then did the first sequence and they showed it was a new coronavirus. Then a whole number of groups worked frantically to try and confirm that and get more data. And I'm working with one of those people. That's your first point about how quickly it happened. It's really an interesting thing. We all remember the AIDS panic. It took two years to discover that HIV was the cause. Two years. It took 40 hours from the samples arriving for us to work out that this virus was the cause of COVID-19. So the change in technology over that time period is really quite staggering. Extraordinary, isn't it?

FK: Now, since then, there's been a lot of politics, but also an immense international effort to work out the origins of this virus. The Office of the US Director of National Intelligence has concluded that a natural origin and a lab leak are both plausible hypotheses. You've been at the forefront of global research on the origins and the development of COVID-19, and I think it's fair to say you've been a major voice for the natural origin theory of COVID-19 rather than the lab leak. Is that still your view? Even after

the investigation, the global investigation and those findings of the Office of the US Director of National Intelligence?

EH: Yes , it very much still is. I'm a scientist. My job is to evaluate data, interpret data on the evidence we have. If there was evidence of a lab leak, I would happily put my hand up and say there's a lab leak, that's what happened. At the moment, though, there is really no evidence and that US intelligence report that you alluded to actually does not provide any evidence for a lab leak either. That's 20 months of the best intelligence agency in the world looking at, and they can't find any evidence.

They say it's still possible, but they can't actually show it. So I still think this is due to the wildlife trade, animal markets. I still think that's the most likely but we can't prove that. Obviously, we need to keep looking. We need to go back and investigate in more detail. At the moment, I still think it's most likely of zoonotic origin.

FK: That position has attracted a fair bit of controversy. I mean, the whole debate about where it's come from: a lab in Wuhan or wildlife, there's a lot of controversy and heat around it. You and your team have been condemned in some quarters for links to the Wuhan Institute. How tough has that been for you?

EH: Yes. That's one of the biggest surprises of the whole pandemic — quite how vitriolic and political it has been. I should say I have no link to the Wuhan Institute at all. I have collaborated in China, but not with that Institute.

FK: So you've collaborated in China, but not with the Wuhan Institute?

EH: Yes. That was a surprise. You have to grow a thick skin pretty quickly. I think the difficult thing now is it's become just so political, both in the east and the west, and both sides are shouting at each other. I understand why that's happening. The politics is like that, but we need to throw that away and get back to the actual science. My concern is that we might lose our focus. This really is a scientific question. We may lose our ability to answer the science question because of the politics. So, I never thought it would turn into quite the political football it has turned into.

FK: And last month, the WHO formed a new body to investigate the origin of the pandemic. In scientific terms, how important is it that knowing where it originated from gives us more ammunition against future variants or against future pandemics?

EH: Yes, I think origins is critically important. I think we need to know exactly what the route was — how the virus got into humans — and then whatever that gap is, we fill that gap. If it does turn out to be the wildlife trade, then that clearly needs to be subject to much better regulation. So I think the origins is absolutely critical, and I hope the governments involved let the WHO team in, let them do their job and let us find the origin of this virus. Then we can all move on and put in place what we've learned from this one to stop this ever happening again.

FK: And I'll come to that if I have time. But really, what's important now is what happens with this virus. You've said, well, we know it's a constantly evolving virus. The world is trying to deal with the Delta variant at the moment, but there's a beta variant out there which you and others, I think, are already warning, is vaccine resistant. What can we expect, do you think, as more of the world gets vaccinated — though we are still a long way from global vaccination?

EH: Yes. So what's going to happen as we get more vaccinations? Obviously, this is a great thing to do that's going to push the virus. The virus is going to find it harder and harder to infect people, so it's going to get pushed. Evolution is going to push it, and it will gradually start to evolve strains that evade immunity. That's what 'flu virus does every year, and the COVID-19 virus will do the same sort of thing. So what that will mean is we will almost certainly need to update our vaccines on a fairly regular basis, but I'm actually pretty optimistic about that. The new technology we have for vaccines is pretty staggering, and I think they should just be able to kind of tweak the sequence of the virus and the vaccines, generate new vaccines, and that will keep us protected. I think it will be a game of cat and mouse for a while — us versus the virus and evolution — but I'm optimistic that we'll manage to dampen this down effectively.

FK: Just finally, you're a world beater when it comes to viruses and beating viruses. You've helped determine the origin and spread of Hep C, HIV, dengue, Zika, Ebola virus. You're calling for some kind of global radar to stop new viruses when they first appear. What do you mean by that?

EH: It's not just me, actually. I think a number of people now have thought this was a good idea. Boris Johnson actually announced it at the G-7 in Cornwall a few months ago. The idea is that countries work together. They have surveillance radar techniques built in. So if you see outbreaks very early on — people with unusual diseases or you see animals dying off of something — that information is then very quickly fed to all the people who need to know, all the health people, all the vaccine developers, the antiviral people, the government.

And then we just act much quicker. And the single biggest thing I've learned in this whole pandemic is, you can have all the technology you want but unless you share your data, it counts for nothing. So sharing your data as quickly as possible globally is the most important thing. That's what the global radar is designed to do.

FK: You need global governments to sign on to that and follow through. Congratulations. It's well-deserved. Australia is very proud of you. Thank you.

HE: Thank you very much.

FK: Professor Eddie Holmes is the winner of the 2021 Prime Minister's Science Prize.

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Taking humour and laughter seriously: The multi-disciplinary field of humour studies

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Abstract

From the time of Aristotle and Plato, philosophers have speculated about humour and laughter, proposing that *ridere est humanum*. But research has shown that chimpanzees and rats also laugh. Sociologist Norbert Elias believed that laughter evolved as an antidote to aggression; but humour can also be damaging. While studies in neuroscience, psychology, linguistics, literature, performance, history, sociology, religion, health and the emotions all now contribute to our understanding of the functions and consequences of humour, the question of whether humour unites or divides the human race is still open to debate. While humour can assist social cohesion in many ways, depending on cultural context (as some examples of peculiarly Australian uses of humour illustrate), and while its creators and practitioners command attention in daily life, it remains resistant to easy definition.

Introducing humour studies

How does someone come to be studying humour and laughter? Is it really a research field? Or is the idea that humour deserves serious attention merely a joke? These questions confront anyone embarking on this field, as they did the present author when, in 1965, I embarked on my doctoral thesis at University of NSW. My supervisor C. R. B. Quentin, the founder of the National Institute of Dramatic Art who also held the Chair of Drama, told me, "Oh Jessica, don't study tragedy [my intended subject], study comedy; you'll never be bored." He was very right and I am still fascinated by it. Back then, I chose to focus on the commonly despised variety of low comedy or farce — the kind that depends on physical and visual humour rather than on witty dialogue as found in high comedy and the comedy of manners. There were very few academic historians of the theatre who thought this was important and the typical reaction was that it must be very easy to comprehend such a basic form of drama. However, from a practical and theatrical point of view, it is anything but simple. Quentin himself, a former director with the Old Vic Theatre Company, preferred directing comedy and considered it far more demanding than tragedy: it was difficult to make it succeed, challenging for the actors and even more resistant to analysis on the cold page.

Beginning with a study of the history and theory of European farce across nine different cultures (working mostly in translation), I progressed to teaching comedy at Stanford University as a visiting scholar in the '70s. Here I was lucky enough to work with famous names in English and Theatre

Studies[1] but also with researchers in psychiatry and human biology.[2] I joined a research group looking at aggression in animals and humans, because I was perplexed how it is that farce manages to combine being the funniest "laugh-out-loud" type of comedy with being the most physically violent (for example, the films of Buster Keaton or "Roadrunner" cartoons). Despite this, it is universally regarded as harmless — the history of the theatre across many cultures demonstrates that it is not farce but satire that falls foul of the censor. How, I wondered, does farce escape this fate? I have some ideas now, but still not all the answers.

With some of these colleagues and others from the Bay Area, we formed a research group to explore aspects of humour (BAHA, or the Bay Area Humor Association, led by Prof. Bill Fry, Stanford University). In 1976, we learned that the British Psychological Society was holding a conference — a world first — on humour and laughter in Cardiff, Wales (see Figure 1). Two of us (Fry and myself) submitted papers and set off to attend.

Among the riches of this event,[3] there was indeed a paper on whether the Welsh have a sense of humour. It was authored by the scholar who has dominated the study of world collections of joke-lore, J. C. H. (Christie) Davies (1941–2017) from Reading University; and concluded that, sadly, they do not, but that they do have a great sense of fun.[4] What it actually means to have a (good or otherwise) sense of humour has now been

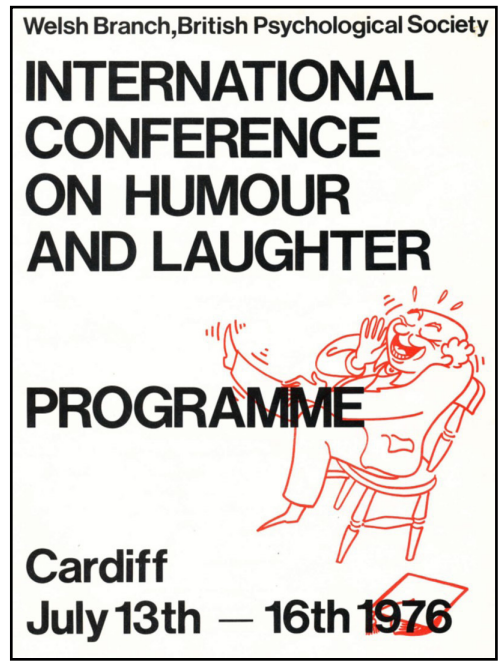

Figure 1: Poster for 1976 conference on humour and laughter convened by the British Psychological Association (Welsh Branch). From the author's personal collection.

clarified by the work of psychologists such as Willibald Ruch (University of Zürich) and Rod A. Martin (Western Ontario), who have developed a carefully defined set of personality traits associated with different senses and habits of using humour. With no disrespect to Christie Davies, the terminology we were all using in 1976 was very speculative — suggestive of Lewis Carroll and Humpty Dumpty's famous advice to pay words tuppence extra to mean what you like.

The conference certainly attracted media attention: *Time Magazine* covered it, so did

1 Martin Esslin (1918–2002) on farce, Ron Rebholz (1957–2020), David Riggs and John Bender on Elizabethan and Jacobean comedy, and John C. Loftis Jnr (1919–2012) on Restoration comedy.

2 Burr S. Eichelman in human biology and William (Bill) F. Fry Jnr (1948–2019) in psychiatry.

3 Conference papers published as Chapman and Foot 1976.

4 For the amusing background to this paper and Davies' connection to Australian academia, see Milner Davis 2017.

The International Herald Tribune. Both treated it with a combination of levity and fascination. Nevertheless, the event effectively founded the field of humour and laughter studies. This was strongly influenced at first by psychology and subsequently by linguistics, when in 1989, at a conference in Hawai'i, the International Society for Humor Studies[5] was formed. The year before, linguists had launched an academic journal dedicated to humour with Mouton de Gruyter in Berlin. *HUMOR: International Journal of Humor Research*[6] from the beginning had a broad, cross-disciplinary Editorial Board (of which I have long been a member) and editors have included as well as linguists, a sociologist, a psychologist and a computational linguist. The journal strives for transdisciplinarity, or at least multi-disciplinarity, in its scope.

Humour studies in Australia

In 1997, after hosting the 1996 ISHS Conference here in Sydney, I founded the Australasian Humour Studies Network[7] in order to foster inter-disciplinary dialogue on the topic in the Antipodes. The original seminar was hosted by the University of NSW and comprised seven scholars, from theatre studies, medicine, management, political science, psychology and social work. In February 2022, the Network holds its 28th annual conference with over forty presenters from roughly a dozen different academic disciplines, plus some real-life practitioners of the comic arts, writers, performers and importantly, the Tasmanian cartoonist, Jon Kudelka. In 2006, Kudelka penned the

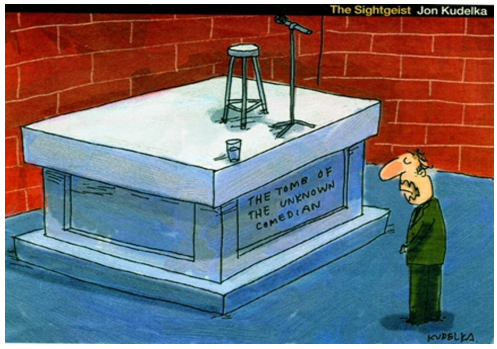

Figure 2: "Derideo ergo sum: I take the piss, therefore I am", by Jon Kudelka. Originally published in *The Australian*, 17–18 June 2006, reproduced with kind permission.

clever tribute to the importance of humour and taking the piss[8] that appears in Figure 2, playing on René Descartes famous dictum, "*cogito ergo sum*" (1637: Pt IV).

Origins of laughing and smiling

Piss-taking is a significant consideration in relation to Australian culture and national identity (Milner Davis 2009), but Kudelka's clever parody acknowledges a much broader connection between human nature and experiencing and responding to humour. From the time of Aristotle and Plato, philosophers have speculated about humour and laughter, with many seeing laughter and its associated playfulness as an essential part of human nature; thus, not merely *erare est humanum*, but *ridere est humanum*. Aristotle claimed (in *On the Parts of Animals*, Bk 3: 10)[9]

5 ISHS: http://humorstudies.org/

6 https://www.degruyter.com/journal/key/humr/html

7 AHSN: https://ahsnhumourstudies.org/

8 Until recently in Australia, more euphemistically termed "taking the mickey", see Milner Davis 2007.

9 For a general account of philosophical tradition and humour, see Morreall 2009.

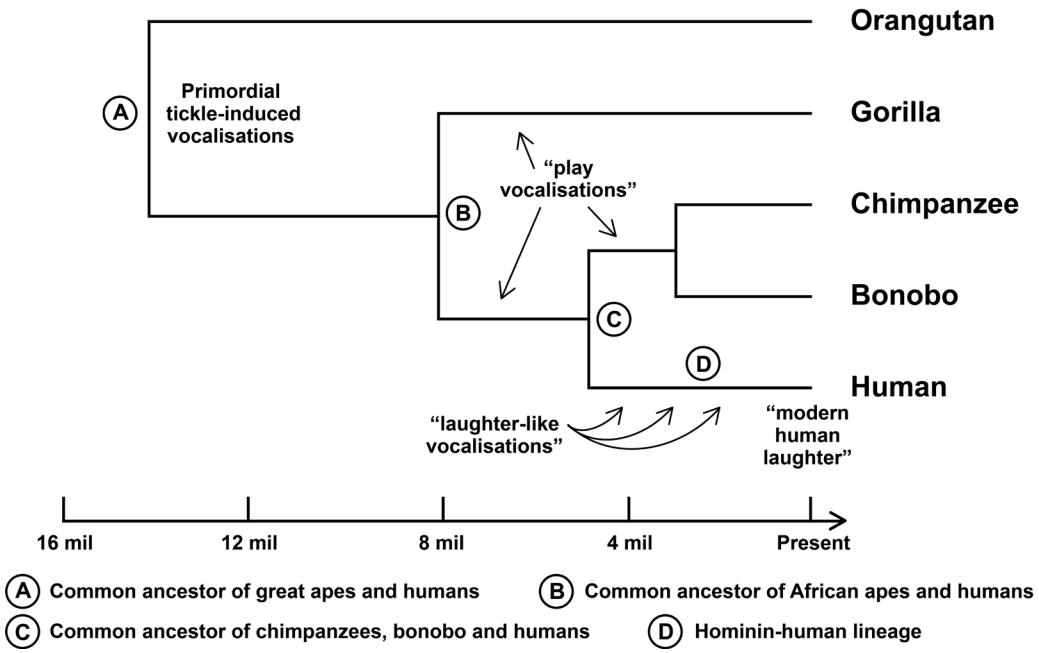

Figure 3: Phylogenetic model of laughter evolution based on acoustic analysis of tickling-induced vocalisations by the Hominidae (after Davila Ross et al. 2009; modified text; from Goddard and Lambert, 2021, in press, reproduced with kind permission).

that laughter was the property of mankind alone, an idea that was still firmly taught in Shakespeare's time (Screech 2015: 1). But play accompanied by laughter — or at least something acoustically similar — is actually found in animals such as chimpanzees and even rats. Rats have a squeak-laugh when playing (Panksepp and Burgdorff 2003) while chimpanzees pant-laugh. Davila Ross and colleagues (2009; 2010) studied the acoustics of tickle-induced vocalisations in human infants and in juvenile great apes (orangutans, gorillas, chimps and bonobos) in order to reconstruct the likely sequence of human laughter's phylogenetic emergence. They found that primordial laughter-like vocalisation dates back 10-16 MYA to the last common ancestor of humans and great apes (including orangutans and gorillas); but that true laughter with its extraordinary range of vocalisations including whoops and cries, and associated behaviours such as tears, hiccups and flopping around from weakness, developed only after the separation of the hominid line from the chimpanzees. This is because true laughter requires the adaptation of the human larynx leading to the development of speech and probably also requires the self-awareness now termed theory of mind.

Nevertheless, evolutionary scientists seem agreed that these early forms of proto-laughter constituted a shared kind of pleasurable "wordless chorusing" that served to reduce stress and promote bonding (Dunbar 2012: 1843). Darwin himself in *The Expression of Emotion in Man and Animals* (2013 [1872]) noted that laughter gives pleasure and that in both humans and apes it is related to social relationships. But he did

Figure 4: Duchenne smile (1) and laughter (2), contrasted with neutral facial expression (3) and Non-Duchenne smile (4). Source: Willibald Ruch and research team, University of Zürich, reproduced with kind permission.

not remark on the contagiousness of laughter, although children (even adults in a silly mood) indulge in spontaneous outbreaks of glee sparked by each other. Hearing laughter stimulates others to laugh (Provine 2000; 2012) and this aspect underlines its "Duchenne" smile and laughter and "non-Duchenne" smiling and laughter. The first is a true smile that engages both the zygomaticus major muscle that lifts the corners of one's mouth and the orbicularis oculi muscles that lift the cheeks and crinkle the corners of the eyes. The difference between a smile that engages these muscles and one that does not is shown in Figure 4, where Duchenne smiling and laughing are contrasted both with a neutral facial expression and with the non-Duchenne smile.

Named after the 19th century French neurologist Guillaume Duchenne, the true smile is associated with actually experiencing the "feel-good" factor of humour and amusement (Ekman et al. 1990; Platt et al. 2013). It can be a response to either spontaneous play or a stimulus that elicits laughter such as tickling, or decoding a humorous remark. Evolutionary biologists Gervais and Wilson (2005) theorised that the non-Duchenne smile — which can appear quite threatening and cold — is a later development, adapting true smiling to a contrary social purpose such as politeness, pretence, or even menace, as in the case of the scary eponymous hero of the 2019 film, *The Joker* (directed by Todd Phillips). A non-Duchenne smile is immediately recognizable and disturbingly ambiguous, because it signals a lack of the positive emotions we associate with humour.

Laughter and humour: linguistic and cognitive studies

The nexus between laughter and humour is thus far from simple. If humour is the stimulus, then smiling and laughter of any kind are only part of a wide range of possible responses and they may be deliberately withheld — or even substituted for with a groan or a protest of "Oh, not *that* one again". In the evolution of humour studies from the 1970s, deeper insight into what it means to experience humour had to await the development of cognitive science with its investigative tools for how the brain's neural nets respond. This kind of research has definitively put aside one long-standing but simplistic approach to humour: that the experience is purely cognitive and one either "gets" the joke or one doesn't. This view was strongly held by many linguists, who argued that the vital ingredient in humour is not its playfulness (as advocated by anthropologists and folklorists) but its logical mechanisms

for playing with and subverting conventions such as Grice's Maxims (Grice 1973) which describe how conversation relies on a speaker meaning what is said. From the 1980s to the turn of the century, the Semantic Script-based Theory of Humour (SSTH, see Raskin 1985 and Attardo and Raskin 1991; later termed the General Theory of Verbal Humour or GTVH, see Attardo 1994; 2001) ruled both humour studies and its Journal, of which Raskin was the founding editor, followed by Attardo. The GTVH posits that humour is created when an incongruous combination of two or more opposed scripts or meanings is resolved by a punchline revealing a hidden meaning. An apt illustration of a joke amenable to this structure is provided in Table 1.

Table 1: Binary joke (collected by the author from unknown source)

There are only 10 different types of people in the world: **Those that read binary** **AND** **Those that don't**

Examining this joke, it is evident that the first line leads one to expect that the final colon will be followed by a list of ten psychological or other types of people. But the second and subsequent lines provide only two: those that can read binary (code) and those that cannot. This numerical mismatch is certainly incongruous and violates several if not all of the Gricean maxims about how rational communication should be structured — meaning what one says, providing sufficient information for decoding and so forth. But the incongruity is unresolved only until the mind travels backwards to re-visit the key figure of 10 written as one followed by zero and to re-interpret it as two numbers set out in binary code. This solution justifies the seemingly illogical claim being made by the joke and the GTVH principles of script opposition (one way of interpreting numbers opposed to a second way) and identifying a logical mechanism for decoding it do work well for dissecting this joke. Despite this, there is some remaining ambiguity about why it should be amusing. The GTVH also stipulates that there should be a target for any joke: but what is the target here? Is it those (like the present author) who failed to get the joke the first-time round? Or is it those numerate persons who intolerantly despise the innumerate? Perhaps it is both. Despite our enjoyment of the joke and despite structural analysis, the hidden animus beneath this verbal construct remains somewhat mysterious.

Jokes such as this have been called the fruit-flies of humour research (e.g., Morreall 2004: 394) and there is no doubt that GTVH analysis works well for many of them. To sociologists and literary and cultural historians, however, that theory fails to take account of the more emotive aspects of humour. Humour always transgresses some rule or another, whether a rule of logic or of propriety. To do this, it must exploit what Wallace Chafe (one of the original members of the 1970s BAHA) has termed "the importance of NOT being earnest" (Chafe 2007), which in literary studies is termed "a playframe". Humour is innately bound up with play and pretence and clearly must involve more than just cognition and logic. In 2001, a breakthrough came from an fMRI study reported by Vinod Goel and colleague which demonstrated that in the reactions of

subjects exposed to humorous stimuli, both affective and cognitive neural nets play a part (Goel and Dolan 2001). These findings have been extensively replicated and, not surprisingly, a host of complex brain processing activities have been uncovered during responses to humour. The mesolimbic reward pathway is strongly implicated; there are marked differences in responding to verbal and to visual humour; also, to different types of humour such as benign or aggressive; and in response-type between genders.

Another key fMRI study was reported by Moran and colleagues in 2004. This showed that there are distinct stages to the processing of humour. The first stage is its detection, that is, an understanding that the stimulus presented is to be classed or treated as humorous. This stage of processing is indeed predominantly cognitive. The second and longer stage, following the first after a millisecond or so, engages more affective pathways: this is the successful and simultaneous comprehension (decoding) and appreciation (or not) of the humour.

Humour and sense of humour

Following these insights, studies of the creation and the reception of humour now distinguish between a number of stages: humour production or creation; humour detection; humour comprehension; humour appreciation; and finally, a range of humour responses, both positive and negative and including humor support for others using humour (sometimes also referred to as humor competence, see Carrell 2009). As a research term, humour has come to have a very broad umbrella meaning that is now adopted across many cultures (and languages is which "humour" is effectively a neologism, such as *youmo* in Putonghua and *yumoa* in Japanese, see Milner Davis in press). It embraces all the phenomena relating to the field, including laughter, smiling, amusement, jokes and joke-telling, comic stimuli such as cartoons, stage- and film-comedies and novels, varieties of humour such as satire, farce and caricature, and humour as therapy or as an educational tool.

The word humour can also refer in a narrower sense to a particular world-view in which one smiles with amusement at the adversities and imperfections of life. In French culture, this is seen as something quintessentially English, *l'humour Anglaise*, as opposed to the witty and more cerebral *ésprit Français*. Traditionally, Anglo-Saxon cultures have indeed valued the civilizing ability to laugh at oneself and this is usually described as having a good sense of humour. From the beginnings of personality testing at Harvard University in the 1930s, Gordon Allport included "sense of humor" as a correlate of personal maturity and good mental health (Wickberg 1998). Sense of humour continues to feature highly in such things as informally stipulated criteria for dating and marriage, and a recent national survey of the Australian judiciary found that, even for these very serious respondents, more than half considered having a sense of humour as essential or very important in their work (Roach Anleu and Milner Davis 2018: 4).

Humour and the sense of humour both embrace gentler and benevolent aspects as well as negative and aggressive comic forms and styles, such as irony, sarcasm and biting wit. All of these can be enjoyable (especially for the humorist using them), but there is no doubt that humour has the power to damage. It can demean its targets and divide us as well as gently correct them and bind us

together. Negative, disparagement humour has classically been frowned on in both the East and the West, by Confucian as well as Christian thinkers. Aristotle's *eutrapelia* — the benign and well-balanced use of humour — was considered the mark of an admirable person long before the famous 18th century dicta of Lord Chesterfield decrying the uncouth behaviour of persons indulging in uncontrolled and boisterous laughter. In his *Letters to his Son, on Education*, Chesterfield wrote (from Bath on 7 March 1748): "I must particularly warn you against it [laughing loudly]: and I could heartily wish that you may often be seen to smile but never heard to laugh while you live ... how low and unbecoming a thing is laughter. Not to mention the disagreeable noise that it makes and the shocking distortion of the face that it occasions" (Stanhope 1847, 1: 120). And again, from London on 5 February 1750: "Vivacity and wit make a man shine in company; but trite jokes and loud laughter reduce him to a buffoon". (op. cit.: 414).

The downside of humour and laughter

Negative reactions to humour today are readily observable today in politicians and others who sue comedians for defamation damages and dictators who seek to jail cartoonists.[10] Such negativism is not confined to political animosity, however. Understandably, it often comes from those who are themselves, or those who seek to defend others who are the targets of racist and sexist jokes — of which there are plenty in Australian joke-lore (Davies 2002: 89–107). Such protests run alongside less defensible efforts at censorship from governments and corporations and are increasingly impacting cultural and personal taste in humour, especially when that is aimed at the underprivileged or minority groups or religious targets. Many comedians testify to the challenge of responding to such changes in audience attitude to humour (see e.g., Marchese 2021).

In addition to political and cultural pressures, however, psychological research has shown that in many cultures and language groups, there exists a small minority of quite normal persons who positively dislike laughter. Not as Chesterfield did, because it is unmannerly, but because it alarms them. Such people were first identified by the German psychotherapist, Michael Titze (1998) and research into the condition has been carried further by psychologist Willibald Ruch and his team at University of Zürich (e.g., Ruch and Proyer 2008; Ruch et al. 2014). The condition is termed gelotophobia, or the fear of being laughed at (NB: the "o" in this term indicates it is not related to icecream). Gelotophobia is now recognised as part of a triad of personality differences relating to humour, termed the PhoPhiKat, a collocation of parts of three technical dispositional terms below (morphemes in italics):

- Fearing being laughed at = gelot*pho*bia
- Enjoying being laughed at = gelot*phi*lia
- Enjoying laughing at others = *kat*agelasticism

These dispositions identify individuals who are habitually predisposed either to fearing being laughed at (gelotophobia), to enjoying being laughed at (gelotophilia), or to enjoy-

10 Many serious and life-threatening cases are recorded on the website, Index on Censorship, see for example, "Cartoonists being silenced during Covid, report shows", at: https://www.indexoncensorship.org/?s=cartoon&id=114715 (accessed 27 October 2021).

ing laughing at others (katagelasticism). All three are inter-individual difference variables that have been found in normal populations across seventy-three different cultures and language groups (Proyer et al. 2009). In its extreme form, gelotophobia can be clinically relevant, seriously hampering life enjoyment (Ruch and Proyer 2008; Ruch et al. 2014). Gelotophobes fear being ridiculed and appearing ridiculous to other people. They have a paranoid sensitivity towards others' laughter and misinterpret normal humor and laughter as being weapons. Displaying negative emotional responses to laughter, such individuals react by avoiding situations where they might be laughed. Importantly, the gelotophobe's interpretation of humour and laughter is independent of any intention towards them (i.e., whether it is harmless or aggressive, directed at them or not), meaning that they mis-interpret most instances as being malevolent.

For the general population, however, a positive appreciation of humour can be regarded both as an innate personality trait and as a settled habit of using humour in various ways as a coping behaviour, as psychological studies by the two leading psychologists of humour, Ruch at Zürich and Rod A. Martin of Western Ontario University, have shown. Some of these habits or "humour styles" are more virtuous and positive in impact on others and are probably linked to better mental and physical health on the part of the user. But conclusions from experimental research on styles of using humour (including some cross-cultural comparisons e.g., between Taiwan[11] and Canada, see Chen and Martin 2007) remain tentative. It is better not to be simplistic about the relationship between humour and health as some types of humour and laughter are probably beneficial to certain aspects of mental or physical health; some are neutral; others may be detrimental and some have been shown to be both beneficial and detrimental. Where effects can be demonstrated, different mechanisms are probably involved for different effects (Martin 2008: 470). One surprisingly negative case has been demonstrated by Paul Thomas FRSN and colleagues at University of New South Wales (UNSW), who showed that for some asthma sufferers, an attack is triggered by laughter and that this follows distinctly different pathways than those implicated in, say, exercise induced asthma (Liangas et al. 2004).

Humour, health and cultural variation

Despite such special cases, humour used well in settings such as hospitals, nursing homes and emergency services has repeatedly been shown to assist in stress reduction (Moran and Massam 1997; Auerbach et al. 2016). This has led to the development of carefully planned interventions and specialist training programmes: in Australia, the leading example is the Clown Doctors, run by the Humour Foundation,[12] with clinical results studied by Belinda Goodenough at Wollongong University and Fay Lee Low at UNSW (Low et al. 2014). Overseas, similar programs are popular in German-speaking lands (for a review of the movement in Europe, see Dionigi et al. 2012). The positive results reported in these studies align with results from fMRI research showing that

11 Taiwan indicates the geographical and political entity known as China, Taiwan, and as the Republic of China.

12 https://www.humourfoundation.org.au/

enjoying funny cartoons triggers subcortical reward pathways in the brain and that the funnier such stimuli are perceived to be, the stronger the reward response (Mobbs et al. 2003). Helping to reduce stress in a natural, drug-free way is clearly of benefit for patients and carers alike.[13]

Evidently, laughter is only part of achieving this beneficial effect. Humour does not always result in laughter; and laughter does not always result from humour. Laughter is ubiquitous for example in casual conversations between friends but often arises there for no obvious reason or may accompany an entirely innocent remark such as "well, I'll be off then". We are dealing with a highly complex behavioural phenomenon. To this kind of complexity must be added cultural differences. Working with humour scholars in other languages and cultures, I rapidly came to realise that it is not in fact *what* we laugh at, nor even *how* we laugh, that varies, but rather when, where and with whom we indulge in laughter. Thus, it is not laughter itself but the cultural conventions that govern its use that vary from one society to another, leading to misunderstandings and possible offence. An example is how, in reporting the 2021 Tokyo Olympics, Western media observed with shock that one teenage diver from China did not smile at all on receiving her perfect results. A report showed her serious, downcast face, and captioned it thus: "Hongchan Quan, 14, looked devastated after being given a perfect score" (Rolfe 2021). In Chinese culture, however, such a reaction to triumph is quite appropriate since smiles more usually admit embarrassment and error (Chey 2011: 41). For their part, Chinese social media expressed bemusement at the whole story (Sun 2021).

Australian culture as noted features frequent, straight-faced mockery or piss-taking. This is a kind of hazing for friends and newcomers alike that falls into the spectrum of what is termed deadpan irony by comedy theorists (Weinglass and Haugh 2020). An illustration comes from The real-life experience of an American fantasy-writer Jack Dann in 1999 provides an illustration. He recounted[14] how he had then lived happily in Australia then for six years but still found himself bemused by what happened to him at an outback petrol station when he asked for directions to the toilet: "Ah", replied the laconic serviceman, "you'll need a compass and a cut lunch for that one". Perhaps even an Australianised American might need to be told that "cut lunch" means sandwiches, but otherwise, what in this statement could have puzzled Jack? It clearly indicates that (i) the place is hard to find and (ii) requires effort equivalent to an all-day wilderness trek with a compass and food. Hence, it is to be deduced that the toilets are hard to find and a long way off. *But are they?* It is equally possible — indeed, to Australian ears, far more likely — that the piss was being taken from an evident foreigner and that the statement ironically indicates that the facilities are only a step or two away, obvious to everyone but Jack.

Despite having been subjected myself to this kind of teasing and deadpan legpulling after arriving from England in the 1950s as

13 It is important to note that to date, the commonly asserted belief that laughter produces endorphins in the brain has not been substantiated by valid research.

14 Interviewed by Murray Waldren in *The Weekend Australian*, 12–13 June 1999; award winning sci-fi author, see https://jackdann.com/ (accessed 2 November 2021).

a schoolgirl, I was not really conscious of it as a typically Australian humour practice until I embarked on a collaboration with colleagues from the Japan Society for Humor and Laughter Studies.[15] This resulted in our book, *Understanding Humour in Japan* (Milner Davis 2007). Being no scholar of Japanese, I had to learn from scratch about the various forms and conventions of humour and comedy as practised and enjoyed in Japan and as I did so, I began to realise how entirely different was my more familiar culture of Australia.

When sociologist Giselinde Kuipers (then at the University of Amsterdam) undertook her ground-breaking study of joking taste cultures in the Netherlands, she had the same experience as I did. She reported: "It wasn't until I did a similar project in the US [in 2003–4] that I realized there was something particularly Dutch about Dutch respondents, despite their great [individual] differences" (Kuipers 2006: 15). Precisely because one is so enmeshed in one's own culture, one is normally unaware of its conventions: because one is too busy carrying out the rules and conventions, one simply does not *see* them for what they are. It was only *after* working with my colleagues in Japan that I could begin to write anything meaningful about Australian humour. Having managed to acculturate to Australia, only later did I realise how I had been acculturated. Appealing again for wry comment on this to cartoonist Jon Kudelka, like his immigrant couple in Figure 5, I too would probably have failed an Australian citizenship test if I had had to sit it.

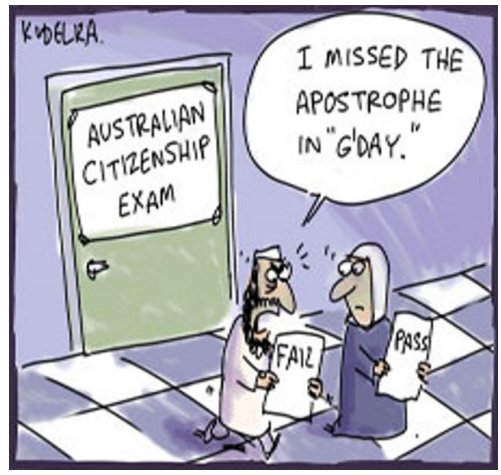

Figure 5: "The Australian citizenship test", by Jon Kudelka. Originally published as a pocket cartoon in *The Australian*, 2008, reproduced with kind permission.

Humour and Australian culture

Australia has in fact a most extraordinarily permissive culture about humour use. From working with Japanese colleagues (and later with others in South Korea, Indonesia, Taiwan, Hong Kong and the PRC), I believe that Japan and Australia may well be at the extreme opposite ends on the scale of regulation of humour and laughter. In Japan, laughter is considered important and modern culture celebrates it, even including obligatory practices such as ritual laughter on specified annual occasions (Abe 2007; Takekuro in press). Parallels such as the Feast of Fools used to exist in medieval and renaissance Europe but for the West now, only pale shadows remain in the form of things like Mardi Gras (adopted as their own by the gay and lesbian community) and school muck-up days. Despite this elevation of laughter in Japan, containment strategies for it have long been internalised into

15 http://www.nwgk.jp/index.html

everyday life, characterised by hierarchical rules about personal distance and considerations of face and shame controlling the use of humour. Traditionally, it was women and warriors who should not be seen smiling in public. One saying held that, for a samurai, one dimple in one cheek each year was sufficient. Although in contemporary times things are changing, my late colleague Mr Oda Shōkichi pointed out that: "In Japan it has long been considered a virtue among upper-class men to refrain from laughing. In general, women traditionally have tried to laugh with their mouths only slightly open and to cover their mouths with one hand when laughing" (Oda 2008: 28). He even coined a term specifically to describe the still limited range of times and places where and when it is socially permissible to laugh: *warai no ba* (笑いの場 laughter containers).

By contrast, we have no need of such a term in Australia. Australians are able to joke with anyone, not just friends but even the Prime Minister, if we were to meet him. The distinguished historian Inga Clendinnan ventured the opinion that Australian jocularity today has something in common with that found in Indigenous traditions (*Dancing with Strangers*, 2003). Although few Indigenous researchers have time to devote to this issue, the Australasian Humour Studies Network has keenly supported those who can. Two in particular, Lillian Holt from Adelaide and Angelina Yoolelar Hurley from Brisbane, are adamant that, for their peoples, humour is inextricably bound up with questions of survival and overcoming odds, both now and in the past (Holt 2009; Hurley 2015). The autobiographical novel, *Don't Take Your Love to Town*, by proud Bundjalung woman, the late Ruby Ginibi Langford, bears this out. Speaking of the liberating role of humour in her own life, she recollected how she used it against unwanted official visitors at the hospital bedside of one of her adopted sons, Nobby, who was ill with hepatitis after his release from gaol (he eventually recovered):

> The police were always checking [Nobby] out and wouldn't leave him alone. Not believing he was sick, they pushed past me. I didn't say anything till all four of them were in the bedroom, when I said, 'I hope you've all had your shots, he's got contagious hepatitis.' You should've seen those dicks fly out of the room, asking where the nearest doctor's surgery was. I fell about laughing and so did Nobby. (Langford 1988: 201).

This was carefully prepared, effective retaliation; it was also very good therapy for the patient.

As our history since European arrival is re-examined from other perspectives, it is becoming possible to discern a long tradition of joking played defensively by our First Nations against their dispossessors. Examining descriptions of the first cultural exchanges found in the diaries of Lieutenant Watkins Tench (1788–1859), Clendinnen describes how Colbee and Boladeree, two Indigenous guides accompanying an exploration party, performed a dance by the campfire in which they took "special delight in miming the more spectacular British slips and stumbles of the day 'with inimitable drollery'", in Tench's words (Clendinnen 2003: 203). These two were very efficiently "taking the piss" out of the hapless newcomers.

This is the positive side of aggressive humour and it is one that has been cheerfully adopted over the last forty years in Australia by our so-called "ethnic stand-

ups". Pioneered by Australian-Italian and Australian-Greek artists in TV series and stage shows like *Wogs Out of Work* (1987) and *Acropolis Now* (1989–1992),[16] these brave young souls set out to "emphasize the ugliness of a lot of old migrants towards the new migrants. To show that they were dealing out the same intolerant attitude to new arrivals that they themselves experienced when they first arrived". These are the words of Australia's first Vietnamese-Australian stand-up comedian, the lanky, dreadlocked Le Trung Hung (stage-name, Hung Le), who escaped Saigon by boat with his family at the age of nine to survive starvation and refugee camps and eventually to gain Australian citizenship. He described audience reaction to his performances in the stage show *Wog-a-rama* (1995, with Mary Coustas and Nick Giannopoulos) as follows:

> People of mostly Southern European descent — or whoever gets to be called 'Wog' — would come to the theatre in packs, and keenly wait to hear the piss being taken out of their nationality ... The bigger the abuse, the crazier the response. After the show people would complain if their country HADN'T received equal piss-take time ... It was craziness ... When packs of boys in Monaros roared past me in the street yelling abuse, they meant it as a sign of affection and appreciation of the show. For two years and five hundred shows, "Hey Ching Chong" meant "love ya work ... China!!" Bizzzaaarre (Le 1997: 146–148).

The success of these comedians inspired others, leading to standing ovations for the August 2002 live show, *Habib on Parole*, that featured Tahir Bilgiç who calls himself "Australia's only Turkish stand-up comedian". At Sydney's run-down Enmore Theatre, Tahir and colleagues drew a largely Australian-Lebanese and Australian-Serbo-Croatian audience at a time when feelings within — and against — local communities were running high. The Milošević trial was taking place in The Hague, Islamicist terrorism threatened, and members of Sydney's Lebanese communities were experiencing racial backlash as a major gang-rape case was going through the courts. The youthful, packed house nevertheless enthused about the "piss-take" accorded each group in turn, with a reviewer noting how "[t]he audience squirmed and groaned, recognizing reality with embarrassment as well as laughter" (Comrie-Thompson 2002).

Many of these comedians have enjoyed commercial success whether they stayed with ethnic comedy or not. In 2003, Bilgiç, Hung Le and others toured Australia with their show, *Lord of the Kebabs*, and in 2005, *Show us Your Roots*. Australian ethnic comedy is available on video, DVD, TV, radio and stage. The latest successful drawcards are Sooshi Mango[17] said to be Australia's fastest-growing ethnic comedy troupe; and Crazy Rich Ethnics,[18] their title playing off the internationally successful film, *Crazy Rich Asians* (2018, directed by Jon M. Chu, based on the eponymous 2013 novel by the Singapore-born American writer, Kevin Kwan).

16 Written by Nick Giannopoulos, Simon Palomares and Maria Portesi, directed by Marc Gracie, it debuted at the 1987 Melbourne International Comedy Festival with huge success and toured for a number of years. Its success led to the TV series *Acropolis Now* and the film *The Wog Boy* (2000, directed by Giannopoulos) among others.

17 https://www.sooshimango.com/

18 http://crazyrichethnics.com.au/

Although it continues to be robust, ethnic comedy here and elsewhere has now evolved some conventions about how it takes the mickey, perhaps reflecting issues of both credibility and political correctness (Lockyer and Pickering 2009). In conducting a public "piss-take" of a group (on whatever social basis, ethnic or otherwise), there is a prior requirement to disparage oneself and/or one's own group before targeting others. Similarly, Australian audiences are now much less likely to believe that comic insight into the ethnic experience can be rendered vicariously by white artists posing as what they are not. Interpretations that were popular in the 1980s (e.g., Mark Mitchell's impersonation of the Greek greengrocer, Con the Fruiterer, in the TV series, *The Comedy Company*, 1988–1990) have been superseded by today's authentic voices. Such caveats apply even more strongly in the case of Indigenous Australian comedians — although they too reach audiences beyond their own nations (Austin 2017). Whatever the reason, laughter today flows more easily when the comic baton is firmly held by an unchallenged voice, speaking from experience. This gives a natural advantage to new performers who arrive to deliver comic pay-back for society's past "flexing of superiority muscles" (Le 1997: 146).

Significantly, respected Indigenous actors were among the original pioneers, especially proud Yamatji man, Ernie Dingo,[19] and proud Walmadjari woman, Ningali Lawson (1967–2019), who collaborated with Hung Le in the 2000 comedy show, *Black and Tran*. Since 2007, the Deadly Funny Awards, the national comedy competition for Aboriginal and Torres Strait Islander talent, have been held at the Melbourne International Comedy Festival (Austin 2017); in 2018, the winner was Leon Filewood, graduate in law from Queensland University of Technology and keynote speaker at the 26th AHSN Conference held at Griffith University in February 2019.[20]

For voices that are marginalised in society, using humour gives some freedom of expression and the opportunity to assert identity. Therefore, across the world, it is much prized in times of struggle, although humourists and cartoonists often suffer for their art. Here in Australia, despite our deep-seated historical separations, humour can perhaps now serve to unite rather than divide. Concluding her study of the vexed cultural exchange between Australia's original inhabitants and invasive European settlers, Clendinnen suggested that this might be the case: "Through processes I do not yet understand, we are now more like each other than we are like any other people. We even share something of the same style of humour, which is a subtle but far-reaching affinity. Here, in this place, I think we are all Australians now" (2003: 288). I hope this is true and continues to be the case.

Conclusion

Studying humour and laughter is a limitless project: as my former Stanford colleague, William F. Fry put it, "[t]he entire universe — everything we think we know,

19 Ernie Dingo (https://www.imdb.com/name/nm0227669/) was one of four Australian comic artists to receive an award from the ISHS Conference held at University of New South Wales in July 1996. The others were Campbell McComas, Ruth Cracknell and Barry Humphries.

20 https://www.comedyfestival.com.au/profileleonfilewood

everywhere within the human experience — has some relevant connection to humor" (Fry 2015: 1, xxvii). Recent recognition achieved by the field has produced several well-ranked specialist journals and book series in addition to the founding journal, *HUMOR*, and the publication of a number of methodological studies, including, significantly, introductions to humour studies from both Oxford and Cambridge University Presses.[21] Key topics now under exploration include a wide range of cross-cultural studies of humour use as well as investigations of what might be called "humours of the past" — cases where the comic elements in classical and religious texts have been ignored or overlooked. Examples are texts from Chinese Daoist and Confucian scholars (Chan 2011; in press; Xu 2011), the Icelandic sagas (Burrows 2020) and even the bloodthirsty and heroic 11th century *Chanson de Roland* (DuVal 2020).

Current research has a particular focus on the impacts of using humour, both personally on the user and also on audiences, with investigations into the benefits and drawbacks of the widespread adoption of humour in advertising (Gulas and Weinberger 2006) and in business culture more generally, usually on popular rather than research grounds (Wood et al. 2007; 2011; Scheel and Gockel 2017). Humour's widespread use in political commentary and mock-news reports is also under intense scrutiny in the present time of increasing political polarisation in Western democracies, with the jury still out on the issue of whether (and if so, how) satire actually changes things such as voter intention and beliefs about candidates (for a current meta-analysis, see Burgers and Brugman 2021). In related areas, Sharon Roach Anleu from the Judicial Studies Project at Flinders University and I, together with colleagues from Scandinavia, UK, USA and Brazil, have explored the different roles played by humour in courtrooms and judicial work (Roach Anleu and Milner Davis 2018).

Another growing body of studies deals with humour's significance in many different religions, revealing for example the complex but enlightened attitudes to humour found in the Mormon Church (McIntyre 2019) and confirming that the more fundamentalist a person is in religious belief, the lower they will likely score on a psychological test of sense of humour (Saroglou 2002). Meanwhile in philosophy, both East and West, the connections between humour and ethics, the good life and transcendental experience are all receiving renewed attention (Gardner 2020). Even if the word itself and the experience it connotes remain difficult to define, one can safely agree with Mikhail Bakhtin, the scholar of the Renaissance world of carnival, that humour has "a deep philosophical meaning [it is] one of the essential forms of the truth concerning the world as a whole … the world is seen anew, no less (and perhaps more) profoundly than when seen from the serious standpoint" (Bakhtin 1984: 66).

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21 For a review of these and other related volumes, see Condren 2021. OUP's volume is more successful than CUP's effort.

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Revivalistics — a new comparative, global, transdisciplinary field of enquiry

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Abstract

Revivalistics is a new comparative, global, trans-disciplinary field of enquiry studying comparatively and systematically the *universal* constraints and global mechanisms on the one hand (Zuckermann 2003, 2009, and importantly 2020), and *particularistic* peculiarities and cultural relativist idiosyncrasies on the other, apparent in linguistic *reclamation*, *revitalization* and *reinvigoration* across various sociological backgrounds, all over the globe (Zuckermann 2020, Zuckermann and Walsh 2011, 2014). Too many documentary and descriptive linguists mislead themselves to believe that they can easily be revivalists too. But there are two crucial differences between revivalistics and linguistics, which are at war between themselves: first, whereas linguists put the *language* at the centre, revivalists put the *language custodians* at the centre. Second, whereas in documentary linguistics the Indigenous/minority people have the knowledge of the language, in revivalistics the revivalist is the one with that knowledge.

Given that the Aboriginal/minority people are the language custodians, and given that the language custodians are at the centre of the revivalistic enterprise, the revivalist must be extremely sensitive. A revivalist is not only a linguist but also a psychologist, social worker, teacher, driver, *schlepper*, financial manager, cook, waiter, babysitter, donor etc. A revivalist must possess four characteristics: a heart of gold, "balls" of steel, the patience of a crocodile/saint, and the agreement to serve as a punchbag. Needless to say: the best-case scenario is that in which the revivalist happens to be the custodian/owner of the very language being revived (see e.g. in the case of Myaamia[1]). But this is unfortunately rare these days, especially in Australia.

Language revival is similar to co-parenting. But the revivalist is only a step-father. The important biological mother is the Indigenous/minority community. If you are the step-father and your spouse, who is the biological mother, makes what you perceive to be a mediocre decision with regard to your children, you cannot just disapprove of it. After all, the children are your spouse's more than they are yours. You must work together for the best possible outcome. Similarly, if the community supports a decision that is not linguistically viable, the revivalist can try to inspire the community members, but must accept their own verdict. That would be difficult for a linguist with poor social skills. This article first introduces cross-cultural communication and then revivalistics, explores its trans-disciplinarity and various benefits, and provides examples from the field that demonstrate the complexity of the revivalist's work and how the revivalist's work is different from that of the documentary linguist.

Introduction: Cross-cultural communication

Respect is a *sine qua non* of good communication, no matter to whom you are talking. Yet, even if you are respectful, it is important to be aware of various cultural differences regarding style of conversation and communication discourse.

1 An indigenous Algonquian language spoken in the United States. [Ed.]

Western vs Aboriginal communication

For example, by and large whilst typical Western conversational interaction is both "dyadic" and "contained," traditional Australian Aboriginal conversational interaction is both "communal" and "continuous." In dyadic Western communication, which is usually between two people, the talk is directed to a particular individual. People face each other, eye contact is important, and the control is in the hands of the speaker.

In communal Aboriginal communication, on the other hand, the talk is not directed to a specific individual but is rather "broadcast." People usually do not face each other, eye contact is less important, and the control is in the hands of the hearer.

In contained Western conversation, the talk is packaged into discontinuous bits. For example, when one asks a question, one expects an immediate answer. Another example: One turns on the TV when one would like to watch it.

In continuous Aboriginal conversation, on the other hand, one is not expected to answer a question immediately. Furthermore, one can come up with the answer to the question much later, and without mentioning the question. The TV is turned on upon acquisition and remains on until caput.

"British" vs "Mediterranean" communication

But even within dyadic cum contained so-called Western communication, there are various differences, e.g. between "British" and "Mediterranean" styles of discourse. For example, as a generalization, "British" communication is "passive-aggressive," and telling bluntly a person what you think of him/her is considered the ultimate crime. "Mediterranean" communication, on the other hand, is diametrically opposite, and is considered "aggressive" by "British" communicators. For example, backstabbing within "Mediterranean" communication is considered the ultimate crime; asking people affronting questions is acceptable, and seen as promoting open and honest dialogue. Honesty is cherished; vacuous politeness is despised.

What is passive-aggressive?

The following two "voice" triads (active — passive — passive-aggressive) constitute a humorous, linguistic way to explain to those unfamiliar with "passive-aggressive" culture what "passive-aggressive" is all about.

Active: I love your language revival.
Passive: Your language revival is loved by me.
Passive-Aggressive: I love how you feel the need to revive a language.

Active: You ate all the chocolates.
Passive: All the chocolates were eaten by you.
Passive-Aggressive: You ate all the chocolates; no worries, it's absolutely fine; I can see chocolate is very important to you.

Revivalistics

Revivalistics is a new comparative, global, trans-disciplinary field of enquiry studying comparatively and systematically the *universal* constraints and global mechanisms on the one hand (Zuckermann 2003, 2009, 2020), and *particularistic* peculiarities and cultural relativist idiosyncrasies on the other, apparent in linguistic reclamation, revitalization and reinvigoration across various sociological backgrounds, all over the globe (Zuckermann and Walsh 2011, 2014).

What is the difference between reclamation, revitalization, and reinvigoration? All

of them are on the revival spectrum. Here are my specific definitions:

- *Reclamation* is the revival of a "Sleeping Beauty" tongue, i.e. a no-longer natively spoken language, as in the case of Hebrew, Barngarla,[2] Wampanoag,[3] Siraya[4] and Myaamia.
- *Revitalization* is the revival of a severely endangered language, for example Adnyamathanha of the Flinders Ranges in Australia, as well as Karuk and Walmajarri.
- *Reinvigoration* is the revival of an endangered language that still has a high percentage of children speaking it, for example the Celtic languages Welsh and Irish, and the Romance languages Catalan and Quebecoise French.

Language endangerment has little to do with absolute numbers. Rather, it has to do with the *percentage* of *children* within the language group speaking the language *natively*. A language spoken natively by 10 million people can be endangered (as, say, only 40% of its kids speak it). A language spoken natively by 3,000 people can be safe and healthy (as 100% of its kids are native speakers).

Figure 1 describes the difference between reclamation, revitalization and reinvigoration:

Reclamation	Revitalization	Reinvigoration
There are NO native speakers when the revival begins.	Severely endangered. The percentage of children within the group speaking the language natively is very low, e.g. 0%, but there are still adults speaking the language natively.	Endangered. The percentage of children within the group speaking the language natively is lower than 100%.
e.g. Hebrew, Barngarla, Wampanoag, Siraya, Myaamia; Tunica	e.g. Adnyamathanha, Karuk, Walmajarri	e.g. Welsh, Irish, Catalan, Quebecoise French

Figure 1: Comparison of Reclamation, Revitalization and Reinvigoration

Obviously, reclamation, revitalization and reinvigoration are on a *continuum*, a cline. They do not constitute a *discrete* trichotomy. That said, the distinction is most useful. For example, the Master-Apprentice (or Mentor/Apprentice) method can only be used in the revitalization and reinvigoration, not in reclamation. This method was pioneered by linguist Leanne Hinton at the University of California, Berkeley (see, e.g., Hinton 1994), who had been working with a wide range of Native American languages spoken or in some cases remembered or documented across California. In many cases, she was working with the remaining handful of ageing fluent speakers of languages such as Karuk. It is a difficult proposition to ask an elderly speaker to come into a

2 The Aboriginal language of Eyre Peninsula, South Australia.

3 From southeastern Massachusetts [Ed.]

4 A Formosan language spoken until the end of the 19th century by the indigenous Siraya people of Taiwan [Ed.]

school classroom and teach children when they themselves are not trained teachers and, in some cases, may never have had an opportunity to attend school themselves. Even if they were able to teach their languages in a school setting, will this really ensure that their language continues into future generations? Probably not. What is more effective is to ensure that highly motivated young adults who are themselves owners-custodians of the language gain a sound knowledge of and fluency in their language. This is achieved through the Master-Apprentice (or Mentor/Apprentice) approach: A young person is paired with an older fluent speaker — perhaps a granddaughter with her grandmother — and their job is to speak the language with each other without resorting to English. It does not matter what they do — they can weave baskets, go fishing, build houses, or fix cars together — so long as they speak the language with each other (Zuckermann 2020).

Revivalistics is *trans-disciplinary* because it studies language revival from various angles such as law, mental health, linguistics, anthropology, sociology, geography, politics, history, biology, evolution, genetics, genomics, colonization studies, missionary studies, media, animation film, technology, talknology, art, theatre, dance, agriculture, archaeology, music (see Grant 2014), games (indirect learning), education, pedagogy (see Hinton 2011), and even architecture.

Consider architecture. An architect involved in revivalistics might ask the following "location, location, location" question, which is, of course, beyond language:

- Should we reclaim an Indigenous language in a natural Indigenous setting, to replicate the original ambience of heritage, culture, laws, and lores?
- Should we reclaim an Indigenous language in a modern building that has Indigenous characteristics such as Aboriginal colours and shapes?
- Should we reclaim an Aboriginal language in a western governmental building — to give an empowering signal that the tribe has full support of contemporary mainstream society?

Why should we invest time and money in reclaiming "Sleeping Beauty" languages?

Approximately 7,000 languages are currently spoken worldwide. The majority of these are spoken by small populations. Approximately 96% of the world's population speaks around 4% of the world's languages, leaving the vast majority of tongues vulnerable to extinction and disempowering their speakers. Linguistic diversity reflects many things beyond accidental historical splits. Languages are essential building blocks of community identity and authority.

With globalization of dominant cultures, homogenization and Coca-colonization, cultures at the periphery are becoming marginalized, and more and more groups all over the world are added to the forlorn club of the lost-heritage peoples. One of the most important symptoms of this cultural disaster is language loss.

A fundamental question for revivalistics, which both the tax-paying general public and the scholarly community ought to ask, is why does it matter to speak a different language? As Evans (2010) puts it eloquently in the introduction to his book *Dying Words*:

> you only hear what you listen for, and you only listen for what you are wondering about. The goal of this book is to take stock of what we should be wondering about as

> we listen to the dying words of the thousands of languages falling silent around us, across the totality of what Mike Krauss has christened the "logosphere:" just as the "biosphere" is the totality of all species of life and all ecological links on earth, the logosphere is the whole vast realm of the world's words, the languages that they build, and the links between them.

Evans (2010) ranges over the manifold ways languages can differ, the information they can hold about the deep past of their speakers, the interdependence of language and thought, the intertwining of language and oral literature. Relevant to revivalistics, it concludes by asking how linguistics can best go about recording existing knowledge so as to ensure that the richest, most culturally distinctive record of a language is captured, for use by those wanting to revive it in the future (see also Brenzinger 1992, 1998 and 2007a; Enfield 2011). Brenzinger emphasizes the threats to knowledge on the environment (Brenzinger, Heine & Heine 1994; Heine & Brenzinger 1988), conceptual diversity as a crucial loss in language shifts (Brenzinger 2006, 2007b, 2018).

The following is my own trichotomy of the main *revivalistic* reasons for language revival. The first reason for language revival is ethical: It is right. The second reason for language revival is aesthetic: It is beautiful. The third benefit for language revival is utilitarian: It is viable and socially beneficial.

Ethical reasons

A plethora of the world's languages have not just been dying of their own accord; many were destroyed by settlers of this land. For example, in Australia we owe it to the Aboriginal and Torres Strait Islander people to support the maintenance and revival of their cultural heritage, in this instance through language revival. According to the international law of human rights, persons belonging to ethnic, religious, or linguistic minorities have the right to use their own language (Article (art.) 27 of the International Covenant on Civil and Political Rights (ICCPR)). Thus, every person has the right to express themselves in the language of their ancestors, not just in the language of convenience that English has become.

Through supporting language revival, we can appreciate the significance of Indigenous languages and recognise their importance to Indigenous people and to Australia. We can then right some small part of the wrong against the original inhabitants of this country and support the wishes of their ancestors with the help of linguistic knowledge.

Aesthetic reasons

The linguist Ken Hale, who worked with many endangered languages and saw the effect of loss of language, compared losing language to bombing the Louvre: "When you lose a language, you lose a culture, intellectual wealth, a work of art. It's like dropping a bomb on a museum, the Louvre" (*The Economist*, 3 November 2001). A museum is a repository of human artistic culture. Languages are at least equally important since they store the cultural practices and beliefs of an entire people. Different languages have different ways of expressing ideas and this can indicate which concepts are important to a certain culture.

For example, in Australia, information relating to food sources, surviving in nature, and Dreaming/history is being lost along with the loss of Aboriginal languages. A study by Boroditsky and Gaby (2010) found

that speakers of Kuuk Thaayorre, a language spoken in Pormpuraaw on the west coast of Cape York, do not use "left" or "right," but always use cardinal directions (i.e. north, south, east, west). They claim that Kuuk Thaayorre speakers are constantly aware of where they are situated and that this use of directions also affects their awareness of time (Boroditsky and Gaby 2010). Language supports different ways of "being in the world."

Such cases are abundant around the world. An example of a grammatical way to express a familiar concept is *mamihlapinatapai*, a lexical item in the Yaghan language of Tierra del Fuego in Chile and Argentina. It refers to "a look shared by two people, each wishing that the other would offer something that they both desire but have been unwilling to suggest or offer themselves." This lexical item, which refers to a concept that many have despite lacking a specific word for it in their language, can be broken down into morphemes: *ma-* is a reflexive/passive prefix (realized as the allomorph *mam-* before a vowel); *ihlapi* "to be at a loss as what to do next;" *-n*, stative suffix; *-ata*, achievement suffix; and *-apai*, a dual suffix, which has a reciprocal sense with *ma-* (circumfix).

Two examples of concepts that most people might never imagine are (1) *nakhur*, in Ancient Persian, refers to "camel that will not give milk until her nostrils have been tickled." Clearly, camels are very important in this society and survival might have historically depended on camel milk; (2) *tingo*, in Rapa Nui (Pasquan) of Easter Island (Eastern Polynesian language), is "to take all the objects one desires from the house of a friend, one at a time, by asking to borrow them, until there is nothing left" (see De Boinod 2005; De Boinod & Zuckermann 2011); (3) *bunjurrbi*, in Wambaya (Non-Pama-Nyungan West Barkly Australian language, Barkly Tableland of the Northern Territory, Australia), is a verb meaning "to face your bottom toward someone when getting up from the ground."

Such fascinating and multifaceted words, *maximus in minimīs*, should not be lost. They are important to the cultures they are from and make the outsiders reflexive of their own cultures. Through language maintenance and reclamation we can keep important cultural practices and concepts alive. Lest we forget that human imagination is often limited. Consider aliens in many Hollywood films: despite approximately 3.5 billion years of DNA evolution, many people still resort to the ludicrous belief that aliens ought to look like ugly human beings, with two eyes, one nose, and one mouth.

Utilitarian benefits

Language revival benefits the speakers involved through improvement of wellbeing, cognitive abilities, and mental health (see Zuckermann and Walsh 2014; chapter 9 of Zuckermann 2020); language revival also reduces delinquency and increases cultural tourism. Language revival has a positive effect on the mental and physical wellbeing of people involved in such projects. Participants develop a better appreciation of and sense of connection with their cultural heritage. Learning the language of their ancestors can be an emotional experience and can provide people with a strong sense of pride and identity.

There are also cognitive advantages to bilingualism and multilingualism. Several studies have found that bilingual children have better non-linguistic cognitive abili-

ties compared with monolingual children (Kovács & Mehler 2009) and improved attention and auditory processing (Krizman et al. 2012: 7879): the bilingual's "enhanced experience with sound results in an auditory system that is highly efficient, flexible and focused in its automatic sound processing, especially in challenging or novel listening conditions."

Furthermore, the effects of multilingualism extend to those who have learned another language in later life and can be found across the whole lifespan. This is relevant to the first generation of revivalists, who might themselves be monolingual (as they won't become native speakers of the Revival Language). The effects of non-native multilingualism include better cognitive performance in old age (Bak et al. 2014), a significantly later onset of dementia (Alladi et al. 2013), and a better cognitive outcome after stroke (Alladi et al. 2016; Paplikar et al. 2018). Moreover, a measurable improvement in attention has been documented in participants aged from 18 to 78 years after just one week of an intensive language course (Bak et al. 2016). Language learning and active multilingualism are increasingly seen as contributing not only to psychological wellbeing but also to brain health (Bak & Mehmedbegovic 2017), with a potential of reducing money spent on medical care (Bak 2017).

Further benefits to non-native multilingualism are demonstrated by Keysar et al. (2012: 661). They found that decision-making biases are reduced when using a non-native language, as following:

> Four experiments show that the "framing effect" disappears when choices are presented in a foreign tongue. Whereas people were risk averse for gains and risk seeking for losses when choices were presented in their native tongue, they were not influenced by this framing manipulation in a foreign language. Two additional experiments show that using a foreign language reduces loss aversion, increasing the acceptance of both hypothetical and real bets with positive expected value. We propose that these effects arise because a foreign language provides greater cognitive and emotional distance than a native tongue does.

Therefore, language revival is not only empowering culturally, but also cognitively, and not only the possibly-envisioned native speakers of the future but also the learning revivalists of the present.

Revivalistics vis-à-vis documentary linguistics

Too many documentary and descriptive linguists mislead themselves to believe that they can easily be revivalists too. But there are two crucial differences between revivalistics and documentary linguistics, which are at war between themselves, resulting in the *Revivalistic Paradox*:

1. Whereas linguists put the *language* at the centre, revivalists put the *language custodians* at the centre
2. Whereas in documentary linguistics the Indigenous/minority people have the knowledge of the language, in the revivalistic case of reclamation, the revivalist is the one with that knowledge.

Given that the Aboriginal/minority people are the language custodians, and given that the language custodians are at the centre of the revivalistic enterprise, the revivalist must be extremely sensitive.

Needless to say: the best-case scenario is that in which the revivalist happens to be the custodian/owner of the very language being revived (see e.g. in the case of Myaamia). But this is unfortunately rare these days, especially in Australia.

A revivalist must master cross-cultural communication (see Introduction). A revivalist is not only a linguist but also a psychologist, social worker, teacher, driver, *schlepper*, financial manager, cook, waiter, babysitter, donor etc. A revivalist must possess four characteristics:

1. a heart of gold,
2. "balls" of steel,
3. the patience of a crocodile/saint, and
4. the agreement to serve as a punchbag.

Consider the following *real* examples from Aboriginal Australia:

1. Seat of emotions: Although the professional revivalist knows, with ample evidence, that the seat of emotions in a specific Aboriginal language is the *stomach*, contemporary indigenous custodians — influenced (subconsciously) by the colonizers' English — tell me that they feel, as the traditional owners of the languages, that the *heart* is the seat of emotions within the traditional language.
2. Neologization: Although the revivalist may think that neologisms would be beneficial for the revival (for example, as children would like to have a word for "computer" or "app"), an Aboriginal tribe told me that they decided not to neologize (for the time being) until everyone knows all the traditional words being reclaimed.
3. Swear words: Although the revivalist might think that swear words would be beneficial for the revival (for example, as people would like to express frustration), an Aboriginal tribe asked me to censor such words from the dictionary.
4. One-to-one correlation between signifiers and referents: Although the revivalist has no problem with homophony and polysemy, an Aboriginal custodian told me that she wanted a system of one word — one meaning.
5. Spelling: Although an Aboriginal tribe decided to stick to B, D and G (knowing that P T and K are not distinct phonemes in their language), some opted to continue to use P and K in a specific name within that language.

Finally, whilst a linguist writes dictionaries and grammars for other linguists, the revivalist must ensure that their lexicography and grammaticography are tailored for lay people. In revivalistics, dictionaries and grammars must be written for the language custodians, in an accessible, user-friendly way.

Concluding remarks

Language revival is similar to co-parenting. But the revivalist is only a step-father. The important biological mother is the Indigenous/minority community. If you are the step-father and your spouse, who is the biological mother, makes what you perceive to be a mediocre decision with regard to your children, you cannot just disapprove of it. After all, the children are your spouse's more than they are yours. You must work together for the best possible outcome.

Similarly, if the community supports a decision that is not linguistically viable, the revivalist can try to inspire the community members, but must accept their own verdict. That would be difficult for a documentary linguist with poor social skills.

Unlike what too many linguists believe, language revival is *not* a stage within the career of a documentary or descriptive linguist. Revivalistics is a distinct field, with different requirements. For example, whilst an Asperger's can be a great language typologist and a wonderful documentary linguist, s/he cannot be a revivalist.

More and more indigenous and minority communities seek to reinstate their cultural authority in the world. Revivalistics can assist them in doing so. One should listen to the voice of Jenna Richards, a Barngarla Aboriginal woman who took part in my first Barngarla reclamation workshop in Port Lincoln, South Australia, on 18–20 April 2012. She wrote to me the following sentence in an unsolicited email message on 3 May 2012:

> Personally, I found the experience of learning our language liberating and went home feeling very overwhelmed because we were finally going to learn our "own" language, it gave me a sense of identity and I think if the whole family learnt our language then we would all feel totally different about ourselves and each other cause it's almost like it gives you a purpose in life.

As Barngarla woman Evelyn Walker (née Dohnt) wrote to me following the same reclamation workshop: *Our ancestors are happy!*

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With the falling of the dusk

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Abstract

A talk given at the Inaugural Meeting of the Western NSW Branch of the Royal Society of NSW, 20 October, 2021. See https://www.youtube.com/watch?v=vaLT4JbTxPk

Introduction

I want to pay my respects to the Gadigal people on whose land I'm standing and to also acknowledge my own ancestry — Wiradjuri, Kamilaroi, Dharrawal, and Irish — which makes me uniquely Australian. I often say there is no other place on Earth that I can come from than Australia, with all of the history that Australia is living inside of me.

With the falling of the dusk

I want to talk to you about the state of our world, what has led us here. It's quite fitting that I'm addressing what used to be known as the Philosophical Society because I want to take you on a historical, political and philosophical journey into the ideas that have animated our world and the challenges that lie ahead.

I want to take you, first of all, on a train to China, to begin with a look through a window of a train heading across the landscape of China. I took my first good look at China from the window of a train on a frozen Christmas morning. I had lived in Hong Kong and made several trips to the China mainland, but this was different. I was here to stay. My first morning in my new home. I woke early in my sleeper cabin as the sun was rising and, with the smooth of my hand, smeared the condensation from the window. It was cold inside the train, and I shivered. A little steam rose from my breath and through the streaky window I looked out on this place.

China had always lived in my imagination — that big, mysterious place on a map that I recalled from childhood, pinned to the wall of my classroom. I remembered sitting on the floor, hands tucked under my legs and watching black and white film of a land crowded with people, grey suits and bicycles. I started school at the height of China's Cultural Revolution, and I imagine every primary-school-aged child in Australia at the time would have heard the name Mao Zedong, the Communist leader of China. I recall the first time I saw his image, a portly, serenely smiling figure standing amid a crush of young, feverish faces, all waving Mao's Little Red Book, the sayings of this man they called the Great Helmsman.

This was the height of the Cold War, when the world lived in the shadow of nuclear catastrophe. I can recall watching a film of American kids doing duck and cover drills, sheltering under the desks to avoid radioactive fallout in the event of an attack. The Communists were the enemy, we were told: the Soviet Union and China. China was distant and exotic and mysterious and exciting

and frightening all at once. Its people had their own culture and language, their own philosophy, faith and story.

What we now call China is the product of thousands of years of war and revolution, and empire. Turmoil is a constant state of being. The famous 14th century Chinese novel *Romance of the Three Kingdoms* opens with the line, "The Empire long divided, must unite, long united, must divide." Empires would rise and fall. Each emperor casting a long shadow, even though all around them was treachery to the Chinese. China was the world. They called it the Middle Kingdom, the centre of all civilisation. But that was long ago.

The China that would be my home had been humiliated. For a century. It had been conquered, exploited, dominated by foreign powers. It had been weak, and this disgrace ran deep. Every Chinese child was schooled in historical vengeance, reminded endlessly of the hundred years of humiliation from the mid-19th century opium wars with Britain to the Communist revolution in 1949. They now would complete the great rejuvenation of the nation to return their motherland to what they believed was its rightful place at the apex of global power.

That's what I saw from my train window, the space between the future and the past, between becoming and being, between progress and eternity. I also saw a country haunted by history. This land seemed to pulse with memory. In the cold morning light, with just the rattle of the train to break the silence, I felt like I could hear the whisper of all the people who had lived here. In the distance I saw an old Buddhist pagoda surrounded by hills with barely any trees. And there on a flat piece of ground was a lone man working his field with a horse-drawn plough.

My wife and our boys were still fast asleep. The day before, we had closed the door on our life in Hong Kong and boarded this train for Beijing. This was the move I've been hoping for — a life of adventure, as China correspondent for CNN, one of the biggest news networks on the planet. The return of China as a great power was already shaping the world. In the years ahead, it would exercise a great hold on me. It would become the defining story of my journalistic career.

This country was in the midst of an economic revolution that had lifted more than half a billion people out of poverty. The Communist Party was defying the Western liberal belief that said the country could not become rich without also becoming free. The Party was instead doubling down on its power. It would stop at nothing, not even the slaughter of its own people, as we saw in Tiananmen Square, to keep its iron grip on the nation. All predictions pointed to China becoming the most economically dominant nation on the planet. Truly an authoritarian superpower.

As the train pulled past, I stared at this man in the field. Although from different worlds, this man and I shared a lot. Our lives stood at the crossroads of history. We were twinned with fate. We belonged each to old cultures whose worlds had been upended by the march of modernity — he in China, me as an Indigenous person of Australia. History lived in us. Every one of our ancestors had a hold on us. This man had likely never strayed far from his village. Yet the world had come to him as China shook itself from its slumber and began to throw off the yoke of 100 years of humiliation. And me? I had left my country to find a place in the world, and my wandering had brought me here.

We find ourselves now at a hinge point of history. To understand the gravity of this moment, we need to take a snapshot of our world. Thirty years after the end of the Cold War, there is talk of Cold War 2.0, the United States staring down a new rival, China, and we are witnessing a return of great power rivalry. Yet China is economically more powerful today than the Soviet Union was then, and the United States is unquestionably, a diminished nation.

America is politically fractured, deeply divided along racial and class lines. It has endured the grip of an opioid epidemic and a frenzy of gun violence. And of course, it has been devastated by the coronavirus. Alarmingly, life expectancy in the richest country on Earth is decreasing. America appears as an exhausted nation. It has been beset by crises for decades. The Al Qaeda-orchestrated terrorist attacks of 9/11/2001, the wars of Afghanistan and Iraq, the banking collapse in global financial crisis of 2007–2008. It is today a nation worn down and poorer. It is less sure of itself, and the world is less sure of American leadership. A decade ago, the journalist and political commentator Fareed Zakaria coined the phrase "the post-American world." The post-American world. He saw a world in which the United States was still powerful but no longer dominant. Others had caught up. Is this now the post-American world? China is on track to become the biggest economy in the world and is building a military, it says, will fight and win any war. The two nations have been on a collision course.

Some historians see an overlay today with the drift to world war in 1914 or 1939. Writing about the lead up to World War One, Christopher Clark, in his book *The Sleepwalkers*, says that political leaders have become hostage to events, "causes trawled from the length and breadth of Europe's prewar decades are piled like weights on the scale until it tilts from probability to inevitability." Are the weights tipping the scales again? The Indo-Pacific is a tinderbox of old enmities expanding militaries, disputed territories, unfinished conflicts and nuclear-armed states. The founding dean of the Harvard University Kennedy School, the noted historian Graham Allison has looked back to 400 BC and the lessons of Thucydides. The historian of the Peloponnesian war between Athens and Sparta. The "Thucydides trap," as it is known, holds that when a rising power leads a waning power, war becomes inevitable. Allison fears the world is lurching towards conflict unseen since World War II. In his book *Destined for War*, Allison writes, it was the rise of Athens and the fear this instilled in Sparta that made war inevitable.

Then it was Athens, Sparta. In 1914, it was Germany, Great Britain. And now it is China, United States. As far ahead as the eye can see, Alison says, the defining question about global order is whether China and the US can escape Thucydides' trap. Most contests that fit this pattern, he says, have ended badly. Allison writes, on the current trajectory, war is not just possible, but much more likely than currently recognised. Now, a virus that came out of China has only added to our global instability. As Australia's Prime Minister Scott Morrison has said, our world is poorer, more disordered, and more dangerous.

Reflecting this threat, Australia has updated its defence strategy, significantly increasing spending and investing in new weaponry. The recent announcement of the AUKUS Alliance — Australia, UK,

US — and Australia's decision to cross the nuclear threshold, purchasing nuclear-powered submarines, only underlies that we have entered a new and dangerous era. War, it must be said, is still thankfully unlikely. But we are not alone in preparing for what was not so long ago unthinkable. John Adams, one of the founding fathers of the United States and its second President, once said, "Remember, democracy never lasts long. It soon wastes, exhausts, murders itself." He said there never was a democracy that did not commit suicide. Is this what we are seeing in our time? Is this the inevitable death of democracy before it has even had time to truly grow old? The turmoil of the world is set against a weakening democracy and a seemingly ascendant authoritarianism.

Freedom House, an organisation that measures the health of democracy,[1] now counts 15 straight years of declining freedom and democracy in our world. It says we are witnessing a return of the iron fist, the resurgence of political strongmen who exploit fear and anxiety and govern over division.

It is only 30 years since the Berlin Wall came down. And then a young American political scientist, Francis Fukuyama, declared the end of history. In 1989, the triumph of liberal democracy over Soviet communism, he said, truly had settled the great ideological questions of humanity.

Is this where the end of history has taken us? It wasn't supposed to be this way. The second half of the 20th century was a boom time for democracy. Germany emerged from the trauma of Nazism. South Africa threw off the yoke of apartheid. Decolonization across Africa and Asia created free democratic nations and in other parts of the world, in Latin America and in Europe, autocratic regimes were swept aside. Between 1970 and 2010, the number of democracies in the world increased from 120 to 350: 63% of the world's people then lived in democracies.

To its defenders, democracy's appeal is obvious. *The Economist* magazine has pointed out that democracies are, on average, richer than non-democracies, are less likely to go to war, and have a better record of fighting corruption. More fundamentally, democracy lets people speak their minds and shape their own and their children's futures. To paraphrase Winston Churchill, democracy is the worst form of government, except for all the others. It's easy to say, I suppose, when democracy has been designed for you. To much of the world, democracy also grew out of ideas of Western universalism, too often imported at the barrel of a gun. To much of the world, Western triumphalism sounds like humiliation.

And now there is a blowback that is shaking the West's faith in itself. Today, what we have called the global liberal order is unravelling. Global politics was in a state of flux before COVID-19 escaped the Chinese city of Wuhan and put our lives into a tailspin. War, economic collapse, refugee crises, political populism. All of these things have tested us and none of us has escaped unscathed. Terrorism has struck in cities from Paris to London to Jakarta to Sydney to Christchurch in New Zealand. People who lost their savings, their jobs or their homes in the financial meltdown a decade ago are still struggling to recover. Some never will. These shifting fault lines have exposed deep socio-economic inequalities, extant racial divisions and simmering political antagonism.

1 https://freedomhouse.org

The Indian writer Pankaj Mishra has called this the Age of Anger. The West has poisoned itself with the very seeds it has sown. The Chinese American lawyer and academic Amy Chua says we are witnessing a resurgence of political tribalism. The old political left-right binary fails to explain, she says, what we are living through. This is the politics of identity, religion, race, ethnicity, nationalism. These are the drivers of our age.

I am reminded of the words of the great Irish poet William Butler Yeats:

Things fall apart; the centre cannot hold;
Mere anarchy is loosed upon the world,
The blood-dimmed tide is loosed, and everywhere
The ceremony of innocence is drowned;
The best lack all conviction, while the worst
Are full of passionate intensity.[2]

As a reporter of four decades, I have traversed this world of intensity and hate. I have stood in the bombed out marketplaces in Afghanistan, Pakistan, and Iraq. I've travelled to the closed world of North Korea and of course reported the rise of the authoritarian behemoth China. I have indeed followed the trail of blood where the ceremony of innocence is drowned.

I have seen how identity excludes and shrinks our world, how easily it is weaponised: Hutu versus Tutsi in Rwanda, Catholic against Protestant in Northern Ireland, the Muslim blood feud of Shia and Sunni, Hindu against Muslim. On and on it goes. I have touched the outer limits of our humanity, and it has proved to me one thing: the Indian philosopher and economist Amartya Sen is right when he warns that identity can kill, and kill with abandon.

This is identity fuelled by grievance, by vengeance and anger. It is identity poured through the strainer of history. Everywhere there is resurgent populism, nationalism, sectarianism, tribalism, and all of it feeds on history. Think of what Xi Jinping tells the Chinese people: remember the 100 years of humiliation. Vladimir Putin laments the end of the Soviet Empire as what he calls the greatest catastrophe of the 20th century. In Turkey, Recep Tayyip Erdoğan reminds his people of the greatness of the Ottoman Empire. In Hungary, Viktor Orban, a populist leader who has boasted of his illiberal democracy tells his people they were cheated after the end of World War I, when the country lost two thirds of its territory, and vows never again. Islamic State is still fighting the Crusades and dreaming of rebuilding the Caliphate ahead of what it sees as the final battle for humanity.

The German philosopher Friedrich Nietzsche told us that we all suffer from a consuming historical fever. History. The vengeance of history is the poison in the blood of our identities. Nietzsche warned of what he called the Man of Ressentiment. His, he says, is the unquenchable thirst for revenge. The refusal to let go. Suffering forms the core of his identity. To Nietzsche, the Man of Ressentiment is a prisoner of his past. Caught in a time warp, he always returns to the source of injustice that he cannot fix and does not want to fix.

This toxic identity that has made our world so perilous has taken root, too, in democracies. As American political scientist Mark Lilla has pointed out, it spreads like a cancer. He argues that the politics of toxic identity is shattering the idea of shared

2 From "The Second Coming," 1919.

citizenship. The word "we," he says, has been banished to the outer reaches of respectable political discourse. Lilla says this is a disastrous foundation for democratic politics. At worst, this pits groups from left and right into open and often violent conflict.

In democracies today there are those who seek power through division, who revel in carnage and exploit fear and anxiety. They vow to return their people to some imagined golden age, while at the same time defining who the true people are, who belongs and who doesn't. And these populists are often very popular. They are seizing power with a simple, seductive message for people who are tired or angry or left out, left behind and fear. This is the state of democracies. Far too often today, a competition for recognition and power that is rendering our polity fractured and unworkable. Talk of unity or hope cannot but sound trite or naïve. When politicians and political parties can so persuasively appeal to a constellation of difference, we define ourselves not by what we are or who we are, but what we are not and who we are not.

Into this mix of great power rivalry, fear of war, rising authoritarianism, retreating democracy, political populism, nationalism, tribalism and toxic weaponised identity, we now add the coronavirus. The last two years have been unlike any other in our recent memories, COVID-19 has revealed and widened the fault lines of our world. Globalisation, which has brought us closer and made us richer, has also left us vulnerable. Our world is smaller and the virus can move so much more quickly.

Our defence against COVID was to lock ourselves away, to seal off our borders. Our isolation is a potent symbol of a political and economic system that seems out of answers, unsure of itself. The poor, the black and brown, the white underclass, those left behind by decades of neoliberalism and its worship of the market are those who have suffered the most during the pandemic. Will democracy meet this challenge? While democracy can be the best vaccine against tyranny, it carries within it its own tyranny.

To many people — the poor and oppressed — democracy appears as a sham, a game played by and for the elites. On 6 January 2021, an American mob stormed the Capitol Building in Washington, D.C. Members of Congress fled and hid as the protesters, some of them armed, overturned offices and stormed the hallways. I was on-air with the ABC as this scene unfolded. Here were America's worst fears made real. The news anchors and commentators on the US networks competed with one another to describe this moment: was it a coup? An insurrection? Was this terrorism or treason? All fingers were pointed at Donald Trump, the Clown Prince of American politics, once called a cartoon fascist by British political scientist David Runciman, who had taken his reality TV show all the way to the White House. I interviewed guests who bemoaned the theft of American democracy. How could this happen in the land of the free and the home of the brave, they said? Where was this glorious City on the Hill? This is not who we are, they told me. But of course it was.

What we saw in the American capital was America laid bare. Like everyone, I suspect, I was stunned by what I saw. It was a moment that fixed in my mind as surely as the attacks on the US on 11 September 2001. Yet I was not surprised. In its own way, this was a moment of honesty, of reckoning. The angry mob storming the Capitol Building reflected a broken country where tens of

millions of people have traded the American dream for what Donald Trump called American carnage, and no longer know what truth truly is.

American politics, business and media have been complicit in delivering the United States to this critical moment. The sad scene of a country that has long billed itself as a beacon of democracy, tearing itself apart, revealed the hypocrisy of those condemning it. Former President George W. Bush called this scene a sickening and heartbreaking attack. On democracy. America, he said, resembles a banana republic. But, remember, this is the man who concocted evidence of Saddam Hussein possessing weapons of mass destruction as a pretext for an invasion of Iraq. His lies led to hundreds of thousands of Iraqi deaths and upturned the Middle East, setting off unending conflict, and cost his own nation $2 trillion and the deaths of so many of its servicemen and women. Another former President, Bill Clinton, said the attack on the US Capitol Building was fuelled by four years of poisonous politics by Donald Trump. But, remember, this is the same Clinton who was President, who perjured himself, disgraced the White House, and became only the second President to be impeached. Donald Trump became the third.

While Trump peddled his conspiracies of election fraud, I could only remember that Hillary Clinton had also told Democrats there was a vast right-wing conspiracy trying to destroy her husband's presidency. The truth is American political leaders have been playing fast and loose with the truth for decades, deepening partisan divisions and whipping up anger among their supporters. Trump exploited a sick politics, from Richard Nixon's Watergate lies and corruption to Bush and Clinton. All roads led to Donald Trump. The dangerous delusions of his crazed followers should only remind us that America has always teetered on the edge of collapse.

It is a nation born in crisis and awash with bloodshed, the genocide of Native Americans, the enslavement of Africans stolen from their lands on whose scarred backs America filled its wealth. Let's not forget this is a nation created by revolution and torn apart by civil war that has seen presidents assassinated. The 1960s was a time of violence, revolt and political killings, and it lit the fuse for the division and tribalism that continues today. America is locked in a perpetual culture war, lacerated by class, race and faith.

Trump was, in fact, right when he said that America was seriously divided before he got there. Previous presidents at least paid lip service to unity. Trump never pretended that he governed for all. The country was ripe for his brand of political opportunism, us versus them populism feeding on fear and anxiety, and exploiting racism. Growing inequality has fractured America, with the working poor left behind, while power and wealth is concentrated in the hands of what's been dubbed an American meritocracy. To be a member of the top 1% in America is to have wealth 900 times greater than a member of the bottom 50%.

The financial crash of 2008 left the country poorer and deeply scarred. Ordinary Americans lost their homes and their jobs while rich bankers got bailed out. Large parts of white America are poorer and sicker. Even before the coronavirus, the country was in the grip of a deadly health crisis. Economists Anne Case and Angus Deaton chronicle this downward spiral in their book, *Deaths of Despair and the Future*

of Capitalism. It is a devastating portrait of a lost generation. They reveal an America of haves and have nots, where a four-year college degree can be the difference not just between better and worse career prospects, but in fact between life and death.

This is an America, they say, of meaningless or no work, of declining wages and shattered families. Most striking of all, for the first time in a century, not since the 1918 'flu, American life expectancy is falling. This generation of Americans is dying younger than their parents, and where people live determines their fate. The largest increases in mortality rates for whites aged 45 to 54 are in West Virginia, Kentucky, Arkansas and Mississippi, which, as Case and Deaton point out, are all States with education levels lower than the national average.

And how are these Americans dying? They are killing themselves. In the words of Case and Deaton, they are drinking themselves to death or poisoning themselves with drugs, or shooting themselves, or hanging themselves. There is no faith in American capitalism, which Case and Deaton write, looks more like a racket to make the rich richer. I defy anyone to read *Deaths of Despair and the Future of Capitalism* and still cling to the myths of America.

One of the most famous portraits of Napoleon has him standing before the tomb of Frederick the Great of Prussia. His arms are folded and he bows his head just slightly. It is staged so that he appears humble and respectful. One of Napoleon's biographers, Philip Dwyer, says the portrait was a powerful tool of propaganda, both a mark of respect for Frederick as a general and a sovereign and a means of enhancing Napoleon's own reputation by obliging people to compare him to Frederick, one of the greatest generals of the 18th century. Napoleon had crushed the Prussian Army under Frederick William III in the battles of Auerstedt and Jena on 14 October 1806. The Kingdom of Prussia now came under the Empire of France.

At this time the philosopher Georg Hegel was living and teaching in Vienna. He glimpsed Napoleon riding through the town. Hegel was moved to describe the great general as the soul of the world. In that moment Hegel had an epiphany. Napoleon was more than Emperor. More than general. He was the fulfilment of human destiny. All of human endeavour, Hegel said, all thought, war sacrifice, life and death had led to this moment. To Hegel, Napoleon was a force from which history was set in motion. This is what humanity was destined for. Napoleon was, to Hegel, the absolute spirit. Hegel saw the Battle of Jena as more than just a military victory. It was a moment of transcendence. As he described Napoleon, "dominating the entire world from horseback," Hegel gave flight to a radical idea. The end of history itself.

Hegel's end of history casts a long shadow. Even those who have never heard of him, let alone read him, live in the world Hegel made. It's not possible to imagine the modern political state without Hegel. One Hegelian philosopher, Stephen Houlgate, has called the 18th century thinker the most important political philosopher of the post-French revolutionary era. Hegel, the philosopher to whom I have turned as a guide to our times, believed he had glimpsed the perfect sight, a state of freedom at the end of history. In Napoleon's France, he believed he had seen the light of the world, the absolute spirit. Humans had reached the summit, the promise of freedom and liberty, the end of history.

Stalin, Hitler, Mao — they, too, believed that they would be the final word on humanity. Perhaps Xi Jinping believes the same today. Those who cling to the American myth might still believe that it is humanity's last great chance. Francis Fukuyama believed he had glimpsed history's end with the fall of the Berlin Wall. The rush to crown the glory of the West has always been premature. Hegel warned that the end of history might also lead to what he called the highway of despair. It is "in utter dismemberment that the spirit finds itself."

What is our despair? It is alienation, the loss of community, the betrayal of leaders, the corruption of capitalism, the destruction of our environment, dehumanising racism, and the brutality of authoritarianism.

American leadership has been a great gift to the world in so many ways. It has given us the computer age. It has taken us to the Moon. It is overseeing what's known as the Great Peace, since the end of World War II. It has helped to bring us to this point, but America alone will not deliver us from it.

We are indeed entering what's been called the post-American world. This is a moment fraught with peril, but inevitable. Pope Francis has spoken to this crisis, questioning Western values in the American way of life. A professor of theology, Massimo Fagioli, has explored the pontiff's role in this world of swirling change. In his book *Joe Biden and Catholicism in the United States*, he says Pope Francis invites a radical critique of the inclination to embrace Western triumphalism as a creed of religious faith that looks forward to the eventual acceptance, willingly or not, of Western-style American-led democracy by the rest of the world.

We face a reckoning, a realisation now that democracy may not be the natural order of things. It may not even be the natural order of the United States. Hegel, the philosopher, warned that we courted danger when we turned away from despair. In despair, we find new ideas, he said, an opportunity to grasp truth. Philosophy, he wrote, reveals the progressive unfolding of truth. It has been described as an engine of change. As Hegel poetically put it, the bud disappears in the bursting forth of the blossom. One refutes the other until the fruit of the blossom reveals a new truth. This, he said, was their fluid nature. What begins, ends and begins and ends and begins and ends again and again and again. Ultimately, for Hegel, the contradictions that drive change are resolved in the ethical state.

This is what Fukuyama believed he had seen at the end of history, the rise of the ethical liberal democratic state. Yet even Fukuyama, in his fervour of Western triumphalism, conceded that it could trigger an immense war of the spirit, as he wrote, engaged in bloody and pointless prestige battles, only this time with modern weapons. Presciently, he warned that this war could start within democracy itself. He said the chief threat to democracy would be our own confusion about what is really at stake. Fukuyama recognised that the end of history might just get history started again.

This is the world I have reported, the return of history and the rejection of the idea that liberalism or democracy speaks equally to us all. We are all on the highway of despair. As to the idea of truth, there is debate now about what that even meant. Democracy itself has broken with liberalism, hijacked by demagogues who use it as a cover for tyranny. The champions of liberal democracy, like Fukuyama, now confront the prospect that their great faith itself may

not outlast history. As we emerge from the worst of COVID-19, the virus has accelerated the change in our world.

Writing more than two centuries ago, Hegel could be speaking to our age and even uses the metaphor of infection. We cannot deny our despair, he said, we must embrace a new consciousness to struggle against it. It betrays the fact that infection has occurred. The struggle is too late and every remedy adopted only aggravates the disease.

I think often of that train ride to China and that man that I saw in a distant field all those years ago. What has become of him? There is no way he could have remained untouched by the momentous change in his own country. Back then, he still worked his land as his ancestors had done. It was still possible for parts of China to remain shielded from the world. No longer.

When the sun set on the Cold War that pitted the West against the Soviet Union, it rose again in China. We may like to think that we can bend time, the universe itself, to our will, that we can capture the human soul and construct a society to fit. We may believe that we can end history itself, but the world is not flat and time is not straight, and history will go where it will. I woke that morning on a train to China in a world of possibility, in a new home with a new story to tell.

But wisdom is not gained in the dawn, as Hegel well knew. The Owl of Minerva, he wrote, spreads its wings only with the falling of the dusk. Thank you so much.

Q & A

Christina Slade:[3] Thank you so much, Stan. Very wise words. You have an extraordinary ability to bring together tales about your life as a correspondent with a long historical and a philosophical view. It's an extraordinary tour de force. I want to ask at first about the question of identity. You warn about great power rivalry, the rise of political and toxic tribalism. Yet you understand the resentment of displacement of those emotions. You're a cosmopolitan, I'm afraid, even though at times you're sceptical about Western liberalism. I want to go back to Amartya Sen's book, I*dentity and Violence*, that you mentioned in your talk. He describes the fashion in which many of us have multiple identities and the fact that you can have multiple identities that are not in conflict. You appear to be an example of that. So how have your multiple identities informed your work? And are there any lessons for us from our ability to reconcile multiple identities in this rather dismal prospect of the future that you have described for us?

Stan Grant: Christina, that is a wonderful observation and a wonderful question. It goes absolutely to the heart of what I've written about in my book, *With the Falling of the Dusk*, and what I've grappled with in my reporting of the world. Identities can be very nourishing and positive things. My identity as an Indigenous Australian, is deeply rooted in a connection to family and place, kinship and belonging. But it is not all I am, nor should it be. The healthiest identities are ones that overlap, that allow us to connect with others.

3 Emeritus Professor Christina Slade FRSN is a Councillor of the RSNSW and helped establish the Western Branch.

I embrace all aspects of my history, my ancestry — Irish, as well as my Indigenous heritage. I think the danger in the world is when identity has shrunk to one simple thing. As Amartya Sen warned of, the solitairist identity, the identity that cannot see the shared humanity with others. And cosmopolitanism has become almost a dirty word in our world. It's attacked. Cosmopolitans are attacked for being ruthless and without a sense of history or belonging. And yet we are all cosmopolitans. We all carry the dust of many lands on our feet.

We all come from somewhere else. We all share ancestry with someone else. All of us are meeting here today from different backgrounds, different histories, different ethnicities, different religions, and all of these things. And we come together and we share something. And where positive, multiple, overlapping, cosmopolitan identities exist, we see healthy societies. But unfortunately, in our world, identity is drawn from the well of vengeance and grievance, unending historical grievance, the wounds of history that have not healed, the sense of injustice that so many people feel from those same crimes of history.

And they fester into a political tribalism that pits us against each other. And it's weakening our democracies. We're seeing this everywhere. And yet it is undeniable. And the challenge of our age is when we live in a world where we are so much more connected, where our economies are connected, where once COVID passes, we can hop on a plane and be in another part of the world within 12 hours, where a boy who grew up as an Aboriginal boy living on the margins of society and the small towns of outback New South Wales, grew up to live in the great cities of the world and report for the biggest news organisations in the world and cover the great stories of our time from more than 80 countries.

That when we live in that world, the challenge of our time now is how do we live in that world with peace? And that's being tested. And it's being tested because the fault lines of identity that run from China to Russia to the Middle East to America, here in Australia as well, tearing us apart. Identity as a word for me has become almost redundant. It is a dangerous word for me, and I try to replace it with ideas of belonging that overlap and don't divide us and put us into our boxes.

Christina Slade: Thank you. Now the questions are pouring in. Sid Parisi talks about the disorder of status systems and asks you your own culture and society of the Aboriginal peoples of this land enjoyed. In his phrase it was a state of "mere anarchy" that is not disorder, but the order of a society without the state. Do you see any value in terms of learning from such anarchy?

Stan Grant: It's another good observation. In fact, just to name-drop here. I was having a conversation with former Prime Minister Paul Keating yesterday. We often have chats and share ideas about things — we've known each other for a long time. And he makes the point, and I think it's a useful point, that the global political structure is anarchical. It is anarchical because we live in a world that is so difficult to order. And when we impose order, inevitably there is tension within that order.

We hear a lot about the global liberal order, as if that is a permanent state of being, an unquestioned good. And, yes, while it has been a force for good in so many ways, it is also an order that has not always included all the states of the world. It has not been a global liberal order, but in fact a global order for liberal states. And so now we're

seeing a tension in our world when you see the rise of a state like China, which does not share the roots of that liberal democratic order and yet is emerging as potentially the biggest power in the world — and certainly economically by the end of this decade, it's on track to be that — and that challenges the order as we know it.

And it reminds us again of the anarchical structure of that order. How we incorporate these tensions in our world without resorting to violence is going to be the test of our times. Now, to relate that to Aboriginal society, while not looking to valorise or to romanticise it, the reality is that for 60,000 years, as far as we know, perhaps even longer, there was a unique culture here where people survived and thrived. And, when the British arrived, had deep connections, trade and ceremony and civilization, art and dance and music and everything else that had thrived here in a state where apparently there was not an overarching political order but a constellation of nations sharing a space.

And perhaps there are lessons to learn from that. And as we open up our minds now to living in a world that is much smaller in its own way, isolated and yet connected, that where the natural order, as we know it has been challenged, there may be lessons to learn with how you live with a positive sense of an anarchism within a political structure. There's a lot to think about that.

Christina Slade: Is there a possibility of a good outcome, in this globalised world? Will we see a rise of competition and coercion and populist government? Will we fall into an abyss? Is there the possibility of a good global outcome? What do we need to do to bring it about?

Stan Grant: The first thing we have to recognise is, as Hegel has pointed out, as Francis Fukuyama pointed out in 1989, the potential to fall into the abyss is real. Despair is a part of the human condition. Orders do not hold. As Yates pointed out to us, the centre cannot hold. And this happens. We've been lulled into a false sense of our own security, really, over the past 50, 60 years, I was fortunate, we all were on here today, to be born within the period of that great peace. Yes, there have been conflict: in Korea, in Vietnam, of course, throughout the Middle East. And we've seen the last 20 years in Iraq and Afghanistan. But the great nation-on-nation, civilizational conflicts of World Wars One and Two, we were spared from. We live within that period of the great peace, and that's almost become unthinkable to us. And yet the reality is when order breaks down, when trust breaks down, when the centre cannot hold, we can so easily slide into war. And we are preparing for that eventuality.

That's the reason we have the Quad Group or the AUKUS Alliance. That's the reason we're spending more on our military. It's the reason Xi Jinping is spending more on his military. We live with the potential of a return to something we have not seen for over half a century. And that is big, great power nation-on-nation conflict, catastrophic in its scope. And that is a real possibility. Now, if we accept that as a real possibility and that history teaches us that these things are entirely conceivable, then how do we avoid that?

That's going to take immense statecraft. It's going to take an immense understanding of the nature of history and the resilience of a global order that can accommodate, for the first time, certainly since the end of World War Two, a global power that does not share the liberal democratic values that we have taken for granted and benefited from in the West. Can we incorporate the rise of China into a global order, or will it

lead inevitably to conflict? And what are the red lines that we draw? Because, of course, we cannot countenance a world of tyranny. We can't countenance it here in our country, there are lines that definitely need to be drawn, and we would hope that once drawn, we can avoid those lines being crossed. And that's the challenge for us right now.

Here's the good news. The good news is that the rise of China thus far has been conducted entirely within a global system and a global system helmed by the United States itself. China has entered into a global order. It is a member of the World Trade Organisation, a member of the World Health Organisation, a permanent five member of the UN Security Council, a contributor to UN peacekeeping missions, a signatory to hundreds of international covenants and treaties that bind it to a global order. The rise of China, unparalleled in our time, a country that could not feed itself in my childhood that has lifted 700 million people out of poverty, that has become the biggest trading partner of Australia, and so many other countries around the world, has been achieved without a single shot being fired. That's a remarkable achievement.

How do we maintain that? And it's going to get harder. It's going to get harder as inevitably American power is challenged, is seen as being in decline. As China becomes more powerful and Xi Jinping becomes more assertive, it's going to be challenged. But we have managed it thus far. And if we want to know what happens, if we fail to manage it, we only need to look to our own history, the catastrophic conflicts of World Wars One and Two and know that they can happen again.

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Behind the scenes of the 1957 Chapel Hill Conference on the role of gravitation in physics

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Abstract

This brief paper will peel back some of the layers of the Chapel Hill conference, to look at its somewhat surprising origins in private philanthropy, motivated by the promise of new technologies based on anti-gravity or gravity control. We are fortunate to have a very full historical record of the conference and the so-called *Institute of Field Physics* that hosted it — the account I present here is a highly abridged version of the more detailed accounts given in Kaiser and Rickles (2018) and Rickles (forthcoming).

Introduction

The *Conference on the Role of Gravitation in Physics*, held in Chapel Hill, North Carolina in 1957, was a pivotal event in the history of gravitational physics.[1] Not only did it establish the reality of gravitational radiation and provoke the experimental search for gravitational waves, after years of controversy (only just successfully brought to fruition, with LIGO), it also founded the subject of quantum gravity as an important field in its own right (here lies my own primary interest in the conference), amongst many other important advances and clarifications. The conference still inspires a younger generation, with recent proposals to realise experimental work on quantum gravity, once thought impossible to bring into reality, some directly based on the thought experiments presented at Chapel Hill by Richard Feynman.[2]

Stranger than fiction

Before the Chapel Hill conference, with a few exceptions, general relativity and gravitational physics was in a state of neglect (this was acknowledged at the time). Indeed, Peter Bergmann (one of Einstein's research assistants) famously said that in these days "you only had to know what your six best friends were doing to know what was going on in general relativity" (cited in Pais, 1983, p. 268). That is not such an exaggeration. Gravity was associated in the minds of the public, military, and industry with something bizarre and magical. The level of knowledge was such that, even amongst those with scientific and engineering backgrounds, it was a common expectation that gravity could be controlled like electromagnetism. This electromagnetic analogy led to people expecting that gravity could be shielded, absorbed, and manipulated to produce novel kinds of flying machine. Ironically this very naivety about the nature of

1 The report from the conference can be found online: http://www.edition-open-sources.org/sources/5/index.html (Rickles and DeWitt, eds., 2011).

2 See for example Marletto and Vedral (2017), and Hansson and Francois, (2017).

gravity led to unusual forms of funding that would not otherwise have manifested. This funding was just enough to raise the study of gravity high enough to secure funding through more standard channels.

For example, Roger Babson, a wealthy financier with a Newton fetish, fully believed in such fantastic gravitational possibilities, motivated partially by his viewing gravity as responsible for the death by drowning of two of his relatives and in part by his friend Thomas Edison's own ideas on the subject (which seem to have been inspired by H. G. Wells' fictional work). Babson was persuaded by Edison to found an institute focused on gravity: the Gravity Research Foundation. While not pursuing research 'in house,' it would aid other researchers in their efforts, with one condition: such efforts must focus on anti-gravity. In addition to amassing the most complete collection of existing documents on gravity, the main contribution was to establish an essay competition — which still exists and receives entries from the finest physicists, including Stephen Hawking and several Nobel laureates.

This competition marks the inauspicious origins of the Chapel Hill conference. Given the lucrative $1000 prize money, Bryce DeWitt, then a young and frustrated physicist forced, by the lack of interest in gravity, to pursue it only as a hobby, decided to enter, writing his essay ("New Directions in the Theory of Gravitation") in an evening.[3] The essay satisfied the foundation's condition that anti-gravity be mentioned only by debunking the whole idea from the perspective of general relativity: there can be no anti-gravity because there aren't positive and negative charges as in electromagnetism. The whole project was, DeWitt claimed "a waste of time."

However, DeWitt dangled a carrot in front of the gravity research foundation: while general relativity might be an anti-gravitational dead-end, *quantum gravity* (his chosen field) might lead to extensions that increased the physical possibilities. Given such tantalizing claims from genuine experts, one can hardly be surprised that less knowledgeable folk might look forward to the day when anti-gravity becomes a reality. Knowledge was too incomplete at that stage and the reason for this, says DeWitt, is that there simply was no funding or support for gravity researchers: progress demands "external stimuli". That caught the attention of the foundation's vice-president (and the essay competition's overseer) George Rideout. Rideout was well-connected to a range of people that might offer up support in search for their holy grail: anti-gravity. This including those in industry and also those with military links, keen to militarize gravity as had occurred with atomic power. Rideout sent DeWitt's paper to several of these pointing out the request for support.

Hence, the poor state of knowledge contributing to the funding of study of general relativity and gravity, thereby providing a springboard from which to propel itself into an area where it received the more orthodox funding and support many other areas of physics were receiving. Respectable physicists had their own grails to search for at the time, including curing some of the problems with elementary particle phys-

3 Interview of Bryce DeWitt and Cecile DeWitt-Morette by Kenneth W. Ford on 1995 February 28, Niels Bohr Library & Archives, American Institute of Physics: https://www.aip.org/history-programs/niels-bohr-library/oral-histories/23199

ics, then facing its own difficulties. It was further hoped that gravity might offer up some clues and that the two might assist one another. The idea of progress through the mingling of gravity and particle physics was further bolstered by the subsequent year's winning entry, by two postdocs at the Institute for Advanced Study, Dick Arnowitt and Stanley Deser (both students of Julian Schwinger, at Harvard, like DeWitt was). However, their paper was a hoax: they hadn't expected to win, and their supervisor, Robert Oppenheimer, was not impressed. Less knowledgeable folk were impressed, especially by the idea expressed in the paper that gravity could be converted into nuclear energy. This hoax paper would attract the attention of military and industrial funding sources, as well as others on George Rideout's radar. Combined with DeWitt's call for action, it provided perfect conditions.

One of these was Agnew Bahnson, owner of a North Carolinian air conditioning manufacturing company and an amateur engineer with an interest in gravity. He was also a pilot and, later, author of a science fiction novel, *The Stars are too High* (New York: Bantam, 1959), describing how a group of brash engineers discover how to harness the power of gravity to build a flying saucer with which they dominate the world! Bahnson genuinely wanted to bring his dream to reality. He approached DeWitt with his vision, albeit tamed with an offer of a university affiliation, with his alma mater the University of North Carolina. DeWitt ignored it, reckoning Bahnson as just another of gravity's many cranks. However, Bahnson was close friends with head of physics at the University of North Carolina, who was himself close friends with the influential physicist John Wheeler, himself recently converted to the study of gravitation (see Rickles, forthcoming B). Wheeler intervened, suggesting DeWitt give serious consideration to the offer, especially in the light of the serious lack of funding in he field of gravitational physics, as DeWitt himself admitted in his competition essay. Bahnson contacted DeWitt again, with lucrative terms including no administrative or teaching duties, and this time DeWitt bit. The result was an unlikely yet enormously fruitful partnership between an enthusiastic but untrained heir of an engineering plant and arguably the most formalistic, number crunching quantum gravity theorist around, that would transform the face of gravitational physics. Bahnson's support led to the creation of the first institute devoted to the study of gravitation (The Institute for Field Physics) whose inaugural conference is without a doubt the most important in the history of gravitational physics. More importantly, it established new research networks and expanded the range of funding available to those working in the field.

Institute for Field Physics, Inc.

The Institute for Field Physics was officially incorporated on September 7th, 1955. With its stated aim to become *the* international centre for activity in gravitational physics. A fairly large part of the early phases of the institute was shrewdly devoted to distancing itself from the more fanciful side of gravity — especially the kinds of anti-gravity interests pursued by Bahnson himself. This ultimately resulted in a "protection clause" that would accompany any publicity related to the institute pointing out that any work carried out there has nothing to do with anti-gravity and is based on the Newton-Einstein analysis. In fact, Bahnson continued

to pursue his dream of anti-gravity (based on the idea of "electrogravitics:" achieving lift through strong electromagnetic fields) with a collaborator, T. T. Brown, while continuing to bankroll the Institute for Field Physics, with its firmly expressed dismissal of such research. He would often rope in DeWitt himself, as well as other notable physicists such as Edward Teller, to assess his experimental work, only to be disheartened by their reactions each time.

Despite his unscientific leanings, Bahnson was an incredibly active fundraiser, and kept donors fully informed of the institute's activities through regular 'memoranda' (a wonderful resource for historians). His connections extended into aviation, computing, and the military, and he was able to pull in founders memberships from a great many sources, including IBM (which also provided computing time for some of the first gravitational simulations), General Dynamics, Glenn Martin, Sikorsky Helicopter, and more. The DeWitts (Bryce and his mathematical physicist wife Cecile) joined the fund raising efforts, securing substantial support from the NSF, the Air Force, the Navy, and beyond. As mentioned, it seems fairly clear that some idea that there might be practical applications motivated much of this funding. Coming on the back of the atomic and hydrogen bombs, the power of physics must have been somewhat humbling for the military agencies.

The Chapel Hill Conference

Support was primarily requested for the conference, which was one of the central aims of the institute, to set the agenda for future research. The first mention of the conference was in November 1955, shortly after incorporation. Originally proposed for June 1956, this date would be taken up by an earlier meeting at Bahnson's summer house in Roaring Gap, with a few select figures, including potential funders and media people — Freeman Dyson and George Rideout (of the Gravity Research Foundation) were also present.

The initial list of invitee suggestions included various notable physicists that didn't make it to the final event, including Wolfgang Pauli, Niels Bohr, and Rudolph Peierls. A later list included Vladimir Fock, Kurt Godel and George Gamov, also absent from the final event. Still, Richard Feynman, Peter Bergmann, Freeman Dyson, John Wheeler, Leon Rosenfeld (after some Cold War complications were dealt with), and others made it. In fact, 11 nations were represented. There were in fact Cold War complications with several of the speakers from behind the Iron Curtain at the time. It was also at this conference that plans for a series of future general relativity and gravitation conferences was made, by Andre Lichnerowicz and others. This led to an international community of gravity researchers, so crucial for the development of the field (see Lalli, 2017, for an excellent recent account of the creation of the community). Without the bizarre, serendipitous confluence of ignorance about gravity, wealthy gravity aficionados, post-war scientific conditions (established by the creation of the atom bomb), and desperate gravity experts in search of funds, it is clear that gravitational research (LIGO very much included[4]) would have been set back by decades.

4 The first firm establishment of the reality of gravitational radiation along with ideas for their detection came directly from the Institute of Field Physics' conference.

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The art of finding and discovering fossils: a personal perspective

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Abstract

Palaeontology, the study of fossils, is an enjoyable activity: one that many from the public rarely see in action. For palaeontologists, *finding* a fossil is not the same as *discovering* a fossil. Anyone can find a fossil by being simply the first person to unearth, pick up and recognizing something of interest. A discovery, however, comes when that fossil is compared to other known specimens, described, identified as an existing species, or named as a new one. Only palaeontologists compare, describe and name fossils something they spend a great deal of time doing. Surprisingly, finding fossils is only a small part of palaeontology and is something palaeontologists rarely do. Discovery is the true joy of palaeontology. The authors share their own personal experiences of how they have found and discovered fossils, as well as unveiling how that process works. Readers will be surprised how exhilarating taxonomy really is once you gain a glimpse into the mind of the palaeontologist.

Finding Fossils

Here's a surprise: palaeontologists rarely find fossils. We do try. The palaeontologist has a hawkeye for detail, yet lacks the natural instinct to look down and randomly pick up natural curios. That task is often left to the millions, no, billions of people across the globe who have started their own collections, be it a pile of rocks on the verandah or something found or bought while on holiday and displayed proudly in the trophy cabinet. Sometimes collectors get curious and want a name and story to these natural curios. That's where we the palaeontologists come in. Often a member of the public walks into a university department or natural history museum (or more recently, sends a carefully worded email with photos) and asks for an expert opinion. It is people like us that identify and describe these fossils for them. Without these citizen scientists, many famous fossils and fossils sites would be unknown, and without palaeontologists ground-breaking discoveries would simply sit on someone's shelf collecting dust.

Collecting fossils at new sites is a palaeontologist's dream, and we do plan meticulous expeditions to areas where (according to the geology and palaeoenvironments) fossils *should* occur. Normally, a short reconnaissance trip is necessary, just to make sure that the site will yield new discoveries. Such trips are taken with caution, as expeditions are costly and funders want written guar-

antees that the sites are fossil-laden with new finds before any funds are transferred. Even the best guesses may lead nowhere: a fossil in the hand is worth more than any palaeontologist's prediction. Finding fossils is simply the first stage of discovering new species. The trilobite or ammonite you've found may actually be a well-known species from which specimens have been collected many times before, or it might be something never professionally described before. In order for it to be *discovered*, you need a palaeontologist who will examine the characteristics, compare the specimen to existing fossils, and, having determined the differences, give it a new name. There is an art to finding and discovering fossils, something that we wish to share with you through our own experiences. Between us, Malte and Patrick, we have discovered and named 6 new genera and 35 new species, but we've only collected a few of them ourselves. How, then, are fossils found?

Fossils are found in many different ways. For instance, Malte worked at a site in western New South Wales containing Devonian (395-million-years-old) shallow marine fauna. The locality was known to a station owner who had found it during the construction of a tank for his livestock. The tank sat directly over the fossil fauna in the Biddaburra Formation, a hodgepodge of rocks, mostly lithic-quartz sandstone interbedded with siltstone, mudstone and fine sandstone. The fossil fauna contains corals, brachiopods (they have hard shells on the upper and lower surfaces), some molluscs and, most excitingly of all, trilobites. Thankfully, the landowner was a former teacher at the local high school and had shown the fossils to a friend of Malte's. That newly found fauna became a Masters project, and later a publication, which included several discoveries of new species of trilobite (Ebach and Edgecombe 1999; Ebach 2002). In fact, there are still more discoveries to be made, as Malte only surveyed part of the site, much of which is buried under metres of alluvial clay. During his research Malte discovered that in the 1960s the New South Wales Geological Survey had visited the very same site and had recorded the same fossils from this formation. These fossils were held in the Survey's collections in Orange, which were later transferred to the Australian Museum, and a typed report with a list of the found fossils was forgotten in a filing cabinet. If the landowner had not rediscovered these fossils, they would have remained unknown to science.

Other discoveries come as the result of dedicated groups of amateur fossil hunters and enthusiasts, for example, "The Fossil Club of Australia." On one of their more recent trips, approximately two years ago, Patrick had the good fortune to be involved in uncovering a plethora of new species of Late Ordovician (450-million-year-old) trilobites. This happened at a highly unlikely place: a garbage tip near the town of Gunningbland (close to Parkes and Forbes) in western New South Wales. The site itself could be described as an eyesore: piles of dull grey-green to yellow boulders skirting an 80-metre-long trench, full of the obligatory old wedding dresses and discarded food scraps. Yet, the innocuous-looking rocks at the site belonged to the extremely old geological unit known as the Gunningbland Formation. This is a series of limestones and shales laid down as deep marine deposits at the foot of a now-extinct underwater volcano. The entire area had been mapped by government geologists in 2001, but they

had missed this particular fossil site as it was buried under soil at the time. The site was only discovered later by the Fossil Club members (and other enthusiasts) after the local council excavated a trench. The site contains a diverse list of trilobite species which were already well described from other areas nearby, including *Amphilichas shergoldi*, *Cromus* cf. *optimus*, *Eastonillaenus goonumblaensis*, *Eokosovopeltis currajongensis*, *Erratencrinurus* (*Prophysemataspis*) sp., *Parkesolithus* sp., *Remopleurides* cf. *exallos*, *Sinocybele thomasi* and *Sphaerexochus* sp. However, two of the Fossil Club members recognized several undescribed forms, which they couldn't place taxonomically. On inspection, Patrick and other colleagues recognized that one needed to be placed in a new genus, and another into a new species, both then recorded in Holloway *et al.* (2020). The first, *Prophalaron jonsei*, is a highly unusual trilobite resembling members of a subfamily called the reedocalymeninae. However, it lacked several key characteristics of the group, and instead is likely an excellent example of the phenomenon called "convergent evolution." The second, *Dicranurus webbyi*, was a totally unexpected find as the family (the odontopleurids) to which it belongs was previously unknown from rocks this of this age in Australia. Hence, it was only through careful fieldwork, observations, and comparisons of their fossils that these enthusiasts were able to bring these specimens to specialist attention. Without their assistance, it is highly likely these specimens would have never been found.

Sometimes, palaeontologists also discover fossils themselves, but not necessarily while they are at work. Whilst on a driving holiday in Gunns Plains in northern Tasmania, Malte answered the call of nature only to discover trilobites embedded in a fine muddy layer at the side of the road within the Ordovician Gordon Group. Usually trilobites are preserved in limestones during secondary mineralisation of the rock. Silica solution that moves through the limestone during rock formation binds to the trilobite carapaces, meaning that they become harder than the surrounding limestone. Once immersed in 20% acetic acid, the limestone dissolves, allowing the carapaces to fall out. These siliceous trilobites are beautifully preserved in three dimensions and display characteristics that may not necessarily be found in trilobites encased in mudstone and other clastic rock. However, here in Gunn's Plains the limestone had a muddy layer through it, possibly due to deep underwater landslides known as slumps. No palaeontologist would think of looking in this mudstone layer, simply because it contains no silicious material, and the chances that the rock would contain a rich fossil assemblage are thought to be low. It just so happened at the time that Malte's Masters supervisor Greg Edgecombe was working on similar fossils preserved in mudstone from a location 80 km away in Moles Creek. Regardless, the species were discovered by Edgecombe et al. (1999) and only a specimen was found by Malte. It wasn't until many years later that Patrick looked through the Australian Museum's collection and found the specimen Malte had donated from the site. It appeared to be missing from Edgecombe et al. (1999), as there were no mentions of this species despite it being relatively large and obvious. That single trilobite was the only one Malte ever found, and, thanks to Patrick's examination of the Museum's collection, was then discovered by Malte and Patrick). We named it *Gravicalymene bakeri*, after Tom

Figure 1. *Gravicalymene bakeri*, named after Tom Baker, the fourth Doctor Who (Photo credit: Patrick Smith).

Baker who played the fourth Doctor Who (Smith and Ebach 2020; Figure 1).

Occasionally palaeontologists do find new species lurking in existing collections, often mislabelled or misidentified. The eminent crustacean systematist Shane Ahyong once asked Malte how many mantis shrimp (stomatopod) fossils there were in Australia. There were none known. After some persuasion Malte patiently showed Shane the fossil crustacean collection at the Australian Museum, sifting carefully through each drawer. The last drawer produced a misidentified and mislabeled fossil mantis shrimp collected in 1916 from Brisbane River in Queensland. Yes, indeed, there were mantis shrimp sub-fossils in Australia. It was a sub-fossil of an already known and living species named *Harpiosquilla harpax*, possibly only 10,000 years old. Australia's first known mantis shrimp sub-fossil, it was reported as a Palaeontological Note in Ahyong and Ebach (1999).

Of course, not all geoscientists are palaeontologists and frequently people working in a different discipline will find fossils without realising their true significance. This is particularly the case for geoscientist looking at geological cores (Figure 2). Since the coring process often takes such a small sample of material from a single bedding plain (generally a resulting in a long cylinder less than the width of a single beer coaster), it's often assumed there won't be any useful fossils found. However, during his PhD studies Patrick found this assumption does not always hold true. Combing through 30-year-old records for the Hermannsburg 41 core, Patrick found a page reporting a layer from the Tempe Formation

Figure 2. Tempe Vale 1 drill core from the Northern Territory containing hundreds of Ordovician trilobites (Photo credit: Patrick Smith).

containing "fine fossil fragments." Piquing his curiosity, as the rocks in this units were relatively unstudied, Patrick visited Geoscience Australia where the core is now stored. Splitting some of these layers revealed over 20 near-complete head and tail shields of a new species of trilobite, named *Gunnia fava*, described in Smith *et al.* (2015, Figure 3). Alongside this trilobite were also brachiopods. These turned out to be species known only from the latest part of the Early Cambrian Period (510-million-year-old), thus enabling a precise date to be given to this geological unit. A precise age for a geological unit is important, as it allows for detailed correlated to be made with other nearby geological formations. Hence, despite these fossil having been "found" 30 years prior, it was only when they were "discovered" that this useful geoscientific information be ascertained. How, then, do palaeontologists "discover" fossils?

Discovering fossils

Once found and collected, fossils are brought back to the Museum or University for preparation. Silicified or phosphatic specimens are steeped in acetic acid for a month or two and monitored weekly. Specimens in clastic rock (composed of fragments of pre-existing minerals and rocks) are prepared by literately cutting them down to a particular size and shape. Often, larger pieces are broken up in the hope that the rock may produce more finds. A diamond-bladed circular saw is used to cut the rocks into the right size and shape in order for it to be stored within a collection. Vibro-tools and Dremel drills are used to clear any rock obscuring the fossil specimen and to remove any protruding rock that might get in the way of photography.

Photographing specimens is important, as it is a visual record of the specimen and its characteristics, namely the parts

Figure 3. An Ordovician aged trilobite pygidium from the Tempe Vale 1 drill core from the Northern Territory (Photo credit: Patrick Smith).

that we use to describe the fossil. In order to get the best contrast, most specimens and the surrounding rock are painted black. These specimens are then coated in either magnesium oxide or ammonium chloride via a process known as sublimation, therefore accentuating the highlights and down-playing the low points (Figures 4 and 5). Some characters that are barely visible under the microscope visually leap out at you once dusted. Siliceous fossils, on the other hand, are perfect in every sense and are sometimes photographed as they are on a black background. Once prepared, the fossils are photographed in black and white to avoid colour giving the false impression of depth. The photographs are assembled into plates and captioned. Photographing and creating plates is a process that has improved greatly since Malte started fossilising. Now the photography and plate assembly are done digitally. No more mucking about with glue, transferable text and darkrooms.

The final plate is the start of the discovery process (Figure 6). Yes, we have *found* fossils that we *suspect* are new. But the real fun, namely the science of discovery, begins once we closely observe and compare the specimens in a process that is off limits to the public and to historians and philosophers of science. Sure, you can sit next to a palaeontologist, or any comparative biologist, and watch them go about their business of observing and comparing, but much of what goes on occurs in the mind's eye of the taxonomist. In other words, what may look to the casual observer of someone sitting there looking down a microscope, is in fact someone having an exhilarating experience, one that is impossible to share with a passive observer.

Figure 4. An example of a fossil specimen that has not been altered in any way. *Prophalaron jonsei* cranidium (head shield) from the Gunningbland Formation. A newly discovered genus initially found by members of the Fossil Club of Australia (Photo credit: Patrick Smith).

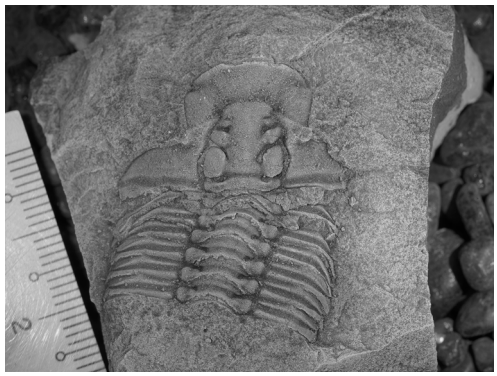

Figure 5. An example of a prepared fossil specimen that has been painted black and dusted with magnesium oxide. Near complete *Prophalaron jonsei* from the Gunningbland Formation. A newly discovered genus initially found by members of the Fossil Club of Australia (Photo credit: Patrick Smith).

It would be difficult to describe exactly what goes on when we observe and compare. You too, dear reader, do the same when you observe and compare the natural world or even the world of man-made artefacts. The taxonomist is simply trained to do this at a higher level, to see characteristics that many people have pondered over for centuries. One or two significant characteristics are enough to justify a new species. In other cases, one characteristic is quite sufficient to justify a genus or a family. Let us consider, for a moment, a collector of man-made objects, such as Faberge eggs or watches. In fact look no further than an episode of *Antiques Roadshow* and the sheer excitement that many of the experts exhibit when they are confronted with a rare watch or silver creamer. The expert seems to have all the fun as they carefully point out hallmarks in silver or missing bezels in Rolex watches. Most impressive is when people show up with plain-looking cups and saucers only to be told that these are Meissen porcelain and made in a factory near Dresden hundreds of years ago. What these experts look for are characteristics that are unique to the object and other characteristics that they share with other objects. Simply put, *Antiques Roadshow* is more about classification (discovery) than it is about estimating the value of man-made objects.

Now imagine that same enthusiasm for natural objects, namely for organisms and their parts that many people rarely see. This is the world of taxonomy and comparative biology. In this world we need to make sense of what is out there in the same way that astronomers make sense of the different types of stars and galaxies, or the way quantum physicists make sense of new quantum particles. All accept that there is a natural order and that discovering that order is essential to being able to propose new theories about the universe. For taxonomists, a major goal is to discover whether their taxonomic groups are part of that natural order.

Consider mammals: they are described as vertebrates that have hair and mammary glands. These characteristics are enough to

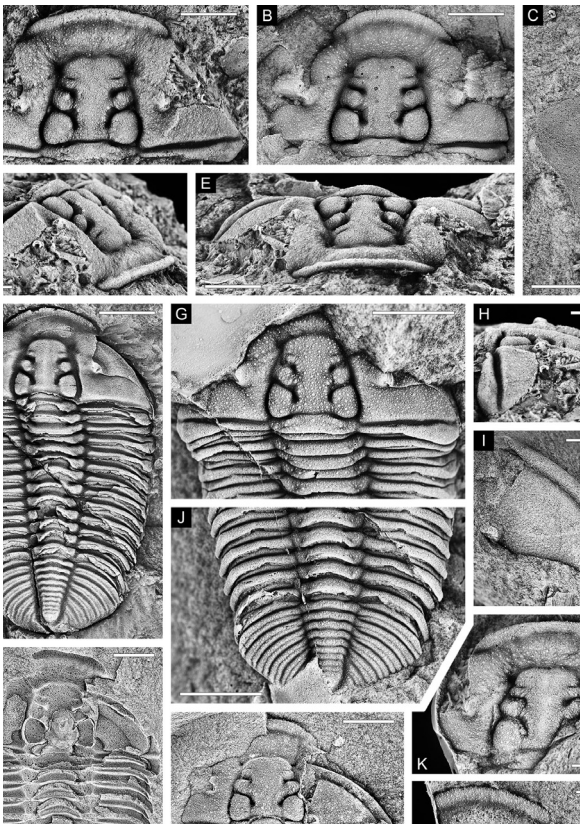

Figure 6. A photographic plate of *Prophalaron jonsei* from the Gunningbland Formation (Photo credit: David Holloway).

classify a mammal. Yet mammals are an easy group to identify. Other groups are harder to identify based on characteristics because they were insufficiently described and named. Consider the fishes. No one characteristic defines the fishes. Reptiles and birds have scales and lay eggs. So do fish. There are many such groups and they exist because someone grouped them based on a name and a written description. These groups are what revisionary taxonomists work on, because they need to be revised (including reptiles and dinosaurs). Describing, identifying and naming new species is only one aspect of taxonomy. Revisionary taxonomy is unfortunately almost entirely left out of many commentaries of taxonomy.

Regardless, let's get back to the matter in hand: discovering new characteristics. Once found, the taxonomist needs to compare a find to other specimens, that is the defining characteristics of other species, and ask "Is this specimen something new or is it part of something known?" Do we have enough evidence to propose that it is a new species? If we do, we create a *Diagnosis*, a concise description of the characteristics that make it new. This is then followed by a *Description* or commentary, which discusses how it differs from other named species from the same genus.

Other data will also need to be recorded, such as the name, the etymology of the name, the age, the geological formation it occurs in, and which specimens are the types and paratypes. Types are essential, as they represent physical manifestations for a given species name. Also important are the specimen numbers, equally essential as they identify the specimens assigned as types and paratypes. If another taxonomist wishes to see the type of any new species, they need to go into the designated museum collection and find the specimen with that number. This all sounds like a lot of work. But believe us when we tell you this is the most fun part of palaeontology. The sheer excitement of finding a new characteristic may seem trivial to a many, but it heralds a landmark in a taxonomist's career — you have discovered something that no one has ever seen or noticed, something that has been hidden away by nature for millions of years — a true scientific discovery! However, many outside the field find the discovery of species not very ground-breaking. Let us compare that to astronomy. There are a finite number of trilobites, many still waiting to be found, either in a rocky outcrop or in a museum collection. Yet, there are seemingly an infinite number or stars and planets, billion upon billions of them, and every time one is discovered it makes it into the news. The odd trilobite makes it into the news, but not fossils such as brachiopods or corals. The reason is quite simple: in order to understand what these fossils are and what characteristics make them unique rarely captures the public's imagination. In stark contrast, in astronomy the discovery of a habitable Earth-like planet 200 light years away would prick up the ears of many a reader.

Naming fossils

Another similarity between astronomy and taxonomy is nomenclature, that is, the rules governing the naming of names. Each group of organisms (plants, animals, bacteria etc.) has its own nomenclatural code. The nomenclatural codes specify that each named organism has a binomial name and is linked to one or more specimens (such as the type and paratype we mentioned above). Nomenclature gets tricky once we discover that two names, proposed by different people at different times, represent the same fossil. This is called a synonymy, and a revision is necessary with the more recent proposed name becoming junior and being replaced by the oldest name. Nomenclature is quite technical, but naming species can be fun.

Astronomers recently named a whole star system, TRAPPIST-1, after Trappist beers (Gillion et al. 2017). Palaeontologists have also named species and genera after people both famous and infamous. The trilobite genus *Arcticalymene* contains *A. rotteni*, named after Johnny Rotten, lead singer of the Sex Pistols (Edgecombe and Adrian 1997). The same palaeontologists (Adrain and Edgecombe 1995) named another genus *Aegrotocatellus*, Latin for "sick puppy" (for added effect they included the species *A. jaggeri*, named after Mick Jagger of Rolling Stones fame). The fun taxonomists have discovering and naming species is evidently not the rather dry and verbose technical language of taxonomic treatments. Every now and then you can see the enjoyment in the names, not unlike the medieval scribes who drew scandalous figures in the borders of religious parchments.

Conclusion

Taxonomy is fun, but it is also a lot of work and commitment. What we have described above can take weeks, months and even years to do. Taxonomic revisions take even longer. Learning and understanding species characteristics takes years to learn. An average postgraduate student would need a minimum of four years, that is, the span of their entire PhD, to familiarise themselves with a subgroup of organisms. Four years does not maketh an expert, and it certainly does not mean you have seen all the characteristics known or to be discovered: that would take several lifetimes. There are people out there who have spent a lifetime working on their organisms, and others, such as us, who have recently begun (Patrick) and who continue to do so (Malte).

The art of finding fossils starts with you, and the discovery of new characters with the taxonomist. Without the public finding fossils and making palaeontologists aware of them, there would be a dearth of scientific discovery. What perhaps is less well understood and less talked about is the excitement and joy comparative biology brings to the taxonomist. The thrill of wandering through a collection or the delight of seeing new a structure in a well-known fossil. This is only possible with years of dedication and a passion for discovery. These are just a few of the experiences we have had. There are many more to come.

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Thesis abstract

Effects of filler and matrix materials on the properties of metal syntactic foams

Kadhim Al-Sahlani

Abstract of a thesis for a Doctorate of Philosophy (Mechanical Engineering) submitted to the University of Newcastle, Australia

Metal matrix syntactic foams (MSFs) are lightweight materials manufactured by embedding hollow or porous lightweight particles in a metal matrix. Recently considerable attention on developed MSFs has been established because of their potential to replace a wide range of ceramics, metallic and foams polymeric because of their unique properties.

To tailor MSFs, there are many parameters to control. Most important of these are the filler and matrix materials properties, which directly affect the mechanical and structural properties of MSF. So far, there has been limited application of such foams because of the low cost-efficiency, relatively high density and unsteady deformation behaviours of MSFs.

This study aimed to investigate various combinations of inexpensive fill and matrix materials to manufacture low-cost MSF with a high strength-to-weight ratio using simple manufacturing processes. Various low-cost, lightweight particles were analysed and classified according to their production. Inexpensive expanded perlite (EP) has the lowest bulk density (0.18 g/cm^3) of particles used to produce low-price, low-density MSFs. Expanded glass (EG) particles (with internal porosity ≥84%) are another innovative and cost-effective filler. EG has superior mechanical and physical characterisation, for example, low density (only 0.23 g/cm^3), spherical shape and reasonably high crushing strength, and particles are available in a wide size range (0.1–8.0 mm). EG is manufactured from recycled glass, which makes it a sustainable resource.

Counter-gravity, pressure-assisted infiltration was successfully used in the current research to manufacture novel EG-metal syntactic foams subsequently called EG-MSFs. One study addressed the particle morphology effect on the mechanical properties of foams using A356 alloy as a matrix. A novel method for controlling EG shrinkage was successfully created and used to produce novel inexpensive EG-MSFs with a range of densities: 1.05–1.17 g/cm^3. The same approach was employed to characterise the effect of particle size on the MSF properties. Three different EG particle sizes were embedded within an A356 alloy matrix to produce MSF samples. A further study was conducted to investigate the effect of thermal treatment and ductility of the matrix of MSFs at cryogenic temperatures. The alloys A356 and ZA27 were compared for their compressive properties under such conditions. The density of Al-EG foams was close to 1 g/cm^3, and a higher density of approximately 1.85 g/cm^3 was obtained for

zinc-EG foams. The mechanical behaviour of the MSFs was investigated and analysed by careful monitoring of the spread of the plastic deformation areas.

The particle strength and matrix ductility of MSFs was also investigated. To this end, pure aluminium (Al) and ZA27 were used to manufacture four groups of foams with embedded sodium chloride (NaCl) particles. In half of the samples, the NaCl particles were leached out. This allowed isolation of the particle strength effect while maintaining similar matrices.

Structural, microstructural and mechanical analyses of the manufactured foam samples were conducted for a comprehensive characterisation of the material. The stress-strain curves of all foams contained three distinct regions: an elastic region, a plateau region, and densification. Mechanical foam properties including 1% offset yield stress, energy absorption, plateau stress, unloading modulus, energy efficiency and plateau end strain were analysed following the ISO 13314 standard. The results identified promising materials for lightweight structural applications and energy absorption.

Finally, a comprehensive comparison of the current results with previously reported data was made, considering mechanical foam properties including yield stress, plateau stress, absorption energy capacity, absorption energy efficiency and plateau strain. Each of these mechanical properties was plotted to create an inclusive diagram comparing MSFs made from various fillers and matrices. The results of this investigation are likely to be valuable in regard to applications of MSF for weight saving and energy absorption. The compressive mechanical characterisation of MSFs is the principal object of this thesis. The outcomes of the current work therefore allow prediction of the mechanical properties of MSFs that undergo compressive loading in industrial applications. This study contributes to increasing the knowledge base regarding MSFs and will help material designers to tailor the properties of MSFs by controlling matrix and filler properties. This will enable the development of novel materials that are optimised for a given application.

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Thesis abstract

A robust multimodal biometric scheme for human recognition and authentication

Mozammel Chowdhury †

Abstract of a thesis for a Doctorate of Philosophy submitted to Charles Sturt University, Australia

Biometric recognition and authentication are crucial and gaining popularity in many security applications, including secure access control, human surveillance, suspicious activity recognition, border monitoring, preventing criminal acts, alarm monitoring and so on. Biometric recognition identifies a human identity based upon their physiological or behavioral characteristics, such as face, ear, fingerprint, palm print, iris, voice, gait and signature. Among these biometrics, the face and ear are considered as the most reliable traits due to their uniqueness and easy data acquisition. However, both face and ear recognition suffer from lack of accuracy and robustness for real-time applications. The performance of the face recognition process is significantly affected by variations in facial expressions, the use of cosmetics and eye glasses, the presence of facial hair, including beards, and aging. On the other hand, the reduced spatial resolution, uniform distribution of color and sometimes the presence of nearby hair and ear-rings make the ear very challenging for non-intrusive biometric applications. Therefore, fusion of face and ear data in an efficient way may be useful for mitigating these challenges. They are also good candidates for fusion due to their physical proximity. In recent years, multimodal biometric systems based on two or more biometric traits have been found to be extremely useful and exhibit robust performance over unimodal biometric systems. We therefore propose a multimodal biometric scheme by combining the local features of face and ear biometrics in a computationally efficient manner.

In this dissertation, we develop robust and efficient algorithms for face and ear recognition and, finally, the fusion of face and ear biometrics for human recognition and authentication. In this research, face recognition is accomplished by means of matching facial local features between the probe image (left or right face sequence) and the gallery face images within a database. For ear recognition, the system first detects and extracts the ear region from the facial image geometry. To detect the ear of the user from the facial images, we employ a fast technique based on the AdaBoost algorithm. Similar to the face recognition scheme, ear recognition is accomplished by matching the ear data (probe) of an individual to the previously enrolled (stored) ear data in a gallery database for verification and recognition of the person.

† Dr Chowdhury died in 2021. He received the Vice-Chancellor's Award as well as the Dean's Award for his outstanding thesis.

In this research, we present a method for fusing the face and ear biometrics at the match score level. At this level, we have the flexibility to fuse the match scores from various modalities upon their availability. Firstly, the match scores of each modality are calculated. Secondly, the scores are normalized and subsequently combined using a weighted sum technique. The final decision for recognition of a probe face or ear is done upon the fused match score. Once the person is identified, based on the fused features of face and ear modalities, authentication to a secure environment is granted. The experimental evaluation reported in this research demonstrates that fusion of these two (face and ear) biometrics results a significant improvement in recognition accuracy, compared to the accuracy achieved by using individual one. The unimodal and multimodal biometric approaches proposed in this dissertation using face and ear biometrics can be extended for recognition with other biometric traits. The dissertation is organized with a set of papers already published and submitted to journals or internationally refereed conferences.

Dr Mozammel Chowdhury died in 2021. His PhD supervisor was Professor M. D. Rafiqul Islam, who can be contacted at mislam@csu.edu.au.

URL: https://researchoutput.csu.edu.au/ws/portalfiles/portal/71248634/Chowdhury_M.M.H_Thesis.pdf

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Thesis abstract

Toddlers with cleft palate: enhancing communication through holistic child- and family-centred practice

Anna Cronin

Abstract of a thesis for a Doctorate of Philosophy submitted to Charles Sturt University, Australia

Cleft palate with or without cleft lip (CP±L) is one of the most common congenital conditions and impacts speech, language, feeding, middle ear function, appearance, and daily life. This thesis consists of two parts.

Part 1 includes analysis of interview data from the author's Churchill Fellowship visits with six international specialist speech-language pathologists (SLPs) in four countries. The International Classification of Functioning, Disability and Health (WHO, 2007) had utility in describing these specialist SLPs' practice.

Part 2 involves observation, interviews, and collection of artefacts from seven Australian toddlers with CP±L, 13 parents, and 12 significant others (e.g., educators, grandparents). Children's speech and language is analysed, and interviews reveal the impact of CP±L on the whole child, family strength and support, and family isolation and trauma.

The thesis is innovative, theoretically driven, and sequential in its approach to recommending a shift in the way SLPs approach practice. There are three main findings: (1) having CP±L affects many aspects of toddlers' lives, (2) children and families' voices should be privileged in co-creating the intervention journey in collaboration with professionals, and (3) non-specialist professionals need to understand the impact of CP±L and know how to support toddlers and families holistically.

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Thesis abstract

Judging the Church: legal systems and accountability for clerical sexual abuse of children

Meredith Edelman

Abstract of a thesis for a Doctorate of Philosophy submitted to Australian National University, Australia

This thesis considers lessons from different legal systems' approaches to holding Catholic dioceses accountable for child sexual abuse. Following a New Legal Realist approach, it provides an account of four legal systems, looking at how the theory, doctrine, procedure, and practicalities of different legal approaches shape legal systems' capacities to deliver justice. With a focus on legal systems relevant to the Diocese of Ballarat in Victoria, Australia, and the Diocese of Gallup in Arizona and New Mexico, in the United States, typologies of repressive, autonomous, and responsive law serve as frames to explore how the overall character of legal systems is shaped by their multiple aspects. This focus provides insight and context for why law matters, and points to why reform efforts that focus on changing doctrine alone may not bring the kinds of results likely to satisfy those seeking substantive justice.

Examining the multiple aspects of Catholic canon law and the common law of tort highlights how both fail to account for the realities of relationships between Church organisations and natural persons, as well as how both systems embed the interests of powerful institutions in fundamental theories underlying the systems' functions in society. The chapter on Catholic canon law considers contemporary views of canon law provisions that relate to child sexual abuse alongside the historical development of canon law, showing how, despite changes to doctrine, the underlying theories and purposes of canon law embed the interests of the Church in ways that render it fundamentally repressive. Connecting this study to Nonet and Selznick's original framing of common law systems as the prototypical autonomous law systems, the thesis demonstrates how tort law, despite significant doctrinal and procedural reforms aimed at allowing more claims arising out of child sexual abuse to go forward, remains a fundamentally autonomous system in both the United States and Australia, often prioritising form over substance and failing to account for the impacts of inequality and domination on the capacity of victims to seek justice.

The thesis then provides accounts of two other legal systems, identifying them both as quasi, but not fully, responsive. The chapter on Chapter 11 bankruptcy proceedings highlights lessons from cases filed by the Diocese of Gallup and similar dioceses in the United States to consider how a purposive approach to dispute resolution can empower victims by giving them credible leverage to negotiate for their own interests. The chapter considering the Australian Royal Commission into Institutional Responses to Child Sexual

Abuse's investigations into events in Ballarat concludes that an approach that reflects an informed and sophisticated understanding of victims combined with procedure intentionally designed to work against existing forces of inequality and domination can provide real vindication, even without the authority to directly impose consequences. The thesis argues that truly responsive legal systems require: (1) embedded knowledge of social realities in multiple aspects of law, (2) a purposive approach, (3) procedural flexibility, (4) the deliberate and effective inclusion of impacted stakeholders in legal processes, and (5) a normative agenda of countering domination and accounting for social disparities. In identifying both bankruptcy and the Royal Commission as quasi-responsive, having some but not all of these attributes, the thesis offers hope that more responsive legal systems are possible, even if piecemeal efforts to reform existing systems are unlikely to have the desired effects.

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Thesis abstract

Multimodal computed tomography: future applications in acute ischemic stroke

Carlos Garcia Esperon

Abstract of a thesis for a Doctorate of Philosophy (Medicine) submitted to the University of Newcastle, Australia

We live in exciting times for stroke medicine. Acute reperfusion stroke therapies have changed dramatically. What we could do 10 years ago has no comparison with what we can offer patients today. It is difficult to imagine that such rapid progress in the stroke field would ever happen.

Some of the old mantra such as 'time is brain' have been found to be only partially true. Time is still important — after vessel occlusion, neurons are dying! However, the pace at which neurons die is very different between patients. Therefore, using time from symptom onset to identify patients as candidates for treatment has become obsolete (one size does not fit all).

The stroke neurologist needs to be familiar with the new imaging modalities, computed tomography perfusion (CTP) being the most relevant. However, CTP is still 'the new kid on the block'; we know a lot about it, but there remain many grey areas about its use and its limitations.

I attempt in this PhD to expand the limits of what has been currently described about CTP in ischaemic stroke patients, taking two directions: current use and expandability from comprehensive stroke centres to rural hospitals, and new possible uses, focusing on the role of CTP in small subcortical lacunar strokes and a possible correlation between CTP and left ventricular cardiac function.

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Thesis abstract

The (re)Indigenisation of space: weaving narratives of resistance to embed *Nura* [Country] in design

Danièle Hromek

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Australia

Space, for Aboriginal peoples, is full of Country. Furthermore, space, place, land, ground, geography, geology, cartography, topography, site, location, landscape, terrain, environment are *held* by Country. Deploying Indigenous theoretical and methodological approaches, I investigate an Indigenous experience and comprehension of space. By reconsidering and contesting the notion of *terra nullius* — an "empty land" — the research considers how First Peoples occupy, use, narrate, sense, dream and contest their spaces.

Narratives and oral recordings are key to First Peoples' expressions of their lived experiences of both culture and colonial trauma. Trauma is embedded in First Peoples' lands and spaces via the invidious forces of invasion and colonisation, described here through select colonial archives and existing white historiography. Critiquing this historical narrative of colonisation, the research deploys instead Indigenous perspectives including lived experiences, oral histories, yarns, reflective practice and wider reading of Indigenous literature. These permit a focus on the (re)Indigenisation of space in order to investigate the question: "What is the presence and space of Country in contemporary Indigenous lives?" The thesis therefore offers a (re)interpretation of the relationship between First Peoples and the land that is based on connectivity and relationality, as opposed to colonial writings that have inferred, stated or demanded that First Peoples' relations with land were and are non-existent and even lost.

This research speaks through a Budawang/Yuin woman's worldview. It considers the importance of stories for holding knowledges and connecting to land, and examines the micro and macro connections between Country, people and making. First Peoples' cultural practices connect to Dreaming and Country. They hold memory of culture and offer a means of (re)connecting to heritage. My investigation brings narratives, remembrance and Country together in a cultural, spatial and performative practice of weaving, exploring spatial reclamation and restoration of Indigenous spatial values. It "names up" methods, linking them with narratives, considering how space can be (re)Indigenised. It rethinks and reframes the values that inform Aboriginal understandings of space through Indigenous spatial knowledges and narratives. By offering a reinterpretation and retranslation of Aboriginal methods of reclaiming space, it likewise reflects on the sustainability of Indigenous cultures from a spatial perspective.

As foundational research in the area of Indigenous space, this research has the capacity to impact policy and practice in

relation to the planning of spaces to ensure they are designed equitably, relationally and with a connection to Country.

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Thesis abstract

Essays in political economics

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Abstract of a thesis for a Doctorate of Philosophy submitted to UNSW Sydney, Australia

This thesis consists of three self-contained essays in political economics. A key theme common to the essays is that policymaking is largely a private affair, conducted behind closed doors. Politicians take many public actions: they endorse policy, introduce legislation, cast votes, and give speeches. However, rarely do these public acts alone determine policy and, in some cases, these acts are completely inconsequential. Instead, policy is determined by many actors, via informal negotiations and institutions, and often beyond the gaze of voters: legislators engage in backdoor deals, exchange favours, spend their political capital, and control the legislative agenda. Disentangling consequential and inconsequential publics act is key to the measurement of many intensely debated issues ranging from polarization and gridlock, to concerns of accountability, and more broadly the efficiency of political institutions. Understanding the nature and consequences of this tension is the focus of this thesis.

In the first essay "Feigning Politicians," I explore a model of politics where politicians publicly propose policies, and the adoption of a proposal is stochastic. Yet, politicians may privately exert *effort* toward their proposal's adoption: they can engage in backdoor deals, spend their political capital, or take particular care when drafting legislation. When the preferences of voters and politicians differ, politicians face limited accountability. Voters may observe that a proposal failed to be adopted but will be uncertain as to why: did the politician exert too little effort, or did the proposal fail despite the politician's every effort? This generates a perverse incentive for politicians to *feign support for policies that voters demand* whereby they publicly propose policies that voters demand but then privately exert little or no effort toward progressing such policies. They do this in the expectation — and hope — that their proposal will fail and knowing that, if it does fail, they will not be held entirely accountable. This essay complements the existing literature on accountability by showing that — in addition to pandering — politicians may feign support for policies that voters demand. The main empirical implication of my model is that, under certain conditions (such as a trade shock), politicians with a history of being less effective legislators will have an electoral advantage: they will feign more often and will be re-elected with higher probability. I empirically test and find suggestive evidence that supports these predictions in U.S. House elections using data on localized trade shocks from China and a measure of House members' legislative effectiveness.

In the second essay "Gridlock, Leverage, and Policy Bundling," I analyse a dynamic model of legislative bargaining where parties may engage in policy bundling and a forward-looking voter elects the agenda

setter. Policy bundling allows legislators to bundle diverse and unrelated proposals into a single bill and is specific to the U.S. Congress. The prevailing wisdom surrounding policy bundling is that it reduces gridlock by facilitating compromise between political parties. In this essay, I argue that this wisdom is incomplete. In a dynamic environment, policy bundling can generate a *leverage* incentive for parties to delay bipartisan policies and, as a result, can increase gridlock. The incentive to delay bipartisan policies arises because, if elected in the future, the delayed policy can be used as leverage in a policy bundle with a future policy that is divisive and otherwise would not pass. From the voter's perspective, I show that this leverage incentive creates inefficiently high levels of gridlock; however, if the voter did not lack commitment power, inefficient gridlock could be largely eradicated. My results have a number of empirical implications. First, I show that — because bipartisan policies may be gridlocked — roll call voting records may overstate the true (unobserved) level of polarization between parties. Second, this overstatement is more likely during periods of economic or political stability.

In the final co-authored essay "Political Capital," we study an informal notion of power — called *political capital* — that appears in organizations and distinguishes leaders from rank-and-file organization members. We develop a two-period model of organizational decision making where the leader of the organization has a stock of political capital that she can choose to spend to influence decisions. The leader's stock of political capital evolves dynamically and may increase or decrease depending on the leader's decision to spend her capital and if her decision to spend was correct ex-post. This presents the leader with an intertemporal choice problem: spending political capital today will improve today's decision (in expectation) but may result in less political capital — and hence less influence over organization decisions — in the future. We characterize the optimal use of political capital by the leader, the evolution of political capital over time, and identify different leadership styles that can emerge. We also explore the implications of our results for institutional design and organizational culture.

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Thesis abstract

Information and noise in stock markets: evidence on the determinants and effects using new empirical measures

Thanh Huong Nguyen

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Australia

The thesis comprises four studies relating to stock market efficiency, its measurement, its effects, and its determinants.

The first study proposes novel empirical measures that separate different types of information and noise as drivers of stock return variance. Specifically, the new methods disentangle four components: market-wide information, private firm-specific information revealed through trading, firm-specific information revealed through public sources, and noise. Overall, in US stocks, 31% of the return variance is attributable to noise, 37% to public firm-specific information, 24% to private firm-specific information, and 8% to market-wide information. Since the mid-1990s, there has been a dramatic decline in noise and an increase in firm-specific information, consistent with increasing market efficiency.

The second study examines how noise affects inference in existing empirical measures, such as idiosyncratic volatility (one minus the R^2 of a market model) and decompositions of cash flow and discount rate news. This thesis finds that after accounting for noise, cash flow information plays a considerably larger role in driving individual stock returns than previously believed and discount rate information plays a smaller role. Furthermore, the decrease in idiosyncratic volatility (increase of market model R^2) since 1997 is the result of a decrease in noise during this recent period. The evidence indicates that the market has become more efficient in the past two decades, contrary to what is implied by standard interpretations of R^2 as an inverse measure of efficiency.

In the third study, this thesis examines the real effects of stock market efficiency by analysing the relation between noise in stock prices and the efficiency of corporate investment and capital allocation at both the firm and industry levels. The analysis uses a long time-series of data from 1963, as well as a cross-section of 42 countries. Consistent with the notion that noise decreases investment efficiency, this research finds strong evidence that noise is negatively associated with the sensitivity of corporate investment to firms' growth opportunities and the sensitivity of industry-level investment to value added. These findings highlight the important real effects of secondary market quality in determining firms' investment behaviour and the efficiency with which capital is allocated.

The fourth essay provides evidence on how individual investors' behaviour, in particular investors' gambling activity in stocks, affects stock market efficiency. We develop novel measures of the amount of gambling in stock markets based on the turnover differences between lottery stocks and non-lot-

tery stocks, and validate the measure. Using a global sample, we examine how much gambling occurs in different countries, what determines these levels, and how the gambling that occurs on stock markets affects a country's capital markets. We find that culture and economic factors are all significant drivers of a country's gambling propensity in both traditional venues and stock markets. Interestingly, we find a substitution effect — restrictions/bans on traditional gambling lead to a spillover of gambling onto stock market(s). Exploiting regulation of traditional gambling as an instrument, we find that increased gambling on stock markets makes them more liquid and efficient. Our findings have implications for using gambling regulation as a policy instrument to affect financial market quality.

Collectively, these studies contribute to our understanding of market efficiency, how to measure it, what drives its variation through time and across stocks, and how it affects resource allocation across companies and sectors.

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Journal & Proceedings of the Royal Society of New South Wales, vol. 154, part 2, 2021, p. 253. ISSN 0035-9173/21/020253-01

Thesis abstract

Conservation biological control in brassica crops using Australian native plants

Sunita Pandey

Abstract of a thesis for a Doctorate of Philosophy submitted to Charles Sturt University, Australia

The practice of planting companion plants to enhance the efficacy of natural enemies as a pest management tool is a form of habitat management. This has an important role in conservation biological control. In such a context, this thesis investigates the use of Australian native plants in habitat management to support conservation biological control in brassica crop systems in temperate Australia. The research found that Australian native plants benefited natural enemies by increasing their lifespan and population in brassica crops adjacent to native habitats. Native plants that provide resources to natural enemies also enhanced complementary ecosystem services such as enhancement of pollinators and wild butterflies. This shows scope for farmers to take advantage of potentially multiple ecosystem services by incorporating native flowering plants into farming systems. This work highlights the importance of plant selection and the risk of trade-offs among ecosystem services. This research also highlights the need for reductions in pesticide use to assist conservation biological control.

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Thesis abstract

Zero-shot learning: recognition, tagging, and detection of novel concepts

Shafin Rahman

Abstract of a thesis for a Doctorate of Philosophy submitted to Australian National University, Australia

Recent advancements in deep neural networks have performed favorably well on the supervised object recognition task. Towards an ultimate automated visual recognition system, we identify three key shortcomings of the existing supervised learning approaches. First, the dependency on a significantly large volume of manually annotated examples (e.g., ImageNet dataset with ~10 million images limits the scalability of deep networks. Secondly, once the model learning stage is complete, it is difficult to add new classes continually when new data becomes available. Lastly, such models lack the notion of human-like understanding, i.e., an object can be recognized by humans without having any visual examples and just by a semantic description of its distinctive characteristics.

In this thesis, we investigate the zero-shot learning (ZSL) framework to address these limitations. ZSL aims to perform reasoning about previously unseen objects without observing even a single instance of them. Such a learning paradigm requires no visual examples of novel objects, no re-training to add new classes and does not rely solely on visual information. Considering the relationship among the semantic description of previously seen examples, ZSL incorporates human wisdom to the visual understanding developed by a machine. In this work, we specifically address three critical bottlenecks in ZSL research which give rise to three ZSL problem settings: (a) unified zero-shot recognition (ZSR), (b) zero-shot tagging (ZST), and (c) zero-shot detection (ZSD) of novel concepts. Established ZSR methods are not flexible enough to adapt to one/few-shot learning (O/FSL) scenario where one/few labeled examples of unseen classes become available during the supervised learning stage. To provide a comprehensive and flexible solution, we present a novel 'unified' approach for ZSL and O/FSL based on class adapting principal direction (CAPD) that computes class-specific discriminative information by relating the semantic description of categories. The primary objective is to learn a metric in the semantic embedding space that minimizes intra-class distances and maximizes inter-class distances. In the real-life scenario, instead of a single object per image, a scene may contain multiple seen and unseen concepts together. To adopt this, we present the DeepoTag approach for zero-shot tagging (ZST) to assign multiple labels to an input. This method considers both global and local details to discover seen or unseen concepts from a given scene. We solve this problem by formulating a multiple instance learning (MIL) framework. Unlike traditional MIL solutions, our method runs end-to-

end without using offline object proposal generation methods. While most of the ZSL methods provide answers to unseen categories in simple tasks, e.g., single or multi-label classification and retrieval, we also focus on predicting both multi-class category-label and precise location of each instance in a given image. To this end, we introduce a new challenge for ZSL called zero-shot detection (ZSD) that simultaneously recognizes and localizes multiple novel concepts. Similar to traditional object detection, we present zero-shot version of double (Faster R-CNN) and single (RetinaNet) stage end-to-end object detectors. For both of the cases, we design associated loss functions that consider visual-semantic relationships to train the network. In addition to inductive learning approaches, we also propose the first transductive learning method for ZSD to reduce the domain-shift and model-bias against unseen classes convincingly. Our transductive approach follows a self-learning mechanism that uses a novel hybrid pseudo-labeling technique. Finally, we recommend training and testing protocols to evaluate ZSD based on large-scale ILSVRC-2017 and MSCOCO-2014 datasets. In summary, this thesis addresses three main ZSL tasks: recognition, tagging, and detection of novel concepts. It investigates different drawbacks of the current literature and establishes state-of-the-art solutions in each respective sub-task. In particular, the ZSD setting proposed in this thesis is highly challenging, and we hope our initial work will attract further efforts on this important and largely unsolved problem.

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Journal & Proceedings of the Royal Society of New South Wales, vol. 154, part 2, 2021, p. 256. ISSN 0035-9173/21/020256-01

Thesis abstract

Modelling cognitive performance in schizophrenia and across tasks

Laura Wall

Abstract of a thesis for a Doctorate of Philosophy (Psychology — Science) submitted to the University of Newcastle, Australia

This thesis comprises two distinct sections with different background, aims and implications, but which share the same methodology — analysis of three cognitive tasks with the Linear Ballistic Accumulator (LBA) model.

In the first section, I investigate the across task consistency of LBA parameter estimates to address an untested assumption that the estimates capture general, underlying cognitive processes, which are more than just task specific. I find that there is indeed consistency in the estimates across three similar but distinct tasks and therefore proceed to develop a novel approach which incorporates this shared information, providing more efficient and precise estimation. I fit the LBA to two tasks simultaneously by including a covariance matrix for two tasks into the hierarchical Bayesian estimation procedure. Despite the additional constraint this matrix imposes, the combined model adequately estimates both the individual and group parameters, as well as the estimates of across task covariance.

In the second half, I then use this new "combined modelling" approach to investigate cognitive deficits in schizophrenia and find that across the tasks there are some consistent differences between people with and without schizophrenia, such as poorer sensitivity, and some that are task and context specific, such as adjustments of caution.

Across both fields of cognitive modelling and cognition in schizophrenia, this new method of combined modelling of multiple tasks is a valuable addition as it allows more precise measurement with fewer data points.

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Thesis abstract

Fast and accurate estimation of angle-of-arrival in millimetre-wave large-scale hybrid arrays

Kai Wu

Abstract of a thesis for a Doctorate of Philosophy submitted to the University of Technology Sydney, Australia

Hybrid array is able to leverage array gains, transceiver sizes and costs for massive multiple-input-multiple-output (MIMO) systems in millimetre wave frequencies. Challenges arise from estimation of angle-of-arrival (AoA) in hybrid arrays, due to the array structure and the resultant estimation ambiguities and susceptibility to noises. In this thesis, we study the unambiguous and non-iterative AoA estimation in two types of hybrid arrays — Localized Hybrid Array of Phased SubArrays (LHA-PSAs) and Lens Antenna Arrays (LAAs). For each type, two AoA estimation approaches are proposed for narrowband and wideband, respectively. The main innovation of the approaches include:

- The deterministic sign rules and patterns in LHA-PSAs are unprecedentedly discovered, and exploited to eliminate the estimation ambiguities;
- The optimal trade-off between different error sources is achieved, minimising the wideband AoA estimation error in LHA-PSAs;
- A new wide beam synthesis method is developed for LAAs, which substantially improves the AoA estimation efficiency in LAAs;
- New spatial-frequency patterns are unveiled exploiting the spatial-wideband effect, leading to fast and accurate wideband AoA estimation in LAAs.

Performance analysis is provided for all the approaches with closed-form estimation (lower) bounds derived. Corroborated by simulations, our approaches are able to dramatically improve AoA estimation accuracy while reducing complexity and the number of training symbols, as compared to the state of the art. The estimation errors of our methods asymptotically approach the (lower) bounds.

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Royal Society of New South Wales 2021

Meetings 2021

Meetings held by the Society in Sydney, in Newcastle by the Hunter Branch, in Mittagong by the Southern Highlands Branch, and in western NSW by the Western NSW Branch.

Sydney Meetings

The program below lists monthly Ordinary General Meetings and the Annual Forum of the Royal Society and Four Academies. In addition to these events, there are three named lectures, associated with the Society's 2020 Awards: Clarke Lecture — Distinguished Professor Michelle Leishman (Macquarie University), Liversidge Lecture — Professor Richard Payne FRSN (University of Sydney), and Poggendorf Lecture — Professor Angela Moles FRSN (UNSW Sydney), together with another lecture in the Ideas@theHouse series, and the Society's contributions to Science Week 2021.

3 February

1290th Ordinary General Meeting and Open Lecture: 2020, Jak Kelly Award and RSNSW Scholarship Winner Presentations:

Controlling how electrons move in silicon at the atomic scale, *Mr Matthew Donnelly* — Jak Kelly Award Winner, PhD Student, Centre for Quantum Computation and Communication Technology, UNSW (Sydney).

3D Printing for Microfluidics (TBC), *Mr Sajad Razavi Bazaz* — RSNSW Scholarship Winner, PhD Student, School of Biomedical Engineering, University of Technology Sydney.

Molecular mechanisms of inflammasome activation by enterotoxins of the foodborne pathogen Bacillus cereus, *Mr Daniel Fox* — RSNSW Scholarship Winner, PhD Student, John Curtin School of Medical Research, Australian National University.

Improving the treatment of Post-traumatic Stress Disorder in refugees: The important role of emotion regulation, *Ms Phillipa Specker* — RSNSW Scholarship Winner, PhD Student, School of Psychology, UNSW (Sydney).

17 February

Annual Meeting of the Four Societies 2021. A joint meeting of the Australian Institute of Energy, the Australian Nuclear Association, the Sydney Division of Engineers Australia, and the Royal Society of NSW: UN Sustainable Development Goals (SDGs) and the Role of Nuclear Technology, presented by Ms Lenka Kollar, Co-founder, Helixos.

24 February
Stewardship of Country, from the Royal Societies of Australia: Stewardship of Country: The Common Ground — A Convergence of Traditions, Presented jointly by the Royal Societies of Australia and Inspiring Australia Victoria. Presentations by: *Adjunct Associate Professor Mary Graham* of The University of Queensland (Keynote), *Professor Peter Bridgewater* of the Australian National University, the University of Canberra and Beijing Forestry University, *Mr David Pollock* of Wooleen Station, *Mr Justin O'Brien*, *Dr Chris Brady* and *Mr Peter Christopherson* of Gundjeihmi Aboriginal Corporation.

3 March
1291st Ordinary General Meeting and Open Lecture: What are the best options for growing Australia's mental health through the COVID-19 recovery? *Professor Ian Hickie* AM FRSN FASSA FAHMS, Co-Director (Health and Policy), Brain and Mind Centre, University of Sydney.

10 March
Stewardship of Country, from the Royal Societies of Australia: Stewardship of Country: Resilience, regeneration and escaping the iron law of business-as-usual, Presented jointly by the Royal Societies of Australia and Inspiring Australia Victoria. Presentations by: *Dr Nicholas Gruen*, CEO, Lateral Economics (Keynote), *Ms Carolyn Hall*, The Mulloon Institute, *Ms Jody Brown*, La Trobe Station, *Mr Nigel Sharp*, Odonata.

24 March
Stewardship of Country from the Royal Societies of Australia. Presented jointly by the Royal Societies of Australia and Inspiring Australia Victoria. Presentations by: *Dr Anne Poelina*, Martuwarra Fitzroy River Council and University of Nore Dame (Keynote), *Professor Kingsley \Dixon*, Curtin University, *Dr Michelle Maloney*, Australian Earth Laws Alliance, Griffith University, *Mr Barney Foran*, Charles Stuart University.

7 April
154th Annual General Meeting; 1292nd Ordinary General Meeting and Open Lecture: Antarctica, this ain't no mirage: The value of art in disseminating scientific information, *Lea Kannar-Lichtenberger*, Artist, exploring connections between science and art practice.

14 April
Inaugural David Cooper Lecture (UNSW): From the HIV/AIDS epidemic to the COVID-19 pandemic, what have we learnt and what do we still need to learn? *Dr Anthony S. Fauci*, Director, US National Institute of Allergy and Infectious Diseases.

5 May
1293rd Ordinary General Meeting and Open Lecture: Big, bad fires in NSW, *Emerita Professor Mary O'Kane* AC FRSN FTSE HonFIEAust, Chair, Independent Planning Commission of NSW and former Chief Scientist and Engineer of NSW.

2 June
1294th Ordinary General Meeting and Open Lecture: Murray-Darling Basin turmoil: past, present and future *Professor Richard Kingsford* FRSN, Director, Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, UNSW (Sydney).

7 July
1295th Ordinary General Meeting and Open Lecture: Society as an information-processing system, and the influence of the media *Dr Erik Aslaksen* FRS, Director, Systems Engineer, and Author.

22 July
Ideas@theHouse: July 2021: Music as a Superfood: How music can help us live longer, sleep better, calm down, find flow, and feel happier, *Greta J. Bradman*, Writer, broadcaster and psychologist.

4 August
1296th Ordinary General Meeeting and Open Lecture: An intimate history of evolution: From genesis to genetic with a scientific dynasty, *Professor Alison Bashford* FRSN FAHA FBA FRHistS, Faculty of Arts and Social Sciences, UNSW (Sydney).

24 August
2021 Clarke Lecture of the Royal Society of NSW: From bulldozers, pests, and pathogens to climate change and urban futures: the tough life of plants, *Distinguished Professor Michelle Leishman*, Director, Smart Green Cities, Macquarie University.

25 August and 15 September
Our Energy Future: The Unrecognised Opportunity in Glasgow — In Two Acts Part 1: Context and Castles, Part 2: Crushed Rocks. *Dr Saul Griffith* FRSN, including a conversation with *Dr Adi Paterson* FRSN

1 September
1297th Ordinary General Meeting and Open Lecture: Taking humour and laughter seriously: Exploring the multi-disciplinary field of humour studies, *Dr Jessica Milner Davis* FRSN, Honorary Associate, School of Literature, Art and Media, University of Sydney.

6 October
1298th Ordinary General Meeting and Open Lecture: Privacy and identity in an AI world, *Scientia Professor Toby Walsh* FAA FACM FAAAS, School of Computer Science and Engineering, UNSW (Sydney).

4 and 5 November
Royal Society of NSW and Learned Academies Annual Forum: Power and Peril of the Digital Age [see discussions in the June 2022 issue].

1 December
1299th Ordinary General Meeting and Open Lecture: Managing psychological distress in times of stress: handling the stress of COVID-19 and all that, *Scientia Professor Richard Bryant* AC FASSA FAA FAHMS — James Cook Medal Winner 2020, School of Psychology, UNSW (Sydney).

Hunter Branch Meetings

26 May
Hunter Branch Meeting 2021-1 and Lecture Jointly with the University of Newcastle as part of the Looking Ahead — In Conversation Series: On readying our region for low emissions technology *Dr Alan Finkel* AO FAA FTSE, Former Chief Scientist of Australia.

30 June
Hunter Branch Meeting 2021-2 and Lecture: Extreme bushfires and the age of violent pyro-convection, *Professor Jason Sharples*, Director, Bushfire and Natural Hazards CRC, UNSW Canberra.

25 August
Hunter Branch Meeting 2021-3 and Lecture: Royal Commission for Ageing and the care and welfare of the elderly, *Professor Kathy Eagar*, Director, Australian Health Services Research Institute University of Wollongong.

29 September
Hunter Branch Meeting 2021-4 and Lecture: Mr Nathan Towney, Pro Vice-Chancellor (Indigenous Strategy and Leadership) University of Newcastle.

Southern Highlands Branch Meetings

18 February
Southern Highlands Branch Lecture 2021-1: The five islands off Port Kembla — a historical and ecological study, *Dr Kevin Mills*, Botanist and Ecologist.

18 March
Southern Highlands Branch Lecture 2021-2: The general development of the Sydney Basin Coast and its recent history since the last ice age, *Dr Howard Brady*.

15 April
Southern Highlands Branch Lecture 2021-3: Particle radiation therapy and human space exploration: commonality in challenges and solutions, *Professor Anatoly Rosenfeld*, University of Wollongong.

20 May
Southern Highlands Branch Lecture 2021-4: Burnout — the hottest issue, *Professor Gordon Parker* AO, Scientia Professor of Psychiatry, UNSW Sydney.

17 June
Southern Highlands Branch Lecture 2021-5: Reach for the Skies, *Max La Galle*, Materials science student, UNSW (Sydney).

15 July
Southern Highlands Branch Lecture 2021-6: Neutron scattering and the ANSTO WOMBAT project, *Dr Helen Maynard-Casely*, Instrument Scientist, ANSTO.

19 August
Southern Highlands Branch Lecture 2021-7: Transgenerational Epigenetics, *Alyson Ashe*.

Western NSW Branch Meetings 2021

19 October
Western NSW Branch Meeting 2021-1: With the Falling of Dusk, *Professor Stan Grant*, Vice-Chancellor's Chair of Australian–Indigenous Belonging, Charles Stuart University.

Awards 2021

Royal Society of NSW Citation

The Honourable John Dowd AO QC FRSN
Having previously served in prominent roles in the NSW Parliament, in 2002, The Honourable John Dowd AO QC FRSN was elected as Chancellor of Southern Cross University, serving until his retirement in 2014. In 2005, he was appointed Protection Ambassador for ActionAid Australia (previously AUSTCARE) and became a Director of the organisation in 2008 and President in 2009. In May 2011, Dowd launched The Justice Campaign in a show of support for human rights and justice with a focus on alleged abuses at Guantanamo Bay, Abu Ghraib and elsewhere with a particular focus on David Hicks. John Dowd provided the Royal Society of NSW with outstanding service in 2020 when he provided pro bono extensive legal advice over an extended period of time on the revision of the Society's Rules which had not been comprehensively reviewed since 1968. This exercise was complex and extensive and involved liaison with a wide range of members of the Society. It resulted in a modernised set of Rules which will stand the Society in good stead for many years to come. This outcome could not have been achieved without his input.

Mr Hubert Regtop MRSN
Hubert Regtop MRSN is a biochemist and microbiologist with a Master of Science from the University of NSW (1973). He has a long and esteemed career as a university lecturer, research fellow and research director of publicly listed companies, receiving multi-million-dollar grants, and responsible for hospital funded projects and partnerships with Universities in the US and UK. In the mid-nineties, he was responsible for introducing standardised herbs in Australia. As a director of Trilogie Pty Ltd, established in 1994, he currently consults and lectures to the major health food companies, doctors and pharmacists in Australia, on the role of nutrition in medicine. He has authored twenty-two publications and has had

twenty-three patents approved. He has been a long-standing Chairman of the Society's Southern Highlands Branch to which he has made a significant contribution over ten years maintaining an active branch with a strong events program.

The James Cook Medal

Scientia Professor Rose Amal, Scientia Professor of Chemical Engineering, UNSW, Sydney.

Professor Amal AC FRSN FTSE FAA FRACI HonFIEAust FIChemE FRSN is an acknowledged international leader in the field of chemical engineering. Her research has changed the way in which the properties of catalysts are understood, with her scientific breakthroughs in catalysis leading to real-world applications for sustainable environment and energy applications. In particular, she is renowned for her photocatalysis breakthroughs for large-scale industrial water treatment, and the generation of "clean hydrogen," i.e. production of hydrogen from water using solar energy powered by an electrolyser, including the generation of hydrogen directly from seawater. Her contributions to science and human welfare in and for the Southern Hemisphere have been extensive.

The Edgeworth David Medal

Dr Lining Arnold Ju ARC DECRA Fellow, Faculty of Engineering, University of Sydney.

Dr Lining Arnold Ju BSc, PhD employs innovative and cutting-edge research in mechanical engineering and biomechanics to open new avenues to diagnose, monitor and treat blood-clotting diseases. In just 8 years since his PhD award and under 35 years of age, he has been an ARC DECRA Fellow, Heart Foundation Future Leader Fellow and won awards such as the MIT TR35 Innovator, Australian Museum Eureka Prize and NSW Young Tall Poppy. His academic standing is on a steep upward trajectory nationally and internationally. He is now spearheading his own Cardiovascular Biomechanics Lab for organ-on-chip blood clot assessment and developing future cardiovascular point-of-care tests and telehealth microdevices.

The Clarke Medal and Lecture (Zoology)

Laureate Professor (David) John Aitken, College of Engineering, Science and Environment,, University of Newcastle.

Laureate Professor John Aitken PhD, ScD, FRSN, FSRB, FAHMS, FRSE, FAA is a global leader in reproductive biology and the 2012 NSW Scientist of the Year. Based at the University of Newcastle, he is President, International Society of Andrology, Director of the Priority Research Centre in Reproductive Science and Professor of Biological Sciences. Professor Aitken heads up a research team that is making significant inroads into human and animal reproductive issues. His research achievements include identifying a major cause of male infertility that has resulted in new methods of therapeutic intervention and the development of a contraceptive that would prevent pregnancy and inhibit the spread of sexually transmitted diseases. He currently has an active program of research to develop non-surgical methods of sterilization for domestic and feral animals. Nationwide, the damage done by vertebrate pests to Australian biodiversity and agricultural productivity amounts to $1 billion per annum. In response to this need, Professor Aitken's research group has developed a

technology for the non-surgical sterilization of mammalian species that opens up a market worth billions of dollars per annum.

Poggendorff Lectureship

Professor Richard Trethowan, Director, IA Watson Research Centre, Narrabri Plant Breeding Institute, School of Life and Environment Sciences, University of Sydney.

Professor Richard Trethowan PhD is a world-leading plant breeder. His work improved our understanding of the genetic control of heat resistance in wheat, an important trait globally, and he contributed significantly to the development of new technologies including hybrid wheat systems and the application of genomic selection to plants. His work led to the development of unique genetic wheat strains that have impacted the productivity of agricultural systems in many countries. These impacts include release of wheat cultivars to farmers from his experimental materials either directly, through their use as parents or the application of knowledge generated from his research.

Pollock Memorial Lectureship

Professor Geraint Lewis, Professor of Astrophysics, Sydney Institute for Astronomy, School of Physics, University of Sydney.

As an outstanding researcher, Professor Geraint Lewis PhD FRSN FLSW focuses on cosmological mysteries. Through exquisite and extensive observations with the world's largest telescopes coupled with synthetic universes generated on immense super computers, he hunts for the dark side — the dark matter and dark energy that shape the cosmos. With significant discoveries that confront our ideas on the formation and evolution of galaxies, he has published extensively in international journals. His passion for cosmology and physics is reflected in his teaching and student supervision, as well as an extensive outreach program which brings the mysteries of the universe to diverse international audiences.

History and Philosophy of Science Medal

Professor Dean Rickles, Professor of History and Philosophy of Modern Physics, University of Sydney.

Professor Dean Rickles PhD has made seminal contributions to both the history and the philosophy of modern physics, creating two-way traffic from conceptual and philosophical issues to historical ones. His work has been used and praised by philosophers, historians, and physicists alike. In particular, he has been a central figure in the emerging field of history and philosophy of quantum gravity (the as yet unknown theory that would treat our two great fundamental theories of physics, general relativity and quantum theory, in a single framework), and has driven much of the current research landscape. He has been responsible for many firsts, including the first detailed histories of string theory, praised by its chief architect (John Schwarz), and of quantum gravity, and the first philosophical papers on dualities and loop quantum gravity.

Warren Prize (Medal and Lectureship)

Dr. Noushin Nasiri, Senior Lecturer, School of Engineering, Maquarie University.

Dr Noushin Nasiri PhD combines multidisciplinary techniques in the field of nanomaterials, nanoelectronics, and chemistry to develop innovative nanomaterials that transform nanosensing technologies. Her work has already resulted in practical, beneficial outcomes, such as the world's first wearable sensor, capable of differentiating between UVA and UVB rays, that alerts users in real time to over-exposure to UV radiation. The technology is tailored for individuals, taking into account different skin types when calculating sun-safe limits.Dr Nasiri heads Macquarie University's NanoTech Laboratory with a team of 10 researchers. Just four years after earning her PhD, she has co-authored 42 papers in high impact journals, 19 as first author, collectively earning 1200 citations, and an *h*-index of 21 and *i*10-index of 25. She is a NSW Young Tall Poppy, a 2021–2022 Superstar of STEM, a 40 Under 40 Most Influential Asian-Australian Leaders, and has presented her research at high-profile events including TEDx Sydney, TEDx Macquarie University, TEDx Bligh Street and on ABC radio's ABC Ockham's Razor.

The Jak Kelly Award

Zain Mehdi, PhD Candidate, The Australian National University.

Zain's research investigates quantum physics in the mesoscopic regime — the intermediate scale between the microscopic world of individual atoms and the macroscopic world of classical objects. Their work focuses on theoretical investigations of exotic phenomena, such as superfluidity and turbulence, in cold atom systems.

Royal Society Scholarships (Ranked)

1. Sajad Moshizi, PhD Candidate, Macquarie University

Sajad Moshizi is conducting the development of hair-cell sensors for using inside the semicircular canals in the inner ear to treat patients suffering from balance problems and gaze instability. He is a recipient of the Biomolecular Discovery Research Centre (BDRC) Postgraduate Prize, the best internationally peer-reviewed paper by a postgraduate student as first author accepted for publication ("Development of an ultrasensitive, and flexible piezoresistive flow sensor using vertical graphene nanosheets," *Nano-Micro letters* (IF=16.419), Volume 109, Issue 12, 2020, DOI: 10.1007/s40820-020-00446-w). He is a recipient of Macquarie University Postgraduate Research Fund (PGRF) scheme up to $3000 and has more than 30 peer-reviewed journal articles, Total citations:618, *h*-Index:13, i10-Index:19.

2. Harry Marquis, PhD Candidate, University of Sydney.

Harry Marquis is a PhD candidate at The University of Sydney, School of Physics. His research is primarily conducted at the Department of Nuclear Medicine, Royal North Shore Hospital, under the supervision of Professor Dale Bailey. His project is titled "Development of a Dosimetry Platform for Theranostic Agents." His key research interests are in quantitative PET and SPECT imaging, diagnostic medical imaging and image processing, theranostics and radionuclide therapy dosimetry, radiobiology and radiation safety. Harry's research has already gained international recognition. In 2020, Harry received the Arthur Weis Award for "Outstanding original work in radiation safety and dosimetry" from the Society of Nuclear Medicine and Molecular Imaging (SNMMI). In 2021, Harry's work was featured in the

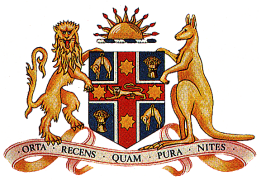
SNMMI plenary lecture highlights "Basic Science Instrumentation & Data analysis: Image Generation" session and was also shortlisted for the best poster award in the physics track. His paper titled "Theranostic SPECT reconstruction for improved resolution: application to radionuclide therapy dosimetry" was published in the *European Journal of Nuclear Medicine and Molecular Imaging* in February 2021 and has received 2 citations.

3. Kevin (The Huong) Chau, Master of Research candidate, Macquarie University.
Kevin joined the Analytical Glycoimmunology team at Macquarie University (MQ) in April 2018 as an undergraduate volunteer to study the removal of synapses by microglial receptors in the brain during sleep. After completing his course work to near-perfection (GPA 6.4/7.0), he decided to complete a Master of Research (MRes) degree focusing on platelet glycobiology. He is only months away from completing this degree. During the past 3–4 years he has shown an immense potential and talent, demonstrated, for example, by the award of multiple prestigious scholarships and awards during his coursework progress, including the inaugural Amgen Scholars Program at the University of Melbourne (2020), the Molecular Sciences Prize for Excellence in the MRes Year 1 (2020), Le Fevre Memorial Prize for proficiency in 200-level Physical Chemistry units (2018) and Macquarie University 2018 Merit List: top 1% highest achieving student (2018). Further, he secured the highly competitive International Macquarie University Research Excellence Scholarship (iMQRES-MRES) in 2020 to support his studies at MQ.

Kevin's MRes research focuses on mapping the glycoproteome of human platelets. He has also presented a poster with his own data at the 18th World Congress HUPO Adelaide 2019, one of the most renowned international conferences in the field. Kevin has also shown that he is a great scientific communicator and mentor for junior students. As a Peer Assisted Learning (PAL) Leader during his Undergraduate program, he provided valuable guidance for first- and second-year students who find the basic concepts in the biomolecular sciences challenging.

Note on Gazetting

The Government Gazette of the State of New South Wales is managed by the New South Wales Parliamentary Counsel's Office and has published Government notices, regulations, forms and orders since 1832. It went on line in 2001 and since 2014 is only to be found at https://www.legislation.nsw.gov.au/#/gazettes.



Government Gazette

of the State of

New South Wales

Number 59–Other
Friday, 12 February 2021

On the initiative of RSNSW Fellow Robert Whittaker AM FRSN, the Society approached His Excellency the Governor to formally gazette fellows of the Society. All current fellows were included in the first gazetting in 2018, and subsequently at the beginning of each year fellows elected in the previous year will appear in the Gazette.

As the Gazette of Friday 12 February 2021 says:

> "Her Excellency, The Honourable Margaret Beazley AC QC, Governor of New South Wales, as Patron of The Royal Society of New South Wales and in furtherance of the aims of the Society in encouraging and rewarding the study and practice of Science, Art, Literature and Philosophy, is pleased to advise and acknowledge the election of the following as Fellows and Distinguished Fellows of the Society in 2020."

Fellows

Proven leaders and experts in their field, entitled to use the post nominal FRSN. Please note Professorial titles — including adjuncts, conjoint, and professors of practice — have been used where applicable. Details as to their field of expertise, their resident university (or universities) or institution may be ascertained from the Royal Society of New South Wales.

ANSLEY, Professor Kaarin Jane Ansley FRSN

BALLEINE, Professor Bernard Walter Balleine FRSN

BARTLETT, Professor Stephen Douglas Bartlett FRSN

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BIZO, Professor Lewis Albert Bizo FRSN

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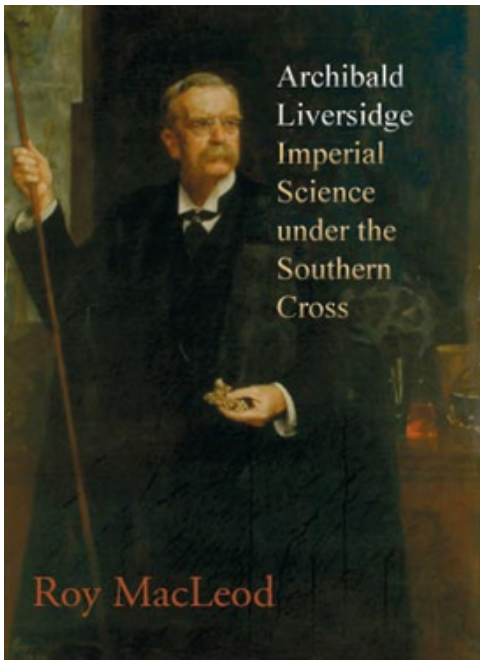

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