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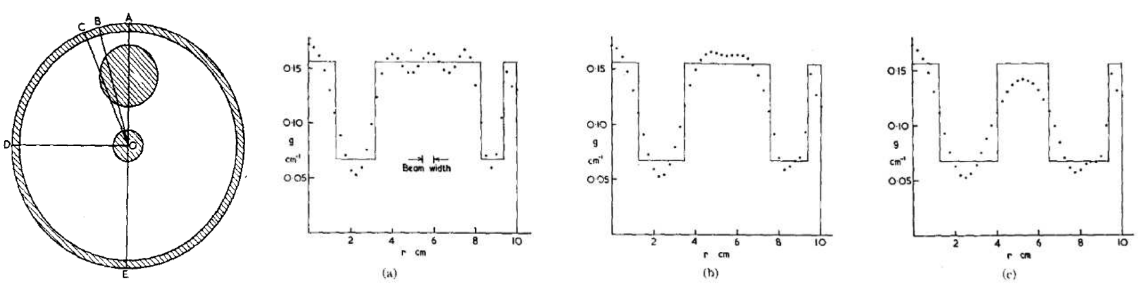
Biomedical Engineering

Allan MacLeod Cormack (1924-1998) was born in Johannesburg and attended Rondebosch Boys' High School in Cape Town. Cormack was born into an engineering family—his father was a telephone engineer, while his older brother William ('Bill') Cormack studied electrical engineering at the University of Cape Town. Bill Cormack later became the head of the Department of Electrical Engineering at the University of the Witwatersrand succeeding G. R. Bozzoli [1].

Allan's favourite subjects at school were physics and astronomy. He observed as a child that in order to become an astronomer, he would need to perfect his mathematics and physics, which is exactly what he did! However, the realities of the job market at the time made him follow brother Bill into electrical engineering at the University of Cape Town. Before completing his electrical engineering degree, he switched to physics. In 1944 he obtained a BSc (in Physics), and his MSc a year later. After completing his bachelor's and master's degrees in Cape Town, he became a research student in the Cavendish Laboratory in Cambridge. For personal and financial reasons, he returned to Cape Town before completing his PhD (A. Cormack never received a PhD).

On his return to Cape Town he was offered a part-time job in the radiology department at the Groote Schuur Hospital, where he became interested in X-ray assisted medical diagnosis. At the time the treatment protocols were based on isodose charts for homogeneous materials. He recalls being shocked by the way in which the human body was being treated as homogeneous. The fact that each body part needed different amounts of radiation appeared self-evident—even to the neophyte. Cormack knew that there was room for improvement and overcoming the inhomogeneity problem would occupy him for the rest of his career.

After spending almost six years back in Cape Town, he moved to a research fellowship position in Harvard (his wife was American). While at Harvard he was offered a position at Tufts University in Massachusetts where he worked through the ranks to become the University Professor of Physics. During the late fifties and early sixties he completed his research on the radiation penetration of inhomogeneous media. In 1963 and 1964 he published a pair of companion papers in the Journal of Applied Physics that address the inhomogeneity problem [1], [2]. In essence, the challenge was to solve repeatedly an integral equation for an absorption coefficient with different boundary conditions. This problem had been solved by Radon in 1917 for problems with circular symmetry, but Radon's solution was too special and significant generalisations were required. Some interesting insights to the non-symmetric case can be found in [3]. The second paper focusses primarily on the practical aspects of the work and demonstrates the efficacy of Cormack's image reconstruction procedure. At the time there was little apparent



(A) (B)

Fig. 1: Imagining results that likely played a substantive role in the decision to award Cormack his Nobel prize. Figure (A) shows an aluminium and lucite surrogate for the human brain. The (B) figure shows the absorption coefficient in the OA, OB and OC directions; the theoretical values are shown solid [2].

interest in these papers, apart from an enquiry from a Swiss Centre for Avalanche Research [4]! Cormack recalls ruefully that if you're too early you will be ignored, but if you are late, you are just late. Under the impression that his work had fallen on deaf ears, he returned to his normal teaching and research and thought very little about the subject. In the early seventies interest in the topic re-ignited—an event of particular relevance was the discovery

[1]W. Cormack was the Head of the Department of Electrical Engineering when the authors were students at Wits. We remember him as an outstanding teacher, a kindly gentleman, and somebody who was generous with his time when it came to assisting students.

of Godfrey Hounsfield's work on the axial tomography scanner. In the late 1960s a Lithuanian of Jewish decent, by the name of Aaron Klug, further energized the imaging field in the related area of electron microscopy (EM).

While on the topic of famous South Africans who converged in Oxbridge, it would be remiss (although briefly digressionary) not to mention Sydney Brenner who also shared the Nobel Prize in Physiology or Medicine for his work on the genetic code and other areas of molecular biology. Brenner (1927-2019) was born in Germiston in Gauteng. He was educated at Germiston High School and the University of the Witwatersrand. Having entered university at fifteen, he would have been too young to practise medicine at the conclusion of his six-year medical degree. To mark time, so to speak, he completed a Bachelor of Science degree in Anatomy and Physiology. He stayed on for two more years doing an Honours degree and then an MSc degree. In 1951 he received the Bachelor of Medicine, Bachelor of Surgery (MBBCh) degree. He then completed a Doctor of Philosophy (DPhil) degree at the University of Oxford as a postgraduate student at Exeter College, Oxford.

Cormack's 1963 and 1964 papers were finally recognised with the award of the 1979 Nobel Prize in Physiology or Medicine that he shared with the aforementioned British electrical engineer Godfrey Hounsfield 'for the development of computer assisted tomography'.

Even a cursory examination of Cormack's papers [1], [2] shows that a person well trained in the fundamentals of mathematics and physics can make contributions affecting a discipline (such as medicine and radiology) that is ostensibly unrelated to his primary field of expertise. This point is reinforced by the Nobel prize presentation speech made by Professor Torgny Greitz [5]: " . . . Neither of this year's laureates in physiology or medicine is a medical doctor. Nevertheless, they have achieved a revolution in the field of medicine. It is sometimes said that this new X-ray method that they have developed—computerized tomography—has ushered medicine into the space age . . . "

We highly recommend [5] to anybody who may be interested in a deeper dive in Allan Cormack's life and work.

Aaron Klug (1926-2018) was born in Lithuania, but moved to Durban as a child. He went to Durban High School, which was run on traditional English lines, with a curriculum that was adapted to South African circumstances. At the time the philosophy of the school was to teach the bright boys Latin, the not so bright science, and the rest geography. Klug read voraciously and widely, and began to find science interesting.

At the University of Witwatersrand, he took a pre-medical course and, in his second year, took biochemistry, which stood him in good stead in later years when he was faced with the analysis of biological material. To establish deeper intellectual roots, he moved to chemistry, and then to physics and mathematics (Durban High School not withstanding!). He graduated with a science degree in 1945. In January 1946 he moved to the University of Cape Town to take a MSc course given then by R. W. James; he completed the two-year physics course in one year. During this time, he checked the page proofs of James's book, the aforementioned *The optical principles of the diffraction of X-rays*, from which he gained a deep understanding of X-ray diffraction [6]. Klug and Cormack were postgraduate colleagues in Capetown, and some years later would overlap to work on almost the same problem, although in different modalities.

On the basis of James's recommendation, Klug was accepted by Sir Lawrence Bragg, director of the Cavendish Laboratory, to do a PhD. By way of an apparent U-turn, he started to work on the microstructure of cooling steel. The work in his thesis gained him a PhD, but was never published. Nonetheless some of the work proved relevant to his later study of viruses. Being keen to work on crystallography, Klug moved to Birkbeck College in London, where he joined up with Rosalind Franklin, and began work on the structure of tobacco mosaic virus. This collaboration continued until her death in 1958.

Following his move to the newly opened Molecular Biology Laboratory in Cambridge in 1962, Klug began to consider how to analyze electron microscope images quantitatively. His key insight was that an EM image of an object with molecular dimensions is a two-dimensional projection of its electron scattering density. This is akin to gaining insight into the configuration of a three-dimensional object by studying simultaneously multiple projected images of the object. Klug analysed the problem for arbitrary view directions, and worked out how to combine many different projections into a reconstructed three-dimensional image. As it turned out, Klug's reconstruction algorithms for EM solved essentially the same mathematical problem as that proposed by Alan Cormack and Godfrey Hounsfield.

In an interview with science writer Joanne Rose [7], Klug explained that he had developed electro-microscopic methods which led to the X-ray CAT scanner. He then said that there had been a Nobel Prize given for it, and that some people think that he should have got it together with Hounsfield and Cormack! He justified his position saying that he had developed the whole technique of doing an objective reconstruction in the context of electron microscopy. The differences were that Cormack and Hounsfield had worked with X-rays, while Krug focused on electron microscopy. The second difference was that Cormack and Hounsfield concentrated on medical diagnosis, while Klug was concerned with the structure of viruses. Regrettably, great accomplishments are sometimes clouded by scientific rivalry.

Klug's work on reconstructive EM ushered in what has come to be called molecular biology. As a result of Klug's work it became possible to dissemble the architecture of the viruses at atomic scale. One of the structures he solved was the tobacco mosaic virus that he had studied years earlier with Rosalind Franklin. Klug later worked on the structure of chromatin, protein-assisted gene switching and the engineering of artificial transcription factors. Towards the latter part of his career, he was director of the Medical Research Council laboratory for molecular biology—he also became interested in the causes of Alzheimer's disease.

On a lighter note, Klug was often asked: what is your work used for? In a moment of jest he recalled the response of Michael Faraday to a similar question. At a public lecture Faraday was asked by an important lady: 'Of what use is your invention, Mr. Faraday?' 'Madam', he replied, 'of what use is a new born child?' [8]. A later addition to this anecdote is: 'in years to come you can tax them.'

Klug received the Nobel prize for chemistry in 1982. From Professor Bo G. Malmström of the Royal Academy of Sciences: 'with your ingenious development of crystallographic electron microscopy you have given science an important tool for determining the chemical structure of complicated components in the most refined chemical systems found in the universe—living organisms . . . '

With the award of the Nobel prize comes all manner of riches. Klug was President of the Royal Society between 1995 and 2000. He also received numerous marks of recognition including Heineken Prize of the Royal Netherlands Academy of Arts & Sciences; the Louisa Gross Horwitz Prize; the Gold Medal of Merit from Cape Town University; the Order of Mapungubwe (Gold) (S. Africa); an Honorary Fellowship from Trinity College, Cambridge; a Foreign Associateship from the National Academy of Sciences USA; an Hon DSc. Hebrew University of Jerusalem; the Copley Medal from the Royal Society; Knight Bachelor from the Queen; an Honorary Fellowship from Peterhouse, Cambridge; and the Croonian Prize Lecture from the Royal Society.

Fig. 2: Commemorative stamps that recognise the Nobel Prizes of A. M. Cormack and A. Klug, November 1996.

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Civil Engineering

Gerhard Jacob Zunz (1923–2018) and John Burland (1936–) both graduated as Civil Engineers from the University of the Witwatersrand. Zunz enrolled in 1942, but his studies were interrupted by the Second World War. In 1943 he volunteered to serve in the South African artillery in Egypt and Italy. He returned to Wits in 1946 and went on to graduate in 1948. John Burland graduated in 1958. After graduating from Wits, Burland completed his PhD in Soil Mechanics at Cambridge University in 1967, before moving to Imperial College London, where he served as Professor of Soil Mechanics for over 20 years; he was Head of the Geotechnics Section in the Civil Engineering Department at Imperial. He has maintained his association with Imperial College as an Emeritus Professor in the Department of Civil and Environmental Engineering.

One of the most striking similarities between Zunz and Burland is the pivotal role they played in connection with some of the world's most iconic structures. Zunz was the lead engineer in the construction of both the Sydney Opera House and, for those who are familiar with the Johannesburg skyline, the Brixton (or Sentech) Tower. Burland became famous as the engineer who saved the Leaning Tower of Pisa. There are other common strands in their life stories—they were both associated with the international civil engineering firm Ove Arup. Zunz joined the firm in 1950 and remained there for the rest of his professional career; Burland worked there from 1961 to 1967. Zunz was Chairman of Ove Arup and Partners between 1977 and 1984, and Co-chair of the Arup Partnership—the holding company—from 1984 to 1988. Both Zunz and Burland settled in London and received many awards for their work.

Zunz's area of expertise was in the construction of steel structures. In 1950 he left South Africa intending to settle in England. There he met the Danish structural engineer Sir Ove Arup when he was assembling a team of talented engineers so that he could take on particularly challenging construction projects. Arup was impressed by the young Zunz and invited him to join his firm. In 1954 Zunz returned to South Africa to set up a branch of Ove Arup. Over the next few years he designed some of Johannesburg's most innovative and interesting buildings, including the Standard Bank Building in Sauer Street in central Johannesburg and the Brixton Tower that houses the SABC's radio transmitters.

The Standard Bank Building consists of a central core which houses lifts and other services. At each floor there are several horizontal cantilevers protruding from this central core. The floors containing offices and meeting rooms are hung from these cantilevers.

At a height of 237 m the Brixton Tower remains Johannesburg's second tallest structure, surpassed only by the Telkom Tower in Hillbrow which is 270 m tall. Zunz designed the Brixton tower to withstand winds of 200 km/hr and to deflect as much as 2 m without damage.

In 1957 the young Danish Architect Jørn Utzon won an international competition for his highly original design of the Sydney Opera House in Australia. In 1961 Zunz returned to Ove Arup's London office and was later given responsibility for the Opera House's construction. Its most interesting feature was the set of 'petals' that made up the roof. Without these structures, Utzon's vision could not be realised. A problem at the time was that none of the engineers in the original team knew how to do the structural calculations. Zunz and Uthon came up with an ingenious solution that involved replacing the original elliptical shells with a design based on sections of a sphere. Utzon explained that the design was inspired by the process of peeling an orange: the 14 shells of the building, when combined, would form a perfect sphere. Dealing with the mathematics of spherical segments was easier than working with the more complex shapes in Utzon's original design. With the riddle of how to build the shells solved, the construction of the roof began in 1963, but as the building started to take shape, relations between Utzon and the NSW Government degraded. As the vaulted sails took shape, Bennelong Point became a political battle ground resulting in Utzon's resignation in 1965; the construction was completed without him. Zunz went on to construct other international landmark buildings, including the HSBC Headquarters building in Hong Kong, which also featured suspended floors. But he always saw the Sydney Opera House as the crowning achievement of his illustrious engineering career.

Zunz was elected a Fellow of the Royal Academy of Engineering in 1983, and together with Sir Ove Arup received the Silver Medal of the Institution of Structural Engineers, with the Institution's Gold Medal in 1988. He was appointed Knight Bachelor in 1989. He received an Honorary Doctorates of Science from the University of Western Ontario, the University of Glasgow, and the University of the Witwatersrand.

While Zunz was an expert in the structural engineering of buildings above the ground, Burland's expertise

Fig. 1: Sydney Opera House at night. Photographed on 16 June 2016 (Thomas Adams).

lay beneath it—his Cambridge PhD dealt with the deformation of soft clays under buildings. When London Underground's Jubilee Line was under construction in the 1970's, Burland provided expert advice on the geotechnical aspects of the project. A particular issue was ensuring that the Houses of Parliament and the Big Ben clock tower were not damaged during construction.

In 1990 Italy's famous 'Leaning Tower of Pisa' had a worrying lean angle of approximately 5.5^o [1]. The famous tower was founded on weak, highly compressible soils and its inclination had been increasing inexorably over the years to the point that it was about to reach the toppling instability limit. That same year Burland was asked to join an international panel of experts tasked with the safeguard and stabilisation of the Tower, which was a difficult challenge in geotechnical engineering. After extensive simulation studies, it was decided that the removal of soil north of the foundations and from below it would be undertaken. A preliminary underexcavation trial was carried out between February and June, 1999. The total volume of soil removed during the preliminary underexcavation was $7\,m^3$, 86% of which was north of the Tower and 14% was from below the foundation. The decrease of inclination in March, 2000 was 2.25^o. The final under excavation was carried out between February 2000 and February 2001. During this final stage, $38\,m^3$ of soil were removed, 31% of which was extracted north of the Tower and 69% from below the foundations. In May 2008 it was announced that the tower had been stabilized for the first time in its history. In April 2011 the scaffolding that had protected the tower was removed and the public could again see this beautiful renaissance structure in its original glory.

Burland was invited to deliver the 30th Rankine Lecture of the British Geotechnical Association titled "On the compressibility and shear strength of natural clays". He was awarded the Institution of Structural Engineers Gold Medal in 1997. In 2016 he was elected an international member of the National Academy of Engineering. He was appointed as a Fellow of the Royal Academy of Engineering, and appointed CBE in the 2005 New Year Honours list. Burland was also named a "Knight Commander of the Royal Order of Francis I" by the Duke of Castro, the official custodian of the (no longer leaning so much) Tower.

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Fig. 2: The leaning tower following Burland’s remedial work. Photographed on 20 January 2007 (David Wilmot).

Engineering Education

Arthur Bleksley (1908–1984) Arthur Bleksley (1908–1984) born in the Eastern Cape and attended the Outeniqua High School in George. After matriculating, he studied mathematics and physics at Stellenbosch University graduating in 1927. He went on to obtain his M.Sc. in 1929. In 1932 Bleksley was appointed as Junior Lecturer in the Department of Applied Mathematics at the University of the Witwatersrand, eventually becoming the head of the department there.

In the 1930s, Bleksley undertook research in astrophysics and obtained his D.Sc. degree at Wits. At the party after his graduation, Bleksley met Phillip Burger of the SABC, who had just received his master's degree and who invited Bleksley to write a series of talks on astronomy. These programmes were well received, and he was subsequently asked to write more talks—his work in broadcasting had begun. With the benefit of hindsight, it is regrettable that he was sometimes viewed as something of an embarrassment to his fellow (and somewhat sniffy) scientific colleagues who disapproved of his popular scientific articles in the press, and his scientific talks on the radio [1].

In 1938 Bleksley was granted sabbatical leave and travelled abroad to continue his research in astrophysics. He visited the University of Cambridge to work with Arthur Eddington who was a distinguished physicist of his day, and who provided one of the earliest experimental confirmations of Einstein's general theory of relativity. Working with Eddington, he helped develop a mathematical model for pulsating stars that he then compared with theoretical prediction.

When Einstein completed his general theory of relatively in 1915, almost no one knew about it. Eddington wrote a number of non-specialist articles that announced and explained Einstein's theory to the English-speaking world. In 1920 he wrote *Space, Time, and Gravitation,* which was followed by *Mathematical Theory of Relativity* in 1923, and *The nature of the Physical World* in 1928. Eddington had the gift of explaining scientific theory to the general public in a way that was both clear and entertaining. His efforts had much wider circulation than anything that Einstein had written. Most people who learned about relativity, probably did so through Eddington (and not Einstein). Einstein himself called Eddington's 1923 book the finest presentation of the subject in any language.

This historical background serves only to reinforce Mason's excellent article [1], where he speculates about the possible origins of Bleksley's love of teaching and popularising science. We will never know, but what we do know is that Bleksley was an outstanding teacher of applied mathematics and mechanics to physicists and engineers alike (he taught both of us applied mathematics). His patient and approachable manner gained much respect from the students. A one time student of his wrote [1]:

> *He was the best of teachers and the worst of teachers—best because he was so crystal clear, worst because he made everything sound so logical and simple that most students assumed they had mastered the material just by listening to him. It worked for good students, but was fatal for weaker students.*

There can be danger in being too good!

Seymour Papert (1928 – 2016) was born in Pretoria. He received a BA degree in philosophy in 1949 and a PhD in mathematics in 1952; both from the University of the Witwatersrand. He went on to complete a second PhD—also in mathematics—from the University of Cambridge in 1959. He then moved to the University of Geneva where he spent several years studying with the famous Swiss philosopher and psychologist Jean Piaget. In 1963 he joined MIT as a research associate, and went on to spend the rest of his academic life at that institution. Following his death at 88, the President of MIT wrote: 'With a mind of extraordinary range and creativity, Seymour Papert helped revolutionize at least three fields, from the study of how children make sense of the world, to the development of artificial intelligence, to the rich intersection of technology and learning. The stamp he left on MIT is profound.' [2]. Each of the fields in which Papert played a significant role remain relevant, and topical, as we move into the much-hyped era of the so-called 'Fourth Industrial Revolution'.

In the field of education, Papert pioneered a theory of learning known as 'constructionism'. At the heart of this theory is the principle that people build knowledge by creating and building things in the real world. In the late 1960s he applied this principle to teach children how to program computers. In an age when computers cost hundreds of thousands of dollars, and filled large rooms, Papert devised a programming language called 'Logo'—the first language developed specifically for teaching children to work with computers. Using Logo, the child learnt to program the movements of a 'turtle', that was represented either as a graphic symbol on a screen, or as a small

Fig. 1: Arthur Bleksley in mid career (Academy of Science of South Africa).

mechanical robot on the floor. Each step in the program moved the turtle a single step forward, backward, left or right. Using this simple paradigm, the child learnt programming logic and the important skill of debugging code. In the early days of computing, as a result of a formative exposure to Logo, many young people became 'hooked' on computers and went on to become the drivers of the digital age.

By observing children learning to program using Logo, Papert and his students also gained a deep insights into how we learn. These insights made a profound contribution to the theory and practice of education. In his book 'Mindstorms: Children, Computers and Powerful Ideas' published in 1980, Papert argued against the notion that 'Computers program the child.' He suggested instead that the child programs the computer, and in doing so, acquires a sense of mastery over a powerful technology. He also argued that learning to program introduced the child to the key ideas that lie at the heart of mathematics, science and modelling. In 1985 Papert entered into a long and fruitful relationship with the LEGO company. His ideas, and the name of his book, inspired the development by LEGO of its popular 'Mindstorms Robotic Kits.' Papert's professorial chair at MIT became the 'LEGO Chair of Learning Research.'

In the field of artificial intelligence (AI) Papert teamed up in the late 1960s with MIT colleague Marvin Minsky. They became co-directors of MIT's 'Computer Science and AI Laboratory', or CSAIL. Minsky and Papert co-authored the book 'Perceptrons: An Introduction to Computational Geometry' in 1969. This book turned out to mark a significant—and controversial—landmark in the history of AI. The book deals with the concept of a 'perceptron' which is a network of artificial neurons similar in concept to the human brain. This concept draws on the work of the psychologist Frank Rosenblatt. In the book Papert and Minsky developed mathematical proofs which acknowledged some of the strengths of the perceptron model. They also showed up some of its weaknesses. Their major finding was that the important 'exclusive-OR', or XOR, operation could not be 'learnt' using a single simulated neuron. Without going into detail here, suffice it to say that this 'discovery' threw into question the practical usefulness of the perceptron as the basis for AI. Papert and Minsky were so influential in the emerging world of AI at that time that attention turned away from perceptrons to AI based on symbolic logic and expert systems. It wasn't until the late 1980's that researchers realised that there was in fact a solution to the XOR problem and attention turned back to the perceptron model—now called 'neural networks'. The 1970s and 80s are now referred to the 'AI Winter'—a period of pessimism and reduced funding for AI research. Many place the blame for this at the door of Papert and Minsky.

Seymour Papert's third major contribution lay in the area connecting technology to learning. Together with Marvin Minsky and fellow MIT Professor Nicholas Negroponte, Papert co-founded the MIT Media Lab. Negroponte and Papert developed a robust low-cost computer suitable for use in the underdeveloped world. This machine formed the basis of the 'one-laptop-per-child' project, which in the 1990s and 2000s brought access to computer hardware to millions of school children and students in some of the poorest parts of the world. A teaching language called ‘Scratch’ was developed by a team in the Media Lab. This is seen as the ‘spiritual successor’ to Logo.

As with all polymaths, it is difficult to attach a single descriptive label to Seymour Papert. Was he an education theorist, a mathematician, a computer scientist, or possibly an engineer? In 2016, his Alma Mater, the University of the Witwatersrand awarded him an honorary doctorate in engineering. We are therefore pleased to claim him as ‘one of ours’ for the purpose of this article!

Fig. 2: Seymour Papert Opening the London Knowledge Lab in 2004.

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Feedback Control and Circuit Theory

Otto Brune (1901 – 1982) was born in Bloemfontein and grew up in Kimberley. He enrolled at the University of Stellenbosch in 1918 and received a Bachelor of Science in 1920, and then a Master of Science degree in 1921. He taught German, mathematics, and science at the Potchefstroom Gymnasium in 1922, and lectured in mathematics at the Transvaal University College, Pretoria (1923–1925). In 1926 Brune moved to the Unites States to attend the Massachusetts Institute of Technology, where he obtained Bachelor and Master's degrees in 1929, and a Doctor of Science degree in 1931 [1]. He returned to South Africa in 1935—this was probably due to the poor economic conditions in the USA in the 1930's.

Brune was educated into an electrical engineering world of passive components such as inductors, capacitors, resistors, and transformers. At that time, it was routine to compute the input impedance of a two-port circuit using Kirchhoff's Laws, but one could not say if a particular impedance function could be synthesized using passive components. With the realisation of circuits with prescribed frequency characteristics in mind, an obvious question arose: what classes of impedance functions can be realised as a passive circuit? Brune answered this question in his doctoral thesis, where he established that the impedance of any passive network is necessarily *positive real*—positive reality essentially ensures that a passive circuit cannot produce energy. More importantly, he also established that positive reality was a necessary and sufficient condition for the realisability of multi-port impedances. Brune's work played a major role in turning network theory into one of the most mathematically sophisticated branches of electrical engineering. In later years this distinction came to be shared with other areas of electrical engineering such as control theory and communications theory.

Brune's doctoral work was supervised by Wilhelm Cauer and Ernst A. Guillemin. On page 343 of Guillemin's book [2], which he dedicates to Brune, he says, and we paraphrase: Brune's classic work, which forms the cornerstone of network synthesis, still characterises the basic approach of numerous other methods and procedures that have since been developed for dealing with problems in this field. Like the earlier work of Foster, it founded a mathematical discipline—the thread of rigorous thought—around which and upon which was built a coherent structure known today as the theory of network synthesis.

Brune would no doubt have realised that the transistor, and more particularly the operational amplifier, would to some extent come to render his work obsolete. What he could not have realised, was the way in which his research would resurface to play a prominent role in control engineering and system theory. In the 1960s Rudolf E. Kálmán found a state-space characterisation of positive reality for single-input single-output systems. This result was later generalised to multi-input multi-output systems and came to be known as the positive real lemma (or the Kalman-Yacubovich-Popov lemma), which characterizes the positive realness of a transfer function matrix of a linear dynamic system via algebraic conditions. This result would, in turn, lead to such things as Popov stability theory, passivity-based control, inverse problems in optimal control, and most recently $\mathcal{H}_\infty$ optimal control [3]. Passive system theory is a topic about which no electrical engineering graduate should be ignorant.

In the opinion of many, Otto Brune is one of South Africa's most brilliant and admired scholars.

Fig. 1: The fathers of modern circuit theory.

David Q. Mayne (1930—) was born in Johannesburg, South Africa. He received the B.Sc. and MSc. degrees in engineering from the University of Witwatersrand, and the Ph.D. and D.Sc. degrees from the University of London. He was a lecturer at the University of Witwatersrand between 1950 and 1959. In 1959 he moved to Imperial

College London where he remained until his retirement. He also held visiting positions at Harvard (1971) and was a professor in the Department of Electrical and Computer Engineering at University of California, Davis between 1989 and 1996.

Mayne entered the field of control theory when ‘modern control’ was still in its infancy. Soon after joining Imperial College, Pontryagin’s maximum principle and Bellman’s dynamic programming made their appearance. A short time later state-space theory entered the field with the advent of linear-quadratic optimal control (and its generalisations) and the Kalman filter. In this sense Mayne was ‘lucky’, but he also had the talent and drive to make the best of this opportunity.

In the 1960s Mayne pursued two parallel research directions, one dealing with estimation and nonlinear filtering, and the other with determination of optimal trajectories for nonlinear systems (optimal control). This work led in 1970 to the development of Differential Dynamic Programming, research conducted jointly with his then student David Jacobson. This work was later refined with Lucien Polak and led to some of the early results on computational optimal control. The Mayne-Polak collaboration was a long and fruitful one and led to many new results.

David Mayne also made pioneering contributions to parameter estimation and adaptive control. In 1963, shortly after his arrival at Imperial College, Mayne presented one of the earliest uses of Kalman filtering for parameter estimation. With another student J. E. Handschin, David developed Monte Carlo methods for stochastic control on what came to known as ‘particle filtering’. Mayne also gave the first solution to the linear-quadratic smoothing problem. His interest in parameter estimation soon led to pioneering work in adaptive control. In the early days of adaptive control closed-loop stability was a thorny unresolved issue. Working with an Australian researcher, Graham Goodwin, David helped solve the stability problem with solid stability proofs established.

David’s expertise in optimization algorithms and optimal control was again harnessed with another PhD student Hannah Michalska. In collaboration they developed receding-horizon control algorithms for both linear and nonlinear systems. In 1997 he started a collaboration with Jim Rawlings on a detailed survey of model predictive control. Their work, which was published in 2000, become the most widely cited paper on model predictive control and was recognized in 2011 with the first IFAC High Impact Paper Award.

Mayne’s long career has been one of unremitting accomplishment and he has attracted a whole string of high honours. These include the prestigious 2009 IEEE Control Systems Award, the 2014 Giorgio Quazza Medal, Fellowships of the Royal Society, the Royal Academy of Engineering, the IEEE, and IFAC. In 1995 he received the degree of Doctor of Technology (honoris causa) from the University of Lund, Sweden.

Control theory aficionados can find a detailed account of Mayne’s many contributions in [4].

David H. Jacobson (1943—) was also born in Johannesburg. He received the B.Sc. degree in electrical engineering from the University of the Witwatersrand in 1963, and the Ph.D. degree from Imperial College London in 1967. He was a Postdoctoral Fellow in the Division of Engineering and Applied Physics, Harvard University, and in 1968 was appointed Assistant Professor. In 1971 he became an Associate Professor of Applied mathematics. In 1972 he returned to South Africa and became Professor of Applied mathematics at the University of the Witwatersrand.

After graduating from Wits, David J. went to study under the guidance of David M; thereafter referred to as ‘the Two Davids’. David M. described David J. as ‘the most original thinking PhD candidate of the many I have supervised.’ One of David M.’s oft repeated stories is how David J. proposed the use of strong variations for determining an improved system trajectory by making large variations in the control over small intervals of time, rather than the more conventional procedure of making small control variations over large intervals of time. David M. did not initially recognise the value of this suggestion and tried to discourage David J. from pursuing it. But like all good students, David J. recognised the limitations of his supervisor and pressed on anyway. This work culminated in a new and then revolutionary theory, known as Differential Dynamic Programming.

David J. also made important contributions to the then established theory of linear quadratic optimal control, including an early treatment of singular problems. Deciding that the conventional quadratic performance index had become dull and overworked, he introduced the theory of risk sensitive optimal control. This work had some unforeseen consequences. In 2013 Lars Peter Hansen, with Eugene Fama and Robert Shiller, won the Nobel Prize in the Economic Sciences. In his Nobel lecture [5], Hansen discussed ambiguity aversion in connection with uncertain (economic) models, and referred to Jacobson work on risk sensitive optimal control *and robustness* as profoundly influencing their thinking. The book ‘Uncertainty in economic models’ by Hanson and T. J. Sargent is dedicated to David Jacobson. Unintentionally, with the use of the word ‘robustness’, Hanson ushered in another link to

Jacobson's work on risk-sensitive optimal control, namely game theory and the relatively new robustness theory of $\mathcal{H}_\infty$ optimal control [3].

David J. made numerous contribution to the governance of science in South Africa and to business. Between 1975 and 1985 he served at the Council for Scientific and Industrial Research (CSIR), and became deputy president in 1980. As Director of the CSIR's National Research Institute for Mathematical Sciences (NRIMS, 1975-1980) he maintained his connection with Wits' Department of Computational and Applied Mathematics as an Honorary Professor. David was also Chairman of the South African Mathematical Society, and President of the South African Institute of Electrical Engineers (SAIEE). David also served on the Wits Council from 1987 to 1997.

Fig. 2: 'Two Davids'—David Mayne (left) and David Jacobson (right).

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Radar and Communications Technology

B. F. J. Schonland (1896-1972) and G.R. Bozzoli (1911-1998). Schonland matriculated from St. Andrew's College as the top pupil in the Cape Province. He then studied physics at Rhodes University and Gonville and Caius College, Cambridge. G. R. Bozzoli held BSc(Eng) and DSc(Eng) degrees from the universities of the Witwatersrand and Cape Town respectively [1].

To some, the Schonland–Bozzoli story might sound like something from a spy novel, but it was deadly serious; it all began in September 1939. War had just been declared between Britain and Nazi Germany. New Zealand scientist Dr Ernest Marsden was on a ship sailing home from Britain via the Cape. Before the ship sailed from Cape Town one of South Africa's top scientists joined the ship. He was Professor Basil Schonland, Director and founder of Wits University's Bernard Price Institute for Geophysical Research (BPI). On the three-day trip from Cape Town to Durban, the New Zealander and South African spent most of the time huddled in Marsden's cabin reading top secret documents [2] and talking about one of Britain's most confidential and important military secrets. In Durban they rushed to Natal University to copy some of the documents before Marsden continued on his journey home to New Zealand, and Schonland to Johannesburg.

As war in Europe loomed and threatened to engulf the world, the biggest threat facing Britain and its allies at that time was Germany's large modern air force. The German Luftwaffe had the capacity to send thousands of bombers over Britain, destroying factories, cities and critical infrastructure. Britain's defences against an air attack consisted of fighter planes and anti-aircraft artillery, but these were no match against surprise attacks by the Luftwaffe. Britain, however, had a secret weapon that was still experimental and largely untested. They decided to share information about it with top scientists in New Zealand, Canada, Australia and South Africa—all part of the British Empire. It was this secret weapon that Schonland and Marsden discussed on the ship as it sailed around the southern tip of Africa.

The British were developing a new system, initially called Radio Direction Finding (RDF), but later renamed 'Radar'. The principle was simple. Radio waves could be transmitted in short pulses which could either be spread out like a floodlight, or directed into a narrow beam like a search light. If the waves encountered a metal object, such as an aircraft or ship, a portion of the reflected energy could be detected by a receiver placed in proximity to the transmitter. The reflected wave was displayed as a 'blip' on a cathode-ray tube. Using simple geometry and knowledge about the way in which radio waves propagate through the atmosphere, signal processing circuits could be used to determine the height, distance, direction and speed of the target.

Calculations carried out in 1935 by British scientists Robert Watson-Watt and Arnold Wilkins determined the energy and frequency required for the transmitted radio signals. They calculated, for example, that to detect a German bomber flying at a height of 6 km and at a distance of 6 km they would need a transmitter with an antenna 17.4 m high transmitting radiation at 6 MHz. They then set to work testing the theory. Instead of building a transmitter of their own, they used an existing BBC radio transmitter in Daventry, England [3]. On 26th February 1935 they successfully tracked an RAF Heyford bomber in the first practical demonstration of radar. It was information about this work and subsequent innovations that Marsden shared with Schonland on the ship in 1939.

Back at his lab at the BPI on Wits University campus, Schonland assembled a team of scientists, engineers and technicians to build a radar system of their own. He enlisted three talented engineers all of whom were experts in the then 'dark art' of radio frequency engineering. From Natal University he recruited W.E. Phillips and from the University of Cape Town N.H. Roberts. The third engineer was G.R. Bozzoli, a senior lecturer in the Wits Department of Electrical Engineering. Before joining Wits, Bozzoli had worked for the African Broadcasting Company, later to become the SABC, as a radio engineer. The fourth member of the engineering team was a physicist, and Schonland's deputy director at BPI, Dr P.G. Gane, a talented designer of circuits using thermionic valves.

Working in great secrecy they set to work developing a working radar system. They faced many difficulties, not the least of which was getting their hands on the necessary equipment and components. Some of the critical components were bought from shops supplying hobbyists and amateur radio enthusiasts. Although they had the top secret documents brought from England by Marsden, there were many gaps in the theory and practice that had to be overcome by Schonland, Bozzoli and the other members of the team.

In the remarkably short time of three months, they had built a complete system, dubbed JB0 (Johannesburg 0), which was a crude laboratory ‘lash-up’. On 16 December 1939, a public holiday, Schonland and Bozzoli tested the system. The transmitter was on the roof of Central Block—above the Great Hall. The receiver was on the BPI building. They successfully ‘detected’ the Northcliff water tower approximately 10 KM away. The system worked!

Being wartime, the development of radar at the BPI was placed under the control of the military authorities. The team became the ‘Special Signals Services’ (SSS) of the South African Corps of Signals (SACS). Systems they designed and built were deployed in East Africa, the Middle East and along the South African coastline. This technology played a key role in the Allies’ war effort.

There are many excellent accounts of this history which we won’t repeat here [4], [5], [6]. One particularly amusing anecdote tells the story of a certain Flight Lieutenant J.F. Atherton of the Royal Airforce (RAF) who was sent to Kenya to assess the effectiveness of the South African radar system. He reported back that it was ‘elementary, homemade … and of little practical value’. A few months later this same system was deployed in the Middle East near the Suez Canal. It was in use side-by-side with a British-built system. The South African radar significantly outperformed the British one!

While we have chosen to focus on the contributions of Schonland and Bozzoli, we should emphasise that there were many other important contributors to South Africa’s contribution to radar. As with many of the other topics discussed in this article, space is at a premium.

Before his role in the development of radar, Schonland was a research pioneer into lightning. After his contributions to the war effort in both South Africa and Britain he established the CSIR in Pretoria and played an important role in the development of atomic energy in Britain.

G.R. Bozzoli became Head of the Wits Department of Electrical Engineering and went on to serve with distinction as the Wits Vice-Chancellor during the tumultuous 1970s. Legend has it that on the day he was named Vice-Chancellor, he invited colleagues and students in the Department of Electrical Engineering to help themselves to any of his engineering books and journals. ‘Now that I am Vice-Chancellor’, he said sadly, ‘I will never work as an engineer again.’

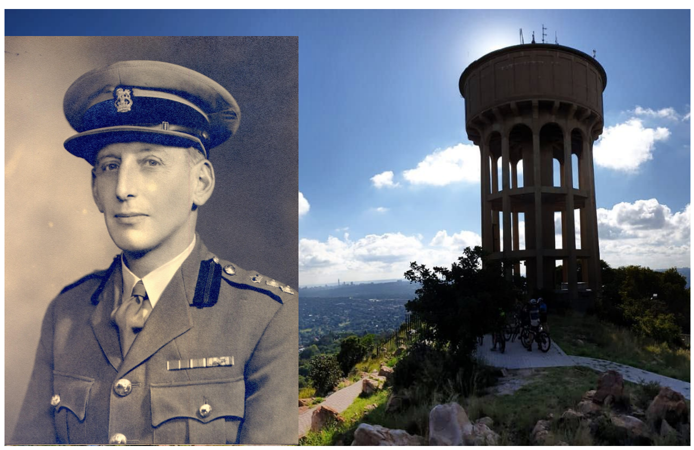

Fig. 1: Colonel B. F. J. Schonland in 1942 with the Northcliff water tower.

Trevor Lloyd Wadley, (1920 – 1981) was born in Durban, and educated at Durban Boys’ High School and Natal University College where he obtained a B.Sc.(Eng.) degree in 1940. He was awarded the D.Sc.(Eng.) degree by the University of the Witwatersrand in 1959. During World War II, he served in the Special Signal Services of the S.A. Corps of Signals and made a major contribution to the design and construction of locally-built radar equipment. In 1946 he became one of the founder members of the Telecommunications Research Laboratory, which had just been established by the CSIR, and which later became the National Institute for Telecommunications Research. Wadley left the CSIR in 1964 and entered private enterprise.

One is often faced with a down-selection problem when reviewing the contributions of productive people. Amongst Wadley’s many contributions, we will focus on three: the Ionosonde, the drift-cancelling communications receiver and the tellurometer. An ionosonde is a device used to examine the electro-magnetic properties of the ionosphere, while the tellurometer is used to make high-accuracy distance measurements. Our task is somewhat simplified by the fact that the ‘clever part’ of the Ionosonde and the drift-cancelling communications receiver are essentially the same—the *Wadley loop*. Despite its name, the Wadley loop is an open-loop system. Communications engineers call this a mere ‘notational quibble’, while control people would refer to this as a blatant abuse of nomenclature!

The Wadley Loop provides a method of accurately down-converting radio frequency signals covering a wide frequency range to a specific narrower frequency range using a possibly poor-quality wide-range variable-frequency oscillator. The Wadley Loop formed the basis of the RACAL RA-17 and RA-117 radio receivers in the 1950’s and 1960’s. In their day, these were premium receivers and the choice of many military, government and commercial services, but fell out of use when phase-locked-loop systems became available. While the Wadley loop is undoubtedly ingenious it is also simple to understand. The phase-locked loop has the insurmountable advantage of being a feedback system and thus a card-carrying member of the noise and drift rejection fraternity.

Arguably Wadley’s greatest achievement was his development of the tellurometer, which was used for measuring distance using radio waves—this invention revolutionized surveying throughout the world. Before the tellurometer surveyors had for decades used rods and steel tapes for measuring distances. The tellurometer is based on measuring the round-trip travel time of a radio signal between two measurement points. As with all these things, there are several sources of error to take into account. One of which is finding an accurate value for the speed of light, which had to be corrected for the temperature, pressure and humidity at which the observations are made. Another source of error arises from the effects of stray reflections of the beam from obstacles in its path such as trees, hills and the ground itself. Rather then get side tracked into these details, we refer the interested reader to [7] and [8].

In 1960 Wadley was awarded the Gold Medal of the SAIEE, in 1976 he received the National Award of the Associated Scientific and Technical Societies of South Africa, and an honorary doctorate in science by the University of Cape Town. To mark the 25th anniversary of the invention of the tellurometer, the South African Post Office issued a special commemorative postage stamp in 1979 carrying pictures of Wadley and a prototype tellurometer.

Fig. 2: Dr. Trevor L. Wadley and the tellurometer.

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Spatial Estimation and Geostatistics

D. G. Krige (1919-2013) pioneered the field of geostatistics. He matriculated from Monument High School in Krugersdorp in 1934 and graduated with a B.Sc. (Eng.) degree in mining engineering from the University of the Witwatersrand in 1938. He then joined Anglo Transvaal where he worked on a number of gold mines until 1943, gaining wide-ranging practical experience in surveying, sampling and ore valuation. He also participated in the uranium negotiations with the British and American authorities and designed the uranium pricing formula for the contracts which led to the establishment of South Africa's profitable uranium industry in the early 1950s. In 1951 he submitted his MSc to the University of the Witwatersrand. This work was soon published [1] and was to make him famous.

Krige noticed that little attention was being paid to the statistical analysis of mine valuation problems. There was a wealth of gold ore related sampling data available, but it was not utilised in a systematic way when making expensive and far-reaching mining decisions. Krige set out to harness basic statistical concepts, and find out how statistical methods could be applied profitably to solve existing problems and improve the standard of mine valuation on the Witwatersrand. A few years later Georges Matheron, a French geologist and statistician, put Kriges work on a sound mathematical foundation in a two-volume monograph [2], [3]; the second of which contains the verb 'kriging' in the title. It was Matheron who brought the word *kriging* into Anglo-Saxon mining lexicon, and urged all scientists concerned with spatial interpolation to adopt the term that had been used routinely in France since 1960.

Even geologists have their fractious moments. The word kriging evoked strong opposition from E. H. T. Whitten who preferred the term 'polynomial interpolation'—if its not going to be named after me, let it be named after nobody! Matheron responded to this criticism in a paper 'Kriging, or Polynomial Interpolation Procedures?' with subtitle: 'A contribution to polemics in mathematical geology.' In his rebuttal Matheron presented an example of how striking but fallacious evidence for a real trend may occur as a result of purely random cumulative effects.

As history would have it, D. G. Krige survived this controversy and was awarded the D.Sc. (Eng.) degree by the University of the Witwatersrand in 1963 and the DIng (honoris causa) degree in 1981 by the University of Pretoria. He received a further honorary doctorate from the University of South Africa in April 1996, and a third honorary doctorate from the Moscow State Mining University in September 1997.

Krige also received several merit awards from the S.A. Institute of Mining and Metallurgy including two gold medals in 1966 and 1980, and two silver medals in 1979 and 1993. In 1984 he also received this Institutes's highest award—the Brigadier Stokes platinum medal. He was awarded the William Krumbein medal from the International Association of Mathematical Geology in 1984 and in 1989 the Distinguished Achievement Award from the APCOM International Council and the Perey Fox Foundation Award in South Africa. In 1987 he received one of the American Society of Mining Engineers highest awards—the Daniel Jackling Award and in 1988 he was made a 'Distinguished Member'. He is the first and only South African to receive these honours. In 1998 The Royal Society of South Africa awarded him the John F. Herschel Medal for outstanding contributions to science in South Africa.

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Fig. 1: Danie Krige ‘on the job’ in 1939.

Vehicle Dynamics

Herbert Scheffel was born in Germany and obtained a degree in mechanical engineering from the Technical University of Darmstadt in 1953. He then emigrated to South Africa in 1955. In 1966 he became head of the mechanical engineering design department of the South African Railways (SAR), where he orchestrated the development of self-steering bogies with axially adjustable axles. For readers in other fields, the 'bogie' is a wheel-carrying chassis that is rotationally attached to the ends of a railway carriage.

An aspiration of Cecil John Rhodes was to build a railway from Cape to Cairo in order to open up the 'dark continent' and exploit its mineral wealth. Motivated by cost reductions and the difficulties associated with building wide-gauge railway lines in mountainous terrain, Rhodes introduced the three-foot six-inch narrow-gauge railway track into Southern Africa. This was a good choice for the relatively slow rail transport used at the time. After WWII the success of this system was recognised by Japan, who adopted both the three-foot six-inch gauge railway lines and the locomotives that went with it. The SAR subsequently learnt several improved maintenance and manufacturing techniques from the Japanese.

As transportation speeds increased, it became apparent that the narrow-gauge carriages of the time were not suitable for high-speed operation. As an added complication, heavy-haul lines often include sharp curves in escarpment regions on the approach to harbours. At speed, the carriages of the time became unstable under cornering—there were high lateral vibration loads on the wheels and tracks, and wear on the rails and wheel tyres became excessive. These problems threatened the viability of the railway, while also attracting the ire of politicians who offered little by way of a solution!

The problem of high-speed stability exercised the mind of Scheffel who was at the time working in the rolling stock design section of the SAR. To cut a long story short, he realised that the bogie suspension and wheel system required re-design [1]. The thrust of Scheffel's work was to introduce a flexible 'cross anchor' bogie with the conventional di-cone wheels replaced with profiled wheel treads that have an increasing effective conicity. This variable-conicity wheel profile allows the inner and outer wheels to accommodate to each other on curves. This self-steering re-design dampened out the lateral forces that produced vibration, and tyre and track wear.

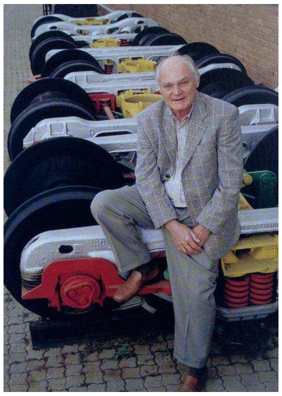

Fig. 1: Herbert Scheffel with various generations of his 'Scheffel bogies' at the Transnet Pretoria Test Centre (photo by Graeme Williams).

Following its introduction into the SAR fleet in 1975, the self-steering 'Sheffel Bogie' significantly reduced tyre and track wear, and provided a stable vibration-free ride. Tyre change intervals increased by a factor of ten (from 10,000 km to 100,000 km), and four out of five maintenance workshop could consequently be closed down. Apart from saving South Africa millions of rands in railway infrastructure management costs, the Scheffel bogie generated much-needed export revenue. Though decades after its initial invention, it is still undergoing development to meet ever increasing performance demands.

In 1975 Scheffel was awarded the Shell Prize for Industrial Design. In 1976, together with Trevor Wadley (inventor of the Tellurometer), he received the Gold Medal of the Associated Scientific and Technical Societies of South Africa. In 1980 Scheffel received the DEng degree from the University of the Witwatersrand for his thesis: 'Development of a high-stability suspension system for railway vehicles'. From 1985 to 1988, Scheffel was the

Chief Mechanical Engineer of the South African Railways. After his retirement, Scheffel founded the company Railway Dynamic Systems, which works collaboratively with the rolling stock manufacturer DCD.

Rory Byrne (1944 —) was born in Pretoria with his name now synonymous with motor racing. While many might assume that he is a mechanical engineer, he in fact graduated with a BSc in Chemistry and Applied Mathematics from the University of the Witwatersrand in 1964. From an early age he was fascinated by 'speed' and vehicular attributes that went with achieving it—aerodynamics and well-balanced light-weight structures. As history would have it, these hobby-related interests seduced him away from chemistry and mathematics and produced a world-famous race car designer. At least for a period, he may well have adopted the mantle of Enzo Ferrari who said: 'I have, in fact, no interests outside of racing cars'.

Byrne's working life began as as chemist in Germiston. He then designed and developed a Formula Ford car, which raced in the South African Formula Ford Championship finishing second in 1972. A combination of hard work, focus and enthusiasm propelled him through the single-seater ranks with Royale, and then the successful Toleman Formula Two team, which subsequently made the jump into Formula One in 1981. In 1986, the team (now Benetton) with Brazilian driver Ayton Senna and powerful BMW engines achieved their maiden success in the 1986 Mexican Grand Prix. After a brief stay with the doomed Reynard F1 project, Byrne returned to Benetton to team up with the young Michael Schumacher who won his first Formula One race in 1994.

In 1996 Schumacher moved to Ferrari, where he was given free rein to build a team of engineers capable of returning the team to the top of the sport after years in the doldrums. Benetton's technical director Ross Brawn was hired, while Rory Byrne was approached to replace the team's then chief designer. Something that is perhaps not widely known, was Michael Schumacher's unique ability to accurately diagnose balance and handling issues with a race car. Schumacher's astute driver feedback accelerated considerably the car's development.

Ferrari were soon competitive again and Byrne began his rise to fame. This was a time when 'aerodynamics' and under-car airflow (ground effect) was recognised as an important untapped resource. Had he still been alive, one can only imagine how Byrne's interests in aerodynamics would have played out with Enzo Ferrari's conviction that 'Aerodynamics are for people who can't build engines.' The 1998 car was Byrne's first design—the following year the team took the constructors' crown. In 2000 Schumacher became the first Ferrari driver to win the championship in more than two decades. Successive championships followed in 2001, 2002, 2003 and 2004. The 2002 and 2004 seasons were particularly impressive. The 2002 season saw a big step forward in car development with wins in 15 out of 17 races. The 2004 season resulted in 15 victories from 18 races, including a record 13 wins for Schumacher. Byrne-designed cars have won 99 Grands Prix, seven constructors' titles and seven drivers' titles.

In 2005 Wits University conferred an honorary doctorate in Engineering on Rory Byrne; Byrne addressed the graduating class of engineers at the graduation ceremony. Rather than sharing stories about the glamorous world of Formula One racing, he spoke, instead, about engineering. What was the secret of his success as a designer? The word he used was 'balance'. In this context balance refers to the maintenance of good grip and handling, while tyres wear and fuel loads reduce. A Formula One car comprises several 'systems' including the tyres, suspension, chassis, power train and the aerodynamic package. The task of the designer, he explained, is to trade-off the performance of each component to ensure that it compliments and supports the rest of the vehicle. There are also the human factors issues to consider—the drive has to like the 'feel' of the car in a way that lends confidence. Byrne is a master at achieving this delicate balance. While the audience at the graduation may have been disappointed to not hear Michael Schumacher stories of derring do, they certainly gained invaluable insights into the art of engineering from one of South Africa's best.

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Fig. 2: Rory Byrne in 2018 in Scuderia Ferrari overalls.