Advances in mathematics and statistics in Western Australia since 1960

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We review some of the key developments in mathematics and statistics over the last half-century concerning researchers either based in, or originating from, Western Australia. We describe the whole range of mathematical sciences from the work in the most abstract and theoretical aspects of pure mathematics through to the most applied area of statistics.

KEYWORDS: applied mathematics, mathematics, mathematical science, pure mathematics, statistics, Western Australia.

INTRODUCTION

It was with more than a little trepidation that we accepted this task of penning a short article on some of the significant advances that have occurred within Mathematics and Statistics by researchers based in our state. Even though our timeframe extends over only roughly a 50 year period, this time has seen some dramatic changes in the mathematical landscape, prompted in part by the sea change that has taken place in computational capability. As a demonstration of this revolution, it should be noted that the first computer installed in the University of Western Australia (UWA) in the early 1960s occupied a large room and had a computational power far less than is in a hand-held calculator now used routinely in a high-school classroom.

Any account such as this can only touch on a few of the key developments within a particular field of science and must by necessity be extremely selective. The responsibility for the choice of subject matter rests solely with the authors who apologise for any glaring omissions. Moreover, since all the writers of this article are based at UWA, there is the clear danger that the overall focus of our account becomes rather UWA-centric—we hope that we have avoided falling into this trap. We mention that there are several seminal reviews of mathematics and statistics in the whole of Australia; of these perhaps the most comprehensive is Cohen (2006) and further details and many references can be found there.

Before any attempt to describe some of the advances that have taken place in the mathematical sciences it is perhaps helpful to outline exactly what mathematical science is in the modern research setting. (In what follows we will occasionally mention mathematical science as a generic term by which we mean mathematics and statistics combined – a phrase that can become cumbersome if often repeated.) Mathematical science is conveniently divided into three subclasses, which we shall refer to as pure mathematics, applied mathematics and statistics. Broadly speaking pure mathematics is the branch that studies entirely abstract concepts; it is possible to study such constructs with respect to their intrinsic properties without need for any application to the real world. On the other hand, applied mathematics is concerned with methods that can be used in a variety of problems that may occur in science, engineering or industry. Last, but by no means least, statistics is the study of collection, organisation, analysis and interpretation of data. The boundaries between these separate branches of mathematics are somewhat blurred — indeed it is difficult to define exactly where studies in some topics, especially within applied mathematics and statistics, morph into other disciplines like physics, computer science or medicine. Mathematical links with computer science are especially strong; for instance the present Deputy Vice Chancellor (Research) at UWA, Robyn Owens, was for some years Professor of Computer Science following on from a PhD in mathematics at Oxford. In order to keep the scope of this article manageable we deliberately focus on activities of workers based in mathematics departments and, to help the reader identify our references to the separate sub-disciplines in what follows, Table 1 sets out how some key personnel fit into the overall picture.

It is important to emphasise that the landscape of the mathematical sciences has evolved markedly over the last half century. Researchers in the field back in the 1960s would not recognise some of the contexts in which mathematics now plays an integral part. The advent of fast digital computers has revolutionised the way in which mathematical research is conducted in all three branches. Whole new fields of mathematics applied to biology and to finance have opened up, while statistics plays a significant role in many parts of health and medical research. Thus modern mathematical developments now occur in a far wider setting than just within the rather traditional university department. Much mathematical work is undertaken in government organisations like CSIRO, within hospitals, or research arms of commercial companies and there are numerous pockets of other activity scattered widely. It would be an impossible task for us to even begin to try to compile an account of all the significant mathematical work done outside universities and we have not endeavoured to do this. Thus our remarks will concentrate on research emanating from Western Australian universities, but acknowledge that this cannot be a comprehensive account of all work that has been conducted in the state over the past 50 years.

Table 1 Some professorial appointments in mathematics and statistics in Western Australian universities together with significant milestones that have occurred since 1960.

Year	Curtin University	Murdoch University	University of Western Australia			Some significant events
			Applied	Pure	Statistics	
Pre-1960	-	-	Weatherburn (to 1952)	Blakers (to 1982)	-	-
1960-1965	-	-	Levey (1961-66) Mahony (1964-86)	-	-	Summer courses for school students
1966-1970	-	-	-	Silberstein (1966-85)	-	-
1971-1975	-	Robertson (1973-90)	-	-	-	Murdoch starts
1976-1980	-	-	-	-	Speed (1976-82)	UWA Statistical Consulting Group Math. Olympiad Committee
1981-1985	-	-	Mees (1984-2002)	Praeger (1983-)	Brown (1987-92)	MISG
1986-1990	-	-	-	-	-	WAIT becomes Curtin
1991-1995	Caccetta (1992-)	James (1991-) Bloom (1995-2011)	-	-	Aitkin (1994-97) Baddeley (1994-2010)	ECU Mathematics Problem Solving Program (1991-) UWA Academy of Young Mathematicians (1995-)
1996-2000	Teo (1997-99)	-	-	-	-	CADO (1996-2005) WAJO
2001-2005	Teo (2005-)	-	Bassom (2005-)	Noakes (2005-)	Gao (2004-07)	WACEIO formed at Curtin
2006-2010	Wu (2008-)	-	-	-	-	CMSC formed at UWA
2011-	Wang (2014-)	Hocking (2011-)	Small (2012-)	Seress (2011-12) Li (2013-)	-	-

1960s AND 1970s

Half-a-century ago the mathematical scene in Western Australia was very different from its relative vibrancy of today. The little research that was being conducted was based at UWA, being the only university in Perth at the time. Staff in mathematics had an almost entirely teaching role and much of their time was spent educating other scientists and engineers in the mathematical methods required for the study of their particular subjects. Significant progress in the research capabilities of the state was achieved by the appointment of Harry Levey to a Professorship in Applied Mathematics in 1962. He came to Perth from the ARL (the Aeronautical Research Laboratories which at the time was a division of the CSIRO). Others subsequently also made the transition along the same route and thereby a nucleus of research activity in applied mathematics evolved. Levey himself enjoyed an international reputation in fluid dynamics, and particularly in gas dynamics (see Mahony 1968) and these subjects occupied a prominent position in the research direction at that time while studies of electromagnetic theory and astrophysics were also undertaken.

The day-to-day nature of work in those early days would be almost unrecognisable to the mathematicians currently engaged in research. In those days, of course long before the birth of email and the internet, there was great emphasis placed in maintaining personal research connections. UWA had particularly strong links with staff at the University of Queensland and with several overseas institutions. In this era even making national and international telephone calls was far from easy and so personal visits of one researcher to another played a very important part in the intellectual life of the university and the state. Western Australia hosted some very eminent workers from overseas. We mention just one, George Batchelor, a world expert in fluid mechanics who was an expatriate from Victoria and eventually become Head of the Department of Applied Mathematics and Theoretical Physics at Cambridge University.

Unfortunately Levey's tenure in UWA was short-lived and he died suddenly during 1966. Slightly earlier a

second Chair in Applied Mathematics had been taken up by John Mahony, who had been a colleague of his at the ARL. The middle-to-late 1960s marked a particularly active period and the main research focus was in the field of continuum mechanics (which essentially is concerned with a mathematical description of the properties of solids and fluids). Several more people joined the group including Neville Fowkes who is still a member of staff in the UWA School of Mathematics and Statistics today. Neville was not only a wonderful mathematician but a fearsome competitor on the tennis and squash courts — he holds the distinction of having beaten Rod Laver in a Queensland boys singles final in the mid 1950s. Under the guidance of Fowkes and Mahony the principal research direction of the group shifted to look at a collection of problems classified as being of singular perturbation type. Loosely speaking, singular perturbation problems are characterised by the property that seemingly small terms in equations, which therefore intuitively ought to be in some sense negligible, turn out to play an integral part in fixing the solution. As an example, fluid friction (termed viscosity) is tiny when calculating the flow of air over an aircraft wing but it is central in determining the drag exerted by the flow on the body. Mahony tackled these types of problems by developing a method now universally referred to as multi-scaling (or two-timing) and which is now a standard method in a plethora of research fields. Further work was directed to understanding the properties of gravity waves and the dynamics of water in reservoirs. Jorg Imberger, who joined the department first as a postgraduate student and later as a staff member, had particular interest in this class of problems. Jorg subsequently became director of the world-renowned Centre for Water Research based at UWA.

By 1970 the academic members of the mathematics group numbered about 15, headed by A L (Larry) Blakers, who was appointed professor on the retirement of the Foundation Professor of Mathematics Charles Weatherburn in 1952. (We remark that Weatherburn inspired a nursery-age book written many years later: see Magain 2011.) Larry's initiatives in the 1950s included being one of the players in the establishment of the Australian Mathematical Society in 1956 (for more details see Cohen 2006). He was also prominent in the formation of the Mathematical Association of Western Australia (MAWA) in 1958 (Blakers 1979) and his drive also established the Australian Association of Mathematics Teachers in 1966 (Gani 2001). Under Larry's leadership there was a dramatic growth in mathematics personnel although there was no Professor of Statistics at UWA until 1976. Rather, research and teaching in that area relied on a variety of short-term senior appointments and a small kernel of more junior staff. Joe Gani had been appointed in the late 1950s to develop statistics but he left in 1960 to pursue a very distinguished career both overseas and elsewhere in Australia. His research area is now known as applied probability, which is concerned with how probability theory can be used to solve practical problems. Gani's focus was in bacteriophages, dams and epidemics. One of his students, N U Prabhu, was a staff member from 1962 until 1965 and worked in the fluctuation theory of queuing systems and wrote two distinguished monographs; one was arguably the earliest text on the subject directed at the advanced undergraduate or graduate student level while the other, that is still cited today, proved to be regarded as one of the best treatments of the subject. These pioneers established a continuing tradition of applied probability at UWA with a whole succession of researchers who went on to become professors at various institutions around the world.

Mention should be made of K Vijayan who was appointed a visiting lecturer in 1967 and returned as a senior lecturer in 1969 when he became the first long-term appointment in statistics. His principal research interests were in the apparently disparate fields of the sampling of finite populations and in the pure mathematics area of combinatorial design theory. Vijayan retired at the end of 2007 and has the unique distinction in Western Australia of being the only mathematician with an Erdős number of one [1]. His most successful PhD student is Lou Caccetta, who is the current Head of Mathematics at Curtin University and Director of the Western Australian Centre of Excellence in Industrial Optimisation (WACEIO) which was founded in 2001. Lou's research interests are primarily in the field of graph theory and its applications in the design and analysis of networks, especially in the context of vehicle routing problems, openpit mining and network reliability.

A significant development occurred with the appointment in 1974 of Terry Speed who was promoted to Professor of Statistics in 1976. Terry brought immense energy and talent to UWA and although his background was in algebra and probability theory, he soon perceived the need for high-level statistical advice. Consequently he set about retraining himself as both a theoretical and applied statistician and actively sought opportunities to find challenging problems that were amenable to statistical analysis. He contributed to the enquiries into Aboriginal deaths in custody, asbestos exposure and mesothelioma. Terry founded the embryo UWA Statistical Consulting Group whose ongoing viability was assured by substantial grants received from the Domestic Water Use Study (DWUS, 1979–84) sponsored by the Metropolitan Water Authority. One of the most extensive such studies, it involved scientific staff from the CSIRO Division of Groundwater Research and the Australian Bureau of Statistics. The Consulting Group was responsible for the storage, processing and analysis of the enormous quantity of data generated by the survey and this required the appointment of several new staff in statistics. Terry's work also involved insightful investigations of the algebraic structures inherent in the analysis of variance and contingency tables. He examined the models coded into Genstat and GLIM that were at the time the two most important statistical computing packages. Terry attracted many high-profile visitors from all over the world and he left UWA at the end of 1982 to take up the position of the Chief of the CSIRO Division of Mathematics and Statistics. One

[1] Paul Erdős (1913–1996) published more papers (over 1500) than any other mathematician. The Erdős number was invented as an informal measure of mathematical prominence. If an individual coauthored a paper with Erdős his number is one; anyone who has written a paper with someone with Erdős number one then has a Erdős number of two and so on. Vijayan is one of only 509 people with an Erdős number 1.

measure of Terry's achievements is the fact that he was elected a Fellow of the Royal Society of London – the oldest and arguably most prestigious scientific society in the world – in between the drafting and revision of this paper; and was awarded the 2013 Prime Minister's Prize for Science in recognition of his contributions to genomics and related technologies, just before this paper went to proof.

One notable appointee in statistics at UWA was Richard Tweedie, who was interested in theoretical aspects of probability. His subsequent very distinguished career included Foundation Dean at Bond University, Professor and Chair of Statistics at Colorado State University and, finally, at the University of Minnesota. The significance of his work is commemorated by the annual Tweedie New Researcher Award presented by the Institute of Mathematical Statistics [2].

The 1970s also saw the emergence of a mathematics department at Murdoch University. In 1963 Larry Blakers was looking for an algebraist to teach at UWA and was recommended to approach a functional analyst (another branch of pure mathematics), Alex Robertson, who was at Glasgow University. Unfortunately he was unable to come to Perth on that occasion but did come (along with his wife Wendy, also a mathematician) as Visiting Professor at UWA in 1969. Subsequently he was appointed Foundation Professor of Mathematics at Murdoch in 1973, 18 months before Murdoch accepted its first students. Alex played a key part in the formation of Murdoch – a role he fulfilled right through to his retirement in 1990. Alex recruited and retained an impressive team of younger mathematicians, many of whom are still active at the University today and to whom the high esteem of the current mathematics degree program at Murdoch can be ascribed. Alex and Wendy Robertson are well known for their book, *Topological Vector Spaces*, used as an advanced text throughout the world, especially in Europe, in its original version and also its German and Russian translations. Wendy Robertson joined the group of pure mathematicians at UWA headed by J P O (Phil) Silberstein, who was appointed professor in 1966. Phil had come to UWA in 1960 from ARL where he had worked on mathematical problems associated with several applications such as the directional stability of aircraft. The flourishing groups of pure mathematicians at Murdoch and UWA established a joint weekly seminar that ran for more than a decade, meeting alternately at each institution. This facilitated active research collaborations, for example, between Ken Harrison (Murdoch) and Bill Longstaff (UWA) working on the theory of subspace lattices. A member of this seminar, Lyn Bloom, later joined the staff of Edith Cowan University where she, together with David McDougall and Ute Muller, developed a successful programme in geostatistics, which trains undergraduate and postgraduate students in the theory and methods for applying statistics and mathematical modelling to the analysis of data arising in the earth and environmental sciences—of particular relevance to the mining, environmental and petroleum industries.

The mid 1970s also saw the appointments of Lyle Noakes and Cheryl Praeger to UWA. During this period George Wilson worked at UWA on problems in algebraic geometry, especially investigations into Hilbert's Sixteenth Problem [3]. George's subsequent work at Oxford included collaboration with Graeme Segal (another distinguished Australian mathematician).

1980s AND 1990s

Apart from conducting original research, one of the most important functions of any body of academics is to train and encourage the young minds of today to flourish and become the subject leaders in their generation. This is a task that has always been taken seriously in Western Australia and significant work in mathematical enrichment and challenge activities began back in the 1960s. Larry Blakers was fully supportive of his staff who wanted to be involved in this type of activity and he was instrumental in setting up both the Western Australian Schools Mathematics Enrichment Course based at UWA and the National Mathematics Summer School at the Australian National University (ANU), both of which were designed for gifted high-school students. Larry was himself the Director of the first 24 national schools and was subsequently awarded an Honorary Doctor of Laws by ANU in 1992 in recognition of his outstanding service. Many UWA staff, as well as teachers associated with MAWA contributed to the Western Australian summer school.

It is perhaps not widely known but each year there is an international competition between the very best mathematics students of each country in an International Mathematics Olympiad (IMO). Teams of six are entered and undergo a rigorous training schedule to prepare them for the fearsomely difficult problems that they will be challenged with at the IMO. In 1980 Norm Hoffman became the Australian Mathematical Olympiad Committee's first Western Australian state director. Several years later he was succeeded by Phill Schultz who, in turn, was followed by Elena Stoyanova and Greg Gamble. Through these programs some truly exceptional Western Australian high-school students were introduced to problem solving and some have become well-known mathematicians. To name just three, mention should be made of Peter McNamara who was the first Australian to win two gold medals at IMOs; Akshay Venkatesh who is now based at Stanford in California and is widely acknowledged to be one of the world's best mathematicians, and of Andrew Hassell, who is a researcher at ANU and has just been elected a Fellow of the Australian Academy of Science. In 1991 Norm Hoffman commenced a series of after-school classes for able primary and secondary school students and hosted by Edith Cowan University. Each year around 200 students participate in these classes.

[2] http://www.imstat.org/awards/tweedie.html

[3] The German mathematician David Hilbert compiled a list of 23 problems in 1900. Some of these turned out to be very influential in the development of 20th century mathematics and several researchers were awarded Fields medals (the 'Nobel Prize' in Mathematics) for their work on them. To date it is accepted that of the original 23 problems, 10 are solved, 5 remain unresolved and partial solutions have been found for the remainder.

The Western Australian summer schools ceased when UWA was unable to continue funding. However Luchezar Stoyanov and his wife Elena Stoyanova arrived in Perth during 1992. They both had had leading roles in the training of the Bulgarian team at the Olympiads and were keen to see renewed support by the UWA mathematics department for mentoring gifted students. Under their charismatic leadership two new initiatives were born. In 1995 the UWA Academy for Young Mathematicians was started providing Saturday morning mathematics enrichment classes for year 10 and 11 students. Subsequently the Western Australia Mathematics Olympiad Committee initiated the Western Australia Junior Mathematical Olympiad (WAJO), an annual team competition for year 8 and 9 high school students. Prizes for performance in the WAJO are sponsored by each of the four public Western Australian universities, MAWA, as well as bodies connected with the public, catholic and independent school systems together with a number of commercial sponsors.

This era not only saw a dramatic increase in engagement between Western Australian universities and high-school activities but also heralded the wide-scale entry of computers into both teaching and research at universities. The first computing laboratory for use by undergraduates was opened at UWA in 1992 by Kim Beazley, as his first public act in his then new role as Federal Minister for Education. In conjunction with this new technology, Kevin Judd developed an assessment package called Calmaeth. This system was many years ahead of its time for it has only been relatively recently that companies have been able to market systems that boast of testing capabilities that exceed those of the original Calmaeth. Although some other universities, in particular the University of Adelaide, did use Calmaeth for a number of years it was never made widely available and remained largely in-house. Nevertheless, as a testament to the durability of the package, it is still an integral part of the assessment procedures used for the large first year mathematics classes at UWA.

When Larry Blakers retired in 1982, UWA searched for a professor in 'any area of pure or applied mathematics', since they had flexibility knowing that Phil Silberstein would also retire in two more years. This search resulted in two appointments: pure mathematician Cheryl Praeger, who had joined UWA from ANU as a lecturer in 1976, was appointed to Larry Blakers' Chair in late 1983, and applied mathematician Alistair Mees from Cambridge became Visiting Professor in 1984 until the retirement of Phil Silberstein. Praeger was only the second female mathematician appointed to a Chair at an Australian University, the first being Hanna Neumann at ANU (from 1964 to her death in 1971). She was second also to Hanna as female mathematicians elected as Fellows of the Australian Academy of Science (they were elected in 1969 and 1996 respectively), and was the first woman Head of the UWA Department of Mathematics (1992–1994) and first female President of the Australian Mathematical Society from 1992–1994 (Bhathal 1999). She is still the only mathematician and only woman to become Western Australian Scientist of the Year (2009), and the only woman to win the renowned Thomas Ranken Lyle Medal of the Australian Academy of Science (2013). Praeger built up a world-leading research team of postgraduate students and postdoctoral researchers in Group Theory and Combinatorics. Her first postdoctoral researcher, Tim Penttila, an Australian Research Grants Scheme fellow (1986–1987) and on the regular staff from 1989, built additional research strength in finite geometry, which models properties of geometric figures under projection. Among Penttila's important discoveries at UWA is a family of geometric configurations that he aptly named the *Subiaco ovals* after the famous local football ground.

The 1980s also saw the instigation of the Mathematics in Industry Study Group (MISG). The driving force behind MISG was Noel Barton who was working for CSIRO in Sydney but who had earlier obtained his doctorate from UWA under the supervision of Peter Chapman. The idea of the MISG is to bring together applied mathematicians with workers from various industries to tackle problems that appear to be amenable to mathematical solution. There is a concentrated workshop held somewhere in Australia for a week each January and, as one of the authors can attest, these are great fun. At a recent MISG there were problems associated with the rolling of steel, the efficient spraying of crops with insecticide and the design of the drum of a washing machine to prevent excessive vibration during a high-speed spin cycle. Western Australian mathematicians from UWA, Curtin and Murdoch were active in the MISG from its inception and this has continued to this day. Indeed the MISG has expanded its activities and Western Australian-based mathematicians regularly support the programme at workshops throughout southeast Asia and Africa.

John Mahony was particularly active during the early days of MISG but he had to relinquish his chair of applied mathematics at UWA in 1986 owing to ill-health (Fowkes & Siberstein 1995). His successor Alistair Mees held the post until 2002 when he moved to the United States. Alistair's principal research interests were in the fields of chaos and dynamical systems. These topics were newsworthy at the time, not only within the scientific world but to the general public as well. It was known that biological or physical systems that are deterministic, but inherently unpredictable, might undergo possible dramatic shifts in state. This phenomenon is associated with a structure with a so-called fractional dimension and such structures can be represented by the popular and beautiful abstract patterns known as fractals. There was a very active research group applying the concept of chaotic dynamical systems to problems in medical science, biology, commerce and finance, and climate science. Kevin Judd's interest in atmospheric dynamics led to the development of innovative techniques for dealing with the uncertainties inherent in a chaotic system and he continues to work on these ideas focussed on the topical problem of climate change.

Alistair Mees collaborated with the pure mathematician Lyle Noakes at UWA on recovering dynamical systems from measurements of random variables. Prominent in this area also was Peter Kloeden (Murdoch), who made important contributions to mathematical meteorology. Together with Phil Diamond from the University of Queensland, Peter wrote a highly cited series of papers on fuzzy metric spaces, leading to an influential book on the subject. With Robert Wells (Penn State) he gave the first

explicit example of a Hopf bifurcation in fluid mechanics, and his paper with Jens Lorenz is widely regarded as a milestone in the development of numerical dynamics. Peter moved to Germany in 1997. In 2005 he was awarded the W T and Idalia Reid Prize, a prestigious international award made by the Society for Industrial and Applied Mathematics for fundamental contributions to the theoretical and computational analysis of stochastic differential equations.

The last few years of the twentieth century also saw continued work in mathematical modelling with particular emphasis on problems arising in fluid mechanics. Research in this area was pursued by Graeme Hocking who was then at UWA but is now Head of Mathematics at Murdoch. Other work in applied mathematics included the application of mathematical techniques to attempt to understand medical problems such as epilepsy and studies with members of the Department of Physical Education on human biomechanics that led to significant improvements in the training regimes for athletes. Investigations with geologists on time-series data used the state-of-the-art construct known as wavelet analysis to infer the evolution of the geological structure of key areas of Western Australia. Jo Ward, a UWA graduate, worked on wavelets while based at Murdoch before moving to become Dean of Science at Curtin.

Another major research thread in the area was that of operations research and optimal control, which is concerned with providing engineers and industry with efficient and safe ways of managing large and complex systems. The Centre for Applied Dynamics and Optimisation (CADO) was founded at UWA and Kok-Lay Teo led this group before moving to Curtin in 1997. Teo has published five books and more than 400 journal papers. His software package MISER (developed jointly with C J Goh, Mike Fisher and Les Jennings at UWA) is a fundamental tool for solving constrained optimal control problems. He was also one of six researchers who in 2000 established the Pacific Optimization Research Activity Group, which now has over 500 members from 50 countries. Teo left Curtin in 1999 for a spell in Hong Kong but re-joined in 2005 when he began a period as Head of the Department of Mathematics and Statistics.

We have already mentioned that in the late 1970s Terry Speed founded the UWA Statistical Consulting Group that was supported by the Domestic Water Use Study (DWUS). The group had several members who went on to have very successful careers. Ian James was principally interested in the general area of biostatistics that is concerned with the application of statistical methods to biological and medical contexts. In 1991 Ian moved to Murdoch as Professor and Head of the School of Mathematics. He helped found, and is Deputy Director of, the Institute for Immunology and Infectious Diseases at Murdoch and Royal Perth Hospital. His work there concentrates on issues arising from the complex interactions between adaptable pathogens, drugs and the human host at the genetic, cellular and clinical levels. Ian served a term as the Editor of the prestigious Australian Journal of Statistics and he directed the UWA Statistical Consulting Group over most of the period 1982 until 1990. Another member of the Group, Matt Knuiman, conducted further research in medical statistics. After a spell in the DWUS, followed by four years with the Department of Biostatistics at Harvard, Matt returned to UWA, not in mathematics, but rather in the School of Public Health. He subsequently became Professor and has been deeply involved in the long-running Busselton Health Study with a particular interest in the epidemiology of cardiovascular and respiratory diseases. Moreover he works extensively in the evaluation of the effectiveness of programmes designed to promote physical activity.

The early 1980s also saw the appointment of Tony Pakes to succeed Richard Tweedie as the resident probabilist at UWA. He has contributed extensively to models of the evolution of the size of populations, particularly those subjected to immigration or emigration, and to the modelling of competition of fodder crops that propagate via seed banks. He has also studied topics in so-called extreme value theory; an example is the number of record attempts that are made in order to break some currently standing record mark.

Richard Tweedie had left UWA to become the Foundation Director of Siromath, a quantitative consulting company established by CSIRO. From 1983 to 1987 Siromath provided John Henstridge with experience in commercial statistical consulting. John had been a tutor at UWA for three years from 1976 and then spent four years as a biometrician with the UWA School of Agriculture. In 1988 he established his own consulting company, Data Analysis Australia, which is based in Perth and has steadily grown to become Australia's largest and most successful strategic data consultancy. It now has over 20 staff and services the needs of government, commerce and industry throughout Australia. John devotes much time and effort towards professional accreditation by the Statistical Society of Australia (SSA) of working statisticians, and his company supports generously the activities of the Young Statisticians Group of the SSA as well as the Western Australia Junior Olympiad. He is currently President of the SSA.

Following academic positions both in the UK and Australia, and after a period as Director of the University of Melbourne Statistical Consulting Centre, Tim Brown was appointed to the Chair in Statistics at UWA in 1987. His research was devoted mainly to the approximation of random processes with applications to telecommunication networks. Tim's rich experience in consulting helped to further secure the UWA Statistical Consulting Group. While consulting with the Ford Motor Company, he became a convert to the Total Quality Management movement. At UWA, Tim introduced a third-year unit on industrial statistics, possibly the first in Australia, and put much effort into writing mathematics texts for the new Year 12 secondary curricula. He left UWA in 1992 to become the Chair of Statistics at the University of Melbourne and subsequently served as Dean of Science at ANU and the pro-Vice-Chancellor for Research at Latrobe University.

Ross Maller left a Principal Research Scientist position with CSIRO to join UWA Mathematics in 1989 and was appointed the Professor of Quantitative Finance in the Business School 10 years later. Ross was an experienced consultant and his interactions with agronomists at the CSIRO led to collaboration with Tony Pakes and a joint research monograph. During the 1980s Ross worked

closely with investigators in the UWA Crime Research Centre constructing novel models of 'criminal careers' with the objective of predicting patterns of recidivism, particularly in relation to sex crime. Ross moved to ANU in 2003, where he is now an ARC Professorial Fellow.

Other significant appointments in statistics in the 1990s include those of Peter Taylor, Adrian Baddeley and Murray Aitkin. Peter was only at UWA for a short time (1990–1901) but contributed substantially to modelling queuing and telecommunication networks by determining structures that yield tractable representations of long-term distributions (for example, the length of a queue). Peter took his skills to the Telecommunication Research Centre at the University of Adelaide and later was appointed (Australia's first) Professor of Operations Research at the University of Melbourne. Murray spent three years at UWA as a Australian Research Council Senior Fellow while on leave from the University of Newcastle (UK).

Adrian arrived at UWA in 1994 with an already formidable reputation for his work in stochastic geometry, spatial statistics, stereology and quantitative microscopy. His research at UWA enhanced further his international standing as attested by his election to the Australian Academy of Science in 2000, receipt of its Hannan medal in 2001 and the awards in 1995 of the Medal of the Australian Mathematical Society and the 2004 Pitman Medal by the SSA. Adrian's work runs the gamut of deep theoretical insight, analysis of spatially varying data and the writing of a very high-quality software package for analysing spatial data. Key themes of his results include the extension of known statistical methodology to spatial data thereby furnishing means by which the degree of accuracy of an idealised model compared to real data may be determined. Adrian has written several definitive reviews of progress in his areas of interest.

Luchezar Stoyanov, a pure mathematician, worked in the area of analysis, geometry and topology, focusing on difficult questions about Hamiltonian dynamics, geodesic and billiard flows, and spectral and scattering theory. As well as his UWA PhD students, Lucho's collaborators included the distinguished international experts V M Petkov and F Takens.

During the 1980s, links were forged between pure mathematicians and logicians in the UWA departments of Mathematics and Philosophy who convened a joint study group to read books and papers on topics such as the nature of proof and different kinds of logic. Among the participants was Graham Priest who published his book *In Contradiction* just prior to taking up a Chair in Philosophy at the University of Queensland in 1988. Alan Woods continued the work in logic. He was interested in the connections of logic and computational complexity within algebra, combinatorics and number theory. Alan's name is attached to the Erdős–Woods numbers; these are integers k such that between some two values n and $n+k$ every number has a factor in common with either n or $n+k$. The smallest of these numbers is k=16, discovered by Alan, associated with the interval [2184,2200]. It is now known that there are in fact infinitely many Erdős-Woods numbers and the first few dozen of them are listed in the on-line encyclopaedia of integer sequences.

Links were also forged between mathematicians and engineering. From the mid-1980s Lyle Noakes studied applications of differential geometry in mechanical engineering, robotics, control theory and approximation theory, with international collaborations at IBM Research, EPFL Lausanne and Imperial College, London. Contributions were also made by PhD students in mathematics, in electrical engineering, and in computer science at UWA, and by UWA staff in mathematics, computer science and political science. Another link between mathematics and engineering was a long-running collaboration between Mike Alder, Chris deSilva and their PhD students on applications of geometry and linguistics in pattern recognition.

Notable among the pure mathematicians in this period was Simon Fitzpatrick, a UWA alumnus, who returned as lecturer to UWA in 1982 after a period in the US. Not only was he respected for his contributions to mathematics through his work on analysis, he also earned the award of International Correspondence Master in 1999 by the International Correspondence Chess Federation based in Switzerland, and was captain of the Australian correspondence chess team in the CC Olympiad XIV preliminaries, the chess-equivalent of the Olympics and conducted by email.

INTO THE 21st CENTURY

Although it might be argued that mathematical advances arising from Western Australia had been dominated by results from applied mathematics and statistics, the 21st century has seen a dramatic shift of emphasis with workers in pure mathematics achieving some remarkable breakthroughs. The reason for this success can be attributed largely to the vision and drive of Cheryl Praeger the foundation Director of the Centre for the Mathematics of Symmetry and Computation (CMSC) housed at UWA. In 2006 she was awarded an Australian Research Council (ARC) Professorial Fellowship and also became the first Australian-based mathematician to be invited to serve on the Executive Committee of the International Mathematical Union. In 2007 she became the first pure mathematician to win a prestigious ARC Federation Fellowship and in recent years the outstanding CMSC has developed tremendously. This Centre has attracted a healthy number of strong researchers as international visitors, postgraduate students and externally funded postdoctoral researchers. Its external visibility is greatly helped by the maintenance of a mathematical blog (SymOmega, http://symomega.wordpress.com/) by three of the members of the CMSC.

Cheryl's research focus is primarily with aspects of mathematical symmetry and how certain mathematical structures (known as groups) act on structures that possess symmetry. The exploitation of this symmetry enables impossibly difficult problems to be made tractable. She has developed classification methods that can be used to study large networks like the internet. Other prominent mathematicians in UWA with similar interests include Cai-Heng Li and Michael Giudici. Cai-Heng has proved a number of quite stunning results about the symmetry of large networks, including solutions to several issues that have been open questions for many decades. Moreover, we believe that Cai-Heng is the most highly cited mathematician currently in Western Australia and was

promoted to Professor in June 2013. Michael is currently the Deputy Director of the CMSC and the author of a book on the detailed structure of finite classical groups. Another strand of interest within CMSC is with various geometrical problems and this area has been significantly strengthened by the recruitment of two world-class mathematicians John Bamberg and Alice Devillers onto the permanent staff. The CMSC also attracted Akos Seress from Ohio State University but his time in the Centre was regrettably short due to terminal illness.

In Western Australia there is currently much activity in the general area of combinatorics, which is concerned with the study of finite or countable discrete structures. Gordon Royle, the current CSMC Director, transferred to the Mathematics Department at UWA from Computer Science and is renowned for his monograph on Algebraic Graph Theory. He maintains a website containing catalogues of combinatorial objects that is widely used by combinatorialists worldwide. Very recently he has been working on the mathematics of the puzzle Sudoku and in particular addressing questions such as: what is the fewest number of entries that need to be given in a Sudoku such that the problem has a unique solution? Other Western Australian combinatorialists include Lou Caccetta, Jamie Simpson and Amy Glen. Jamie, from Curtin, is interested in number theory and the combinatorics of finite sets; in particular he works with Amy at Murdoch on the combinatorics of words.

As well as pure mathematics research in WA, work continues in other areas of mathematical science. Martin Hazelton at UWA worked with Adrian Baddeley and one of their papers had the rare distinction of having been read to the Royal Statistical Society. Martin also conducted research involving the economics of motor traffic, for example estimating the trip rates from certain origin–destination data. He left UWA in 2005 to take up the Chair of Statistics at Massey University in New Zealand. The economic theme was continued by Jiti Gao who devised and applied nonlinear time series models to climatic and financial data. Jiti moved from UWA to a Chair in Econometrics at the University of Adelaide and recently moved to Monash University. The current Professor in Statistics at UWA, Berwin Turlach, researches in the area of computer-intensive statistical methods and its applications with particular results having relevance to biostatistics, hydrology and forensic science. Studies in applied mathematics have been strengthened immensely by the recent appointment of Michael Small from Hong Kong. To show that not all mathematicians pursue what many people think are very specialised and intrinsically dull subject matter, Michael wrote a paper in 2012 concerning how a computer can be used to give a gambler the edge over the casino when playing roulette. The paper, which appeared in the well-regarded *Chaos*, was the most highly read article published in the journal during the year.

AND THE NEXT FIFTY YEARS ….?

If there is one lesson to be learnt from the history of the development of the mathematical sciences, it is that it is seldom predictable. We have already alluded to the fact that our forerunners would probably be very surprised as to some subjects that are accepted as belonging in modern mathematics and statistics. With that in mind, to expend too much effort in looking to the future serves little purpose. Nevertheless, there are some aspects of the present Western Australian scene that provide strong evidence of some of the mathematical work that will be required. The subject of operations research is likely to be of interest to many of the resource industries, especially those in remote locations for whom questions of efficient scheduling and allocation of personnel and equipment are important. Equally there are likely to be tremendous opportunities for those mathematicians and statisticians with skills in the area of the analysis and processing of data. We now know that a significant part of the Square Kilometre Array is to be located in rural Western Australia. This experiment is predicted to generate mind-boggling quantities of raw data that will need to be processed in an efficient way and devising procedures to do this is likely to represent a formidable intellectual challenge.

We can be confident that the immediate future of mathematical sciences in Western Australia is in safe hands. Recent appointments at the State's various universities have secured many young researchers who come with excellent records and very promising careers ahead of them. More worrying though is the longer-term fate of the mathematical sciences both locally and, more generally, nationally. There is a well-reported drop in the number of high-school students opting to study advanced year 12 mathematics courses and this does not augur well for the fate of the subject in the medium to long term. Perhaps the onus is on those presently working with mathematics—and this includes engineers, economists and physical scientists through to medical and agricultural scientists—to make it more widely known that advanced mathematics is not only important both for intrinsic interest and its multitude of highly relevant applications but, perhaps selfishly, can lead to exciting and fulfilling employment.

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