July 2011

UNIVERSITY OF JOHANNESBURG

Faculty of Science NEWSLETTER

IN THIS ISSUE WE FOCUS ON

THE NEXT ISSUE WILL FOCUS ON THE DEPARTMENTS OF BIOCHEMISTRY, BIOTECHNOLOGY, BOTANY AND PLANTBIOTECHNOLOGY, FOOD TECHNOLOGY AND ZOOLOGY.

The Academy of Computer Science and Software Engineering

ACCREDITATION

In 2003 the Academy for Information Technology became the first Information Technology/ Computer Science Department at a tertiary institution in Africa to be accredited by the BCS. Currently, there are only 9 other Universities outside of the United Kingdom that have BCS accreditation. This really puts the Academy of Computer Science and Software Engineering in a league of its own among its South-African counterparts.

For any student enrolling for the four year programme in Information Technology (BSc Information Technology Degree followed by the BSc (Honours) Information Technology), the following benefits apply:

- Fully complying with the educational requirement for Chartered Information Technology Professional
- International recognition of the degrees completed. The accreditation places the degrees completed on the same level and standard as equivalently accredited courses in the United Kingdom.
- An advantage when applying for employment opportunities both nationally and internationally.
- The opportunity to study at a dynamic department with international standing.

The Academy for Information Technology Celebrates its 40TH Birthday

On 28 October 2010 the Academy for Information Technology celebrated its 40th Anniversary with a breakfast event at the School of Tourism and Hospitality.

The event was attended by many alumni students as well as ex staff members.

The Department of Computer Science was formally established by Rand Afrikaans University in June 1970, and took in its first students at the beginning of 1971.The first Chairperson of the Department was Prof Andries van der Walt, who came over from the Department of Mathematics. The first lecturer appointed, and the second staff member of the Department, was (now Professor) Basie von Solms who started on 1 October 1970.

At the end of 1977 Prof Van der Walt left for the University of Stellenbosch, and he was succeeded by Prof Von Solms.

In the 1990s the subject of Informatics was introduced to address the more management aspects of the growing field of Information Technology.

In about 1998, because of substantial financial support from Standard Bank, the Department was renamed to the RAU-Standard Bank Academy for Information Technology. It kept that name till the establishment of the University of Johannesburg, after which it took the name – The Academy for Information Technology.

In 2006 Prof Von Solms resigned as HOD, and was succeeded by the present HOD, Prof Elize Ehlers.

Prof Elize Ehlers

In 2003 the then Department of Computer Science was successful in its application for accreditation of its 3 year BSc(IT) course with the British Computer Society for a 5 year period. At that time the Department was the only accredited one in Africa, and only the third outside the UK. The accreditation was successfully renewed for another 5 years in 2008 for the 4 year BSc(IT) (Hons) degree. This accreditation makes it possible for graduates to achieve the internationally coveted Chartered Information Technology Professional (CITP) status, and puts the Academy's course on par with that of Universities like Oxford and Cambridge who are also accredited in this way.

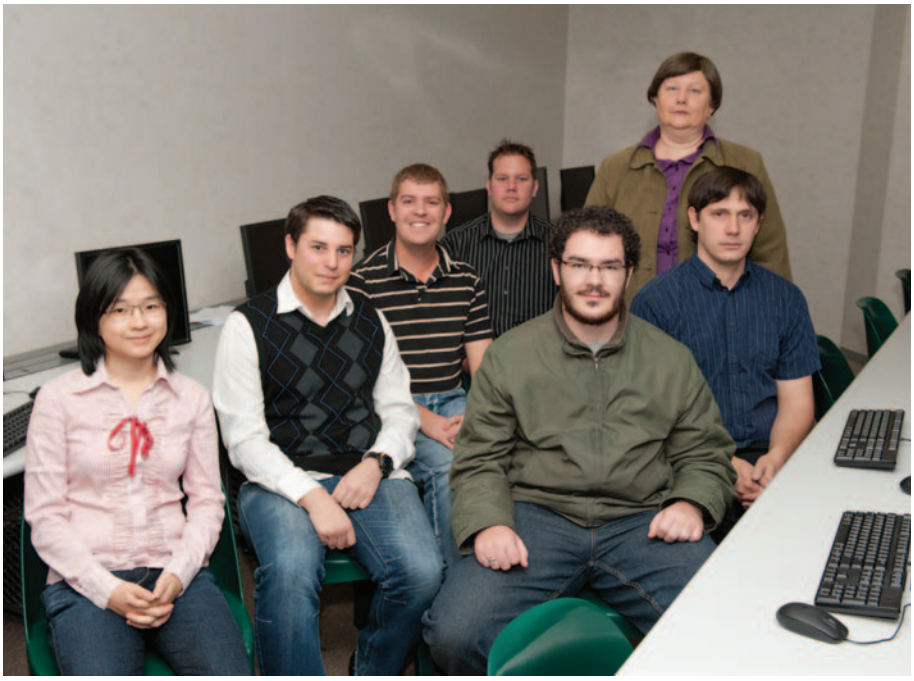
Over these 40 years the Academy has delivered a very large number of graduates and postgraduates in the field of IT – skilled people who are now working all over the world. The Academy has established an enviable research record amongst its international peers, and is continuously disseminating its research results at international conferences.

As from 2011 the Academy will again change its name and will be known as the Academy for Computer Science and Software Engineering (ACSSE) of the University of Johannesburg.

RESEARCHERS IN THE ACADEMY OF COMPUTER SCIENCE AND SOFTWARE ENGINEERING

Professor Elize Ehlers' research group is focused on intelligent agents and multi-agent systems.

The goal of developing artefacts capable of behaving intelligently in the field of Artificial Intelligence has inspired attempts to simulate human capabilities in which machines are able to behave reactively and proactively in an autonomous manner, resulting in the intelligent agent and associated multi-agent paradigms. As developers across a broad range of problem domains strive to develop smarter, more helpful and capable systems amidst an increasingly complex society with wide and varied demands, there is a need to research and develop the ways in which intelligent agents and multi-agents may be successfully applied to make the wide-spread deployment of intelligent artefacts in everyday life a reality.



Prof Elize Ehlers and students (clockwise from left): Wai Sze Leung, Jade Venter, Kieron Ekron, Deon Cotterrell, Prof Ehlers, Duncan Coulter, Mark Heydenrych

Under Professor Ehlers' supervision, projects currently underway include:

Distributed Cognitive Architecture for Co-operative Multi-Agent Learning

TD Barnett

The research aims to develop a distributed cognitive architecture for co-operative multi-agent learning. The architecture is intended to facilitate scalable cognitive machine learning on distributed computer systems and is applied to a simulated robotic search and rescue scenario. The architecture investigates the applicability of emotion, *consciousness*, embodiment and sociability in cognitive architecture design.

Generation of Building Plans Based on User-Specified Information

JJ Bijker

The time taken by architects and video game developers to design fully-furnished buildings may be reduced if building plans can be generated automatically, based on user-specified information such as building perimeter, types and number of rooms. A combination of artificial intelligence techniques such as multi-agent systems, artificial immune systems, ant algorithms and particle swarm optimisation are applied to the development of such a building plans generator.

Applying Learning to Particle Swarm Optimisation in Dynamic Environments

JJ Catto

Swarm Intelligence algorithms can be adapted to solve problems that occur in dynamic environments. In many cases, it can be reasonable to expect the algorithm's current solution will affect the environment in the future, thereby affecting future solutions. To capitalise on the information, the algorithm should be given the ability to learn how its solutions affect the environment. Methods of applying the learning ability to various implementations of Particle Swarm Optimisation (PSO) when applied to the problem of real-time parameter configuration of a next generation mobile telecommunications' utilisation management scheme are investigated.

Symbiotic Agents for Games

D Cotterrell

The introduction of new technologies has forced developers to re-evaluate current strategies in how games are developed. For example, the expectations of players have increased with regards to realism in games while cloud computing has presented additional and novel development challenges. To facilitate game developers, a symbiotic agent merging multiple agents into a single agent is introduced to bring forth a more robust and flexible agent for game development.

Developing Biologically-Inspired Multi-Agent Software

DA Coulter

Exploring the intersection between multi-agent software development and biologically inspired artificial intelligence with a special emphasis on artificial immune systems, open problems in both multi-agent systems and artificial immune systems are addressed through the creation of novel hybrid approaches. Questions which have been successfully addressed as part of this research include multi-agent resource allocation for collaboration purposes and obsolescence management within multi-agent systems. Work is currently underway at addressing multi-agent coordination and improving negative selection coverage within artificial immune systems.

Computational Intelligence-based Data Pre-processing for Data Mining

L de Bruin

The investigation entails developing a computational intelligence (CI) based data pre-processing system for data mining

applications. The system performs pre-processing of relational data. Tasks performed on the data include: classification, clustering and dimensionality reduction, which produces a test set for the data mining algorithms to perform rule mining. The crux of the research is testing the viability of using CI-based techniques for data pre-processing.

A Generic Framework Multi-Agent Life Simulation Learning System
G Doukas

The research examines how the architecture of an agent can be improved by means of artificial life simulation rules so that the system can progressively mature towards solving its specified goal. The creation of generic multi-agent systems using A-Life principles and machine learning are researched to achieve a multi-agent antivirus system.

Distributed Multi-Agent Crowd Simulation
KC Ekron

The research looks at creating a scalable, general-purpose simulation model, making use of intelligent agent technology. The model should be capable of accurately simulating a variety of different crowd scenarios ¬– including evacuations, extreme congestion and general every-day usage.

Critical Information Infrastructure Protection using Multi-Agents
M Heydenrych

The research investigates methods of Artificial Intelligence for use in Critical Information Infrastructure Protection. Specifically, the focus is on a multi-agent learning architecture for protecting such critical systems. In addition, immune agents are being investigated along with economic agents in an attempt to create powerful, adaptable agents able to respond dynamically to many threats.

The Active Detection of Fraud in Financial Information Systems
WS Leung

Fraud detection systems (FDAs) are used to assess transactions, bringing possible fraudulent records to the attention of anti-fraud professionals to follow up. As the financial landscape constantly shifts to innovations from both financial institutions and fraudsters alike, FDAs need to be as accurate as reasonably possible so as not to waste valuable follow-up time. A multi-agent-based FDA model is developed to adapt to such changes.

Wireless network planning and optimisation
P Prinsloo

The research examines how biologically-inspired algorithms may be applied to the automatic planning and optimisation of wireless communication networks so that coverage, capacity and reliability are maximised while the hardware cost and radio frequency interference is minimised.

A Language to Describe Ontogenetic Agent-Based Systems
JA Venter

Agent ontogeny refers to a self-development framework for agents based on the study of the lifetimes of organisms. Much like how DNA is used to describe living organisms, a new architectural description language (ADL) will be developed for ontogenetic agents by evaluating, combining and extending existing ADLs.

Prof Basie von Solms

Prof Basie von Solms is a specialist researcher and post graduate supervisor in the area of Information and Cyber Security. He has an established international reputation as a researcher, and is the immediate past President of the International Federation for Information Processing (IFIP), which represents 60 countries and was established by the UN's UNESCO agency.

The ubiquitous use of the Internet by millions of users has created a range of possible risks which could compromise the privacy, confidentiality and integrity of data and information – for individual users, companies and Governments. This makes the Internet a growing medium for cybercrime, cyber terrorism and cyber warfare. It is therefore essential to keep researching methods and techniques to protect and secure any usage of the Internet. This is precisely what Prof Von Solms and his research team are presently addressing.

Prof Basie von Solms and students (left to right): Ian Ellefsen, Frans Blauw, Manuel Corregedor, Prof von Solms, Jonathan Roussel, Dustin van der Haar

Specific projects and initiatives which are presently active include:

New ways to make the home user more cyber security aware

Cyber criminals are using very sophisticated ways to create attacks against the Internet user. It is therefore very important for all users, including users of social networks, to be aware of such forms of attacks. The team is researching new ways of making Internet users more aware of cyber security risks including the concept of an Internet Security Driver's License.

Prof Basie von Solms

New ways to protect a user's electronic identity against Identity Theft

When accessing any application via the Internet, the user needs some logon information to be identified and authenticated as the real and genuine user. This logon information is part of the user's electronic identity and must be secured and protected at all times. Cyber criminals are anxious to get their hands on this logon information in order to masquerade as the user and compromise the user's privacy, financial assets etc. Presently logon information includes the use of passwords which is not very secure. The team is therefore researching more secure ways of logging on, including biometric methods like electronic fingerprints, electronic face recognition, electronic blood vein recognition, voice recognition etc.

A user's electronic identity can also be compromised by techniques like malicious software, social engineering, phishing, spoofing etc. All these techniques are also researched and counter measures developed.

New ways to protect the home user technically

Today cyber criminals are using very sophisticated techniques which make it basically impossible for the user, specifically the home user, to keep ahead of new forms of malicious software, operating system patches, anti-virus software and related security techniques. Therefore it becomes very difficult, if not impossible, for the user to protect his computer. The team is also researching ways to move such responsibility away from the user and make the Internet Service Provider more responsible for security and protection of the end user...

New ways to protect SA's Critical Information Infrastructure

Many of SA's strategic computer infrastructures are dependent on the Internet for its operation. Such structures include the systems used by banks for internet banking, systems handling strategic services like electricity supply, water supply, some Government services like SARS etc. It is essential that such Internet based strategic services be protected. The team is researching methods to create structures to help protect such Critical Information Infrastructures. The Team is also planning a course in Critical Information Infrastructure Protection in 2012 – this course will be offered by international experts and will be open to 4th year students from all Universities in Africa as well as to delegates from industry.

New ways to protect users of Internet banking against malicious software

Home users whose computers are not properly secured can be infected by malicious software, causing all sorts of problems. The Team is developing a basic *locked down* operating system, specifically for internet banking, stored on a USB memory stick. This solution is much more secure and will drastically lower the risk of infection of the user's operating system and browser.

New ways to secure virtualized systems

In virtualizing an IT environment, serious security risks are possible. A project to create a secure framework for securing virtual systems is being developed.

New ways to advance Cyber Forensics

With the rise in cybercrime, the discipline of Cyber Forensics is growing in importance. A new framework for managing cyber forensics has also been developed.

New ways of oversight over Cyber security in SA

Prof Von Solms is also investigating the role SA's Parliament can play to provide a larger role in overseeing Cyber Security in the country and ensuring users are protected against cybercrime. Contact has already been made with interested Parliamentarians.

The Centre of Competency for Cyber Security and Related Areas

This Centre, which will service Southern Africa, will be involved in research, capacity building and skills development in the area of Cyber Security and Critical Information Infrastructure Protection. Prof Von Solms has already got a positive reply from the International Telecommunications Union (ITU), one of the largest agencies of the UN, to be involved with this Centre. The Centre will hopefully be operational in 2012.

The National Cyber Security Awareness Week

Prof Von Solms is also instrumental in organizing the First National Cyber Security Awareness Week in October 2012. This week will consist of a dedicated program to advance the level of Cyber Security Awareness in SA, concentrating initially on schools and Universities.

Prof Marijke Coetzee and student (left to right): Prof Coetzee, Tristan Lavarack

Supervisors and students: (left to right, front) Prof Marijke Coetzee, Dr Bobby Tait (left to right, back) Tristan Lavarack, Atish Maganlal, William Bezuidenhout

Dr Bobby Tait

Prof Marijke Coetzee

Prof Marijke Coetzee joined the Department in August 2005 as lecturer. Her research focus is on Information Security. As there are many facets to Information Security, she has delimited her research to the following three sub-fields: Information security of web services and services-oriented architecture, trust management, and information security for wireless and mobile technologies. She currently supervises one PhD and six master's students. She has published 33 accredited research papers since 2001.

An important focus of her research is on trust management for distributed systems, supported by web services technologies. The unique proposition put forward by this research is that access control decisions made by the web services access control service are not based only on credentials presented by subjects, but also on the trust relationship with the requestor presenting the credentials. This can be seen as a first step of this kind, and has influenced some other works in this research field. From this work, another project followed with a student that investigates the evaluation and negotiation of machine-readable security policies of providers and consumers. The result of this research is the definition of a tool to assist administrators to determine the level of security supported by a web services security policy using domain vocabularies, fuzzy techniques and domain-specific preferences. This research supported a step towards automated security policy evaluation for web services to support policy intersection processing and further negotiation. In line with the above projects, the governance of information security for service-oriented architectures is being addressed with a student.

She has also cultivated a research interest in wireless security, particularly with focus on Bluetooth and RFID. She has completed projects with students on Bluetooth information security and Bluetooth-based mobile social networks where they proposed the BlueFOAF prototype application that uses a trust mechanism called BlueTrust. As the trust level can be used to share information, work on access control for mobile social networks and a model for a socially-aware mobile tourist recommendation system was completed and published. She and a masters student are currently busy with a project on multi-hop Bluetooth messaging, which could be very useful in environments where no other wireless access exists. She has recently started to collaborate with SAP Research in Pretoria where a masters student on an internship is investigating reputation systems for digital business ecosystems.

Prof Marijke Coetzee

Dr Bobby Tait

Dr Bobby Tait's primary research revolves around different aspects of information security, with a specific emphasis on biometric security. Biometric security and the supporting biometric technologies are often incorrectly perceived as secure and trustworthy, current research projects test this premise with focus on prominent biometric technologies such as finger print, iris, retina, and voice recognition. Vulnerabilities in these technologies are documented and presented in research papers.

Current work in progress involves aspects such as an applied phon curve algorithm for improved voice command interpretation, to assist a robot, or computer system to better understand instructions supplied by a human.

Masters students are currently being mentored in aspects such as improved universal serial bus security – a source of many malware attacks on current operating systems. Secondly, improving the security of RFID tags is another research project currently being mentored, where the vulnerabilities of RFID tags are being investigated, based on the types of vulnerabilities, various suggestions are made for improving security relating to this technology.

White hat hacking is a major interested and very relevant. He is often invited to local conferences (and conferences outside of South Africa, such as Namibia, Botswana, and Zambia) to present discussions pertaining to the ethical hacking processes.

Respected leader in the IT World

Prof SH (Basie) von Solms is a Research Professor in the Academy for Computer Science and Software He had been the Chairman of the Academy for Information Technology from 1978 to 2006. In 2010 Professor Basie von Solms received the Computer Society of South Africa (CSSA) Distinguished Service in ICT Award. A candidate receiving the CSSA Distinguished Service in ICT Award must have been a member of the professional body of the CSSA for at least 10 years, has demonstrated a long-term commitment to the objectives of the Computer Society of SA, has been a role model and mentor showing dedication to the advancement of the ICT industry in SA and has made an exceptional career-length contribution to the ICT industry. Also in 2010, The South African Institute for Computer Scientists and Information Technologists (SAICSIT) awarded the recently founded Pioneers in Computer Science and Information Technology Award to Prof Von Solms for his contribution to Information Technology, and specific Information Security, over the last 40 years. He was also honoured for his international role as President of IFIP, the International Federation for Information Processing.

The 2010 IFIP TC-11 Kristian Beckman Award was also awarded to Prof Von Solms to honour him for his never tiring work towards broadening the meaning of Information Security in various aspects, eg by adding management aspects to the academic perception of information security and by creating the field of Security Governance. The Award was also to honour his work as Chair of TC-11, where he strongly demonstrated the importance of information security within IFIP and the whole field of information processing, and his various achievements in the area of IT Security Education on all levels

Prof Von Solms is the Immediate Past President of IFIP, the International Federation for Information Processing. The South African Academy for Science and Arts announced in April 2006 that the MT Steyn Medal for Scientific and Technical Achievement for 2006 had been awarded to Prof Basie von Solms. The Academy describes the award as follows :

'The medal is one of the most important awards made by the Academy for leadership on the highest level in an area of science and technology. The award is the crown on a life time career, and can only be awarded to a person once in his/her life time. The award reflects the candidate's creative contributions towards the development, organization and continuous expansion of a branch or branches of scientific or technology, where such contribution has played a significant part in the advancement of science and technology, and had also been to the benefit of the country.'

In 2005 he was awarded the ICT Leadership Award by the South African IT industry and the Computer Society of South Africa for 'exceptional thought leadership qualities and sustainable contribution to the development and growth of the South African IT Industry.'

He is a Fellow of the Computer Society of South Africa (FCSSA), and a Fellow of the British Computer Society (FBCS). The Professor is also a Chartered Information Technology Professional (CITP), as well as a SAATCA certified Auditor for ISO 17799.

Microsoft Imagine Cup SA 2010 Awards Ceremony: Mteto Nyati (Microsoft SA MD), Mark Heydenrych (second in Software Design), Clifford de Wit (Microsoft Developer and Platforms Group Lead)

Department of Applied Mathematics

The discipline of Applied Mathematics is best described as one in which problems from real life are solved by the use of mathematical models. The Department of Applied Mathematics, which is located on the APK Campus of UJ, therefore offers educational programmes which include the introduction of applicable Mathematics as well as problem fields from many different fields in Science. Its members are also active in research in a number of important sub-fields in modern Applied Mathematics.

Teaching Programs

The Department offers teaching programmes to roughly 900 students from the Faculties of Science and Engineering and the Built Environment. These programmes are supported by four permanent and three contract staff members.

The **undergraduate program** features introductory courses in mechanics, differential equations, numerical mathematics, optimization and quantum information. The educational model which is followed is a tried and tested one which involves a problem solving approach and which places a strong emphasis on the independence of the student. Promising science students are encouraged to follow the **Computational Science program**. This is a degree program which combines courses in Mathematics, Applied Mathematics, Computer Science, Physics and Electronic Engineering to produce students that can integrate analytical, experimental and computational techniques in the pursuit of Science. Students that are initially underprepared for a degree course are diverted for the first year to the **Extended Program**. Two members of the Department, **Dr Moshe Molelekoa** and **Ms Christel Sciarone**, are dedicated to this program. Making use of intensive educational methods, they manage to produce a strong throughput of students that are well prepared for the second year of study.

The **Honours program** offers fifteen elective modules, all of which are advanced courses related to the research fields of the Department. These modules reflect the wide impact of Applied Mathematics and range from traditional fields such as Lie Algebras on the one hand to modern applications such as Dynamical Systems Theory and Computational Science on the other.

Prof Charles Villet
HOD, Department of Applied Mathematics

Back: Prof Charles Villet, Dr Justin Prentice, Ms Christel Sciarone, Prof Willi-Hans Steeb and Dr Moshe Molelekoa
Front: Mrs Sandra Geldenhuys, Dr Yorick Hardy and Mr Ismael Akhalwaya

RESEARCH IN THE DEPARTMENT

THE RESEARCH DONE IN THE DEPARTMENT IS BEST DESCRIBED BY NOTING THE CONTRIBUTIONS FROM EACH OF ITS MEMBERS.

Prof Willi-Hans Steeb was appointed on contract as Professor in 2011 after retiring at the end of 2010 with 26 years of full time appointment, first at the Department of Physics and then at the Department of Applied Mathematics. Over the years he has contributed too many topics in physics, engineering and applied mathematics such as solid state physics and magnetism, Bose Fermi systems, nonlinear dynamics with limit cycle and chaotic behaviour, symmetries in linear and nonlinear differential equations, solitons, electronic circuits and chaotic behaviour, computer graphics, nonlinear maps and nonlinear differential equations and its connection with integrability.

Over the last few years his research focus shifted to three topics: Quantum Computing and Quantum Information, Nonlinear Dynamical Systems, Genetic Algorithms and Neural Networks and Scientific Computing on the other.

Quantum Computing and Quantum Information: This research is mainly done in cooperation with Dr Yorick Hardy. The focus lies on both finite dimensional Hilbert spaces and infinite dimensional Hilbert spaces. In particular entanglement and teleportation are investigated. Breakthroughs have been achieved in the description of the connection between entanglement and diabolic points. For the infinite dimensional Hilbert space case Prof Steeb concentrates mainly on number states, coherent states and squeezed states, which play a central role in quantum optics. The research results are summarized in the third edition of the book: *Problems and Solutions in Quantum Computing and Quantum Information*. He also investigates how Bose operators and coherent states can be utilised to describe nonlinear dynamical systems.

Neural Networks, Genetic Algorithms and Nonlinear Dynamical Systems: This topic focuses mainly on the application of neural networks and genetic algorithms to dynamical systems with applications to chaos and fractals. Furthermore cellular automata and hidden Markov models are under investigation. Some of the research results are summarized in the 5th edition of their popular book among graduate students and researchers: *The Nonlinear Workbook*. There is also a close cooperation with the Department of Neuroinformatics at the ETH in Zürich. The research focuses on the nonlinear dynamics of the chochlea and hearing problems.

Scientific Computing: Here the focus is optimisation problems, gene expression

programming, multiexpression programming and fuzzy logic. Besides extending the theoretical foundations, software development in C, C++ and Assembler is high on the agenda. Computer algebra is studied in cooperation with Dr Yorick Hardy. In particular the group looks at applications and extensions of their software system *SymbolicC++*. Some of the results have been summarised in the second edition of the book: *Quantum Mechanics using Computer Algebra*.

Prof Steeb is currently supervising a PhD project by Mxolisi Mbandezi on Particle Swarm Optimization and an MSc project by Jacqueline De Greef on Quantum Computing and Spin Systems. He has to date published 244 papers and 53 books. In 2005 his collaborators at ETH (Zürich) organised a celebratory conference in Klosters to mark his sixtieth birthday. It was attended by collaborators, colleagues and students of 8 nationalities.

Dr Justin Prentice started his academic career in the modelling of **condensed matter systems**. This included the problem of the simulation of amorphous silicon-based thin-film photovoltaic devices, using a finite-difference solution of Maxwell's equations appropriate to a multilayer semiconductor structure. This project required two computational innovations, in particular:

(i) The development of a matrix method for computing optical reflectance, transmittance and, most importantly, absorption in the active layer, consistent with the AM1.5 solar spectrum. This method was able to deal with both a photon and a wave model of incident light.

(ii) The development of an algorithm for computing *natural boundary* conditions which could then be used as input for the simulation, when experimental boundary conditions are not known. This algorithm exploited the concept of Fermi level pinning in heavily doped semiconductors. A number of physical properties of a-Si:H cells were investigated using this simulation. These included the effect of surface and interface states at the oxide interface, intrinsic layer phosphorous doping, gap state parameters, limiting carrier effect, spectral response, current-voltage asymmetry and the relation of these to the form of the optical generation rate profile in the active layer.

Dr Prentice subsequently turned to research in more fundamental aspects of **numerical analysis**. He developed a hybrid method for solving initial-value problems (IVPs) in ordinary differential equations, based on explicit Runge-Kutta (RK) methods and Gauss-Legendre quadrature. The method, designated RKGL, is more efficient than its underlying RK method, due partly to fewer function evaluations, but primarily to an enhanced order. RKGL has order one greater than its underlying RK method, leading to a quenching of global error at regular intervals over the region of integration. This quenching slows the accumulation of global error, leading to an enhanced effective order. A detailed study of the error terms for this method was performed. The error has two components and it was confirmed that RKGL preserves the order of the RK local error in its global error. A partially recursive implementation of RKGL, in which RKGL replaces RK within itself a finite number of times, enables a simple low order method such as Euler's method to achieve a high-order character (indeed, Euler's method can achieve fourth order in its global error with such an implementation). The task of approximating univariate functions by means of strict interpolation with Gaussian basis functions has been investigated, wherein the first derivative of the target function is included in the approximation criteria. This mimics Hermite polynomial interpolation, and the algorithm was presented in the form of a piecewise neural network with a linear training procedure. It was found that the network approximation error was two orders better than the case where the first derivative was not incorporated into the network training.

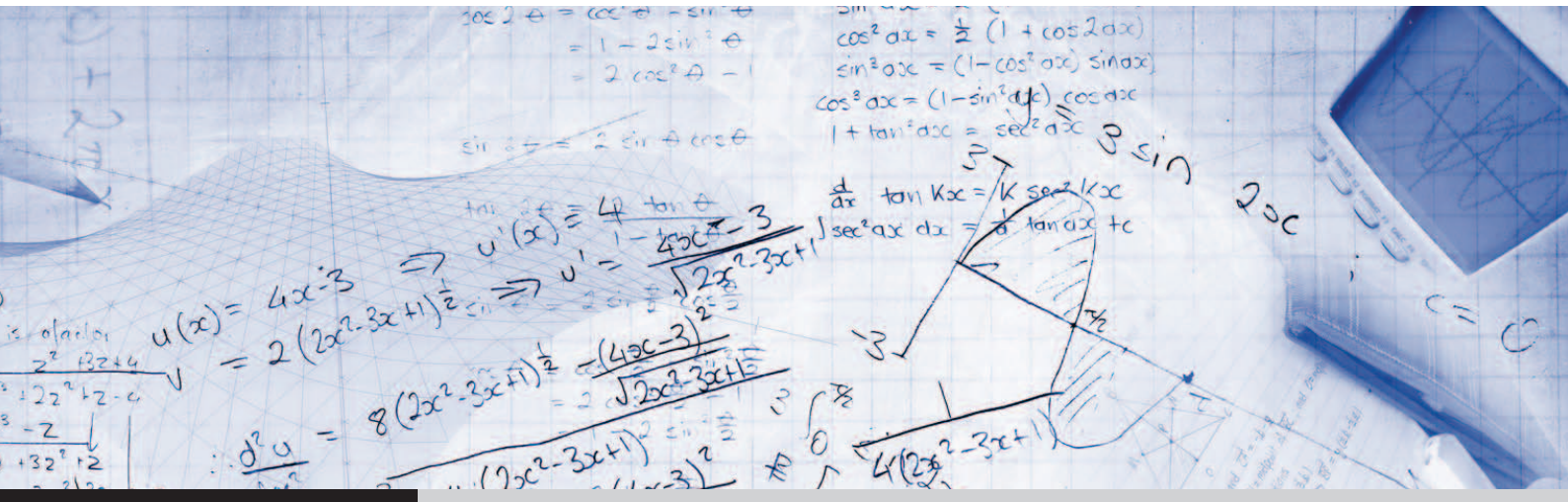
His current research concerns novel aspects of error control in various numerical methods, particularly with respect to relative error. Work done thus far includes (i) general error analysis of three-point finite-difference approximations to first- and second derivatives of a univariate function, taking into account roundoff error, (ii) development of an algorithm for controlling relative error in interpolatory quadrature/cubature, without a priori knowledge of the magnitude of the integral, and with a facility for detecting the need for absolute error control in the case of integrals of small magnitude, (iii) range and domain partitioning in interpolatory polynomial approximation, for reducing computational effort in relative error control, through logarithmic scaling of subintervals, (iv) tri-grid method for relative error control in a finite-difference solution of Poisson's equation, with a determinant-based stability device, and (v) a method for stepwise local and global error control in RK methods, such that a reintegration process is not necessary. Further investigations will consider error control in methods for parabolic and hyperbolic partial differential equations, and nonlinear two-point boundary value problems.

Additionally, some work regarding papers of an educational nature has been conducted, concerning, inter alia, Gaussian quadrature and roundoff error in RK methods. There has even been some overlap with this work and the research described previously.

Dr Yorick Hardy has a background in applied mathematics, mathematics and computer science. He primarily does research in quantum computation and information. In support of this research, Dr Hardy also does research in computer algebra, multilinear algebra and evolutionary computation. Some of this research is done in collaboration with Prof W-H Steeb.

Quantum Computation and Information:
This research concerns entanglement and the generation of entanglement, decompositions of unitary operators based on tensor product structure and the algebraic structures and properties of quantum computation.

Entanglement is an important resource for quantum cryptography, for teleportation of quantum information and for other applications. The generation of entangled states for certain quantum systems has been considered. Genetic algorithms and gene expression programming have been applied to problems such as maximizing certain measures of entanglement.



The quantum bit or qubit is generally used as the basic unit of quantum information. Consequently it is useful to consider operators on qubits coupled with an arbitrary system. In particular systems described by finite dimensional Hilbert spaces are considered. Quantum computations are then described in terms of unitary operators on a product Hilbert space. A decomposition of a class of unitary operators on these product spaces with Schmidt rank 4 has been discovered with interesting properties when considered as communication of quantum information between two quantum systems. Work is ongoing to generalize this decomposition to all unitary operators on such product spaces. Some of this work will appear in the book *Problems and Solutions in Quantum Computing and Quantum Information* (3rd edition) (World Scientific, 2011).

The implementation of β reduction in the λ calculus and the linear λ calculus in quantum systems is also being considered.

Mr Jaco Le Roux is completing an MSc degree in quantum computation. He investigates current models for optical quantum computing, their simulation using computer algebra and mathematical methods for reducing unitary operators for optical quantum circuits to a sequence of simpler known quantum circuits.

Computer Algebra: SymbolicC++ is a computer algebra system embedded in the programming language C++. It was developed by Dr Hardy, Prof Steeb and Tan Kiat Shi. SymbolicC++ is described in the book *Computer Algebra using SymbolicC++* (World Scientific, 2008). SymbolicC++ has been used for many applications in quantum mechanics and quantum computation (*Quantum Mechanics using Computer Algebra*, World Scientific, 2010).

SymbolicC++ development is ongoing and releases under the GNU public license are made regularly. Current work focuses on reimplementation of the Gröbner basis algorithm and on implementation of the various symbolic integration algorithms. In the longer term an implementation of the Risch algorithm is planned.

Multilinear Algebra: Mathematical techniques in quantum computation and information is an important application of linear and multilinear algebra with special sessions at linear algebra conferences now being dedicated to quantum computation and information.

Techniques from multilinear algebra are applied to entanglement and to the algebraic structure for quantum computation. In particular the commutation relations of unitary operator have been investigated. The problem to determine when the commutator of two unitary operators is again unitary has been solved for unitary operators acting on coupled systems described by two dimensional Hilbert spaces. Current research focuses on the commutators of unitary operators on higher dimensional Hilbert spaces and on anti-commutators of unitary operators.

Decompositions of matrices are also being investigated, in particular of unitary matrices, and the decomposition of unitary matrices over tensor products of finite dimensional Hilbert spaces are the subject of ongoing research. Some of this work appears in the book *Matrix Calculus and Kronecker Product* (2nd edition) (World Scientific, 2011).

Dr Hardy is also currently the supervisor for Ruth McDonald, who has just completed an MSc project in the field of Symmetry Methods in Differential Equations.

Mr Ismael Akhalwaya is active in two fields of research.

Quantum Information is the study of physical processes that acts on quantum systems when viewed from an information theoretic point of view. The fundamental questions involve the entropy and entanglement quantification, and the storage and transmission of quantum information.

The domains of application of quantum information include the practical (quantum simulations of pharmaceutical drugs), the scientific (quantum metrology), the covert (quantum cryptography) and even the philosophical (quantum interpretation and the fundamental physical foundations of the universe).

Research that is currently carried out includes the study of the capacity of Noisy Quantum Channels. The capacity is the amount of information that can be transmitted through the channel per use. Channel Capacity is crucial to the information age. A correct understanding of the maximum amount of information that can be transmitted through a channel and its concomitant encoding permits efficient use of the available resources. Channel capacity theory is the basis of technological communication. The next major advancement in the field of communication is the move from classical channels to quantum channels, which brings with it new unrivalled possibilities such us Quantum Cryptography. To correctly understand the Channel Capacity requires research into new tools and methods.

High Performance Computing (HPC) is a crucial modern pillar of science, increasingly as important to the methodology of science as experimentation. It enables the exploration of regimes that were previously inaccessible, by rendering high-fidelity simulations, thereby enabling deeper analysis and hidden insights. HPC also dramatically improves research turn-around-time by providing rapid feedback to the modelling process. Finally, HPC nurtures technical expertise that have spin-off benefits to the computing and information technology industry.

The research that is currently carried out is mainly concerned with applying HPC techniques to Monte Carlo simulations. Though future research may delve into investigating the actual techniques themselves. Monte Carlo simulations lend themselves very naturally to parallelisation and take full advantage of the power of supercomputing.

Prof Charles Villet has done research and published in the fields of Nuclear Physics, Solid State Physics and Dynamical Systems. Presently he works on aspects of Dynamical Systems and Celestial Mechanics.

Dynamical Systems: One aspect of modern dynamical systems theory which is very striking is that of chaotic motion, i.e. behaviour by a deterministic system which seems to be random. This phenomenon has over the past few decades been exhaustively investigated and is now well understood. A surprising property of chaotic systems however is that they offer opportunities for critical control methodologies. One such method (the so-called OGY method) has been applied in a study at this group to an involved dynamical system (the coupled logistic map). A novel numerical procedure resulted in a numerical method that allows one to target a stable configuration of the system in an optimal way. This procedure will next be studied for other coupled systems.

Celestial Mechanics: One of the problems in our understanding of the formation of our solar system is that of bodies with orbits which do not lie in the plane of the ecliptic. From the theory of two-body systems it is not possible for the Sun to capture such bodies in order to stabilise them in closed orbits. It is therefore necessary to introduce a third body in an effort to effect so-called gravitational capture. Of course, the three-body problem is non-integrable and very sophisticated numerical methods need to be implemented to study the problem. Keegan Anderson is at present completing a MSc project on this topic under the supervision of Prof Villet.

Support Staff

The departmental secretary, **Mrs Sandra Geldenhuys**, has been with the Department for more than 20 years. She delivers an invaluable service to the Department by handling all academic administration for its 900 students. Her biggest value though concerns the production of high quality mathematical documents. Her mastery of high-level tools such as LaTeX and CorelDraw allows the Department to adhere to the highest standards set by journals and publishers.

Department of Statistics

Since the merger of UJ, the Department of Statistics is based on 4 campuses of UJ with 14 permanent staff members. The majority of courses offered are introductory statistics courses to approximately 7000 students in the Faculties of Engineering and the Built Environment, Financial and Economic Sciences, Humanities and Management. Apart from the service courses offered to these students, the Department also offers statistics as a major subject to students studying mathematical sciences. The main cohort of students in the Department mostly studied Actuarial Science until 2003 at which time the degree was phased out. From 2003 onwards the focus of the Department turned to Financial Mathematics, a new degree that was introduced at that time.

Emeritus Prof Freek Lombard renowned researcher

A distinguished member of the Department during the past 23 years, Prof Freek Lombard, retired at the end of 2010. In 1998 and 2006 he has won the Sichel Medal award, an annual award to a member of the South-African Statistical Association (SASA) with the best publication in a particular year. Currently he is also a fellow of SASA and a member of the American Statistical Association. For the past 10 years Prof Lombard was appointed 3 months per year as a visiting professor at Texas A&M university in the United States. During his career in the Department of Statistics he delivered numerous MSc and PhD students in a wide variety of statistical fields of which the majority of research fields were related to time series analysis and stochastic processes.

Prof F Lombard (Emeritus)

Currently the Department still uses his services for supervising masters and doctoral students.

Mr Wickes Robbertse
HOD, Department of Statistics

Dr T Kaseke, Mr J Van Appel, Ms H Sonnekus, Mr W Robbertse, Mr S Malandala, Mr N Crotty

RESEARCH

The main fields in which research is undertaken in the Department are Financial Statistics and Industrial Statistics. The applications are primarily in finance and in industrial quality control. The research in finance involves the study risk and finacial instruments. Industrial research is done in collaboration with ESKOM.

Prof Lombard and Dr Potgieter are working on problems where two random variables *X* and *Y* belong to the same location-scale family if there are constants a and b such that *Y* and *a+bX* have the same distribution. They consider non-parametric estimation of the parameters *a* and *b* from independent samples under minimal assumptions regarding the form of the respective distribution functions. They discuss an approach to the estimation problem that is based on asymptotic likelihood considerations. The results enable them to provide a methodology that can be implemented in finite sample situations and which yields estimators that are often near optimal. The performance of the estimators is evaluated in a series of Monte Carlo simulations. Furthermore, in testing whether two samples come from the same location-scale family, they consider a test on the empirical characteristic functions of the standardized samples. As with tests based on empirical distribution functions (EDF), the tests considered by them are not asymptotically distribution free. However, unlike the EDF method tests, the bootstrap does provide a reasonable approximation to the distributions of the test statistics. Only in the case of an underlying Cauchy distribution they note that the bootstrap performs poorly. The relative powers of the tests are illustrated in a Monte Carlo simulation.

Prof Lombard and Dr Potgieter are also working on industrial applications of statistics. Particle size analyses of a raw material are commonplace in the mineral processing industry. Knowledge of particle size distributions is crucial in planning milling operations to enable an optimum degree of liberation of valuable mineral phases, to minimize plant losses due to an excess of oversize or undersize material or to attain a size distribution that meets a contractual specification. The problem addressed is how to test the equality of two or more underlying size distributions. The problem stems from a desire to test for bias when sampling a stream of material using a mechanical sampling device rather than a (superior but operationally infeasible) stopped belt method. They propose a robust test procedure based on ranks as a competitor to Hotelling's T-Square. In contrast to the latter statistic, the power of the rank test is not unduly affected by the presence of outliers or of zeros among the data.

Prof Lombard and Mr R Maxwell's research involves an application in astrophysics, where they propose a sequential cumulative sum (CUSUM) procedure based on a martingale difference sequence to detect deviations from uniformity in angular data. In this research they show that the applicability of the

Frederik vd Walt

theoretical results is supported by Monte Carlo simulation results.

Prof Lombard and Dr J Lyman (Australia) are working on the Grubbs estimation of the precision of an online gauge. Typically, this type of estimation involves independent results from two or more reference instruments (sampling and laboratory analysis operations). The properties of the estimator are then independent of the product variability. However, the use of more than one reference instrument entails significant additional costs. The two instrument Grubbs estimator, which is based on results from a gauge and a single reference instrument, has the unpleasant property that its standard error is heavily dependent on the degree of product variability. They propose a new estimator that has a variance that is more or less independent of product variability. In fact, the variance is typically less than that of the Grubbs estimator based on the use of two reference instruments.

Prof Lombard and Mr Robbertse's research is based on long memory time series. This phenomenon has been observed in numerous scientific areas such as hydrology, Ethernet traffic data, stock returns and exchange rates, to name just a few. Many methods have been proposed to estimate the long memory parameter H. However, in many instances the statistical properties of the different types of estimates are largely unknown, hence this estimate is not of much use in statistical inference. Furthermore, for long time series, maximum likelihood estimation can be computationally demanding due to the large dimension of the covariance matrix. In particular, they are investigating the estimation of the long memory parameter in the context of fractional Gaussian noise. They show that fractional Gaussian noise may be transformed to a short memory process by taking first order differences. Then H may be estimated in large samples by dividing the data into disjoint blocks of data, estimating H for each block of data and then averaging the estimates to obtain an overall estimate. Due to the short memory properties of the differenced fractional Gaussian noise, one may assume approximate independence between the estimates of H. Therefore averaging the estimates leads to a fast and efficient approximate likelihood method. Another aspect of investigation is that in some time series H appears to be changing over time. They propose a permutation test to test the null hypothesis that H stays constant and show through Monte Carlo simulation that the permutation test has good power for rejecting the null hypothesis when it is false. Two advantages of the permutation test is that (i) one does not need an asymptotic distribution for the test statistic to test whether H stays constant or not and (ii) it may also give an indication of the location in the time series where the value of the parameter changes.

Prof Lombard and Mr Van der Walt are researching reduced form models for estimating credit risk in large retail loan portfolios. The standard approach towards quantifying portfolio credit risk rests on the use of so called structural models which consider directly the relationship between outstanding loans and underlying asset values. The application of this approach to large retail credit portfolios is problematic because of the general unobservability of true asset values of individual obligors. Reduced form models, which are based on stochastic point processes that describe individual defaults, seem to provide a more flexible approach to the problem. In particular, these models are more amenable to stress testing than the standard structural models. The objective of the research will be to develop a number of reduced form models and to gauge their applicability to data obtained from a large South African bank. The methodology is based on point process theory coupled with methods from survival analysis and the stochastic calculus of continuous martingales, the latter being used to describe the time-evolution of appropriate macro-economic indicators. Among aspects that will be investigated are (1) the selection, using statistical techniques, of appropriate covariates which will include a number of macro-economic indicators (2) the transformation of a distribution of times-to-default into a numerical default probability and (3) a data-based comparison of the efficacy of reduced form and structural models in the context of large retail loan portfolios. It is expected that the research will result in reduced form models that can be applied successfully to predict default rates for large retail loan portfolios. Existing structural and reduced form models are focused mainly on corporate loan portfolios or on individual corporate entities. Comparisons between the models are seemingly also restricted to this context.

Prof Lombard and Mr Crotty's research focus on the estimation of treatment effects in censored matched pair data. There are no established statistical methods for the estimation of general treatment effects that incorporate matched paired data when censoring is present. The objective of this work is to develop such methods. The research will result in hypothesis tests for linear effects, confidence regions for effect parameters and tests of the applicability of linear effect models. Prof Lombard previously considered matched paired data but censoring was not taken into account. Methods that are applicable to censored data have only considered independent samples. Current methodologies include the bootstrap, a regression based method, and the construction of confidence tubes for a treatment comparison function applicable to censored data. The research will impact medical, financial and industrial fields where such data are commonly encountered. The quantile comparison function (QCF) which compares the marginal distributions will be used as a measure of treatment effect. The methodology developed by Prof Lombard will be extended to the case of bivariate censored data giving rise to a nonparametric estimate, as well as nonparametric confidence bands using a Kolmogorov-Smirnov type statistic. Methods of estimating parameters in a linear QCF are also being investigated.

Prof Lombard and Mr De Jager's research is concerned with modeling discrete time default rates using survival analysis techniques. In particular, they investigate the use of survival analysis in modeling and predicting corporate default rates, with specific emphasis on discrete time data. The results of the study will compare the current techniques available in the literature, as well as the application of these to South African banking

data. The idea of using survival analysis, specifically in the modeling of corporate default rates, is a field that has only recently emerged in the literature. In addition, these techniques have apparently not been applied to South African banking data. Survival analysis generally deals with data measured in continuous time. However, the primary focus of this study will be the case of discrete time data because default in actual fact occurs in discrete time. Such an approach provides additional modeling challenges but also practical benefits. Standard techniques of survival analysis such as Cox's proportional hazards model and default rate modeling using point process ideas will be used. Maximum likelihood estimators of parameters in various models will be compared in respect of their biases and variances. The selection of appropriate explanatory variables plays a key role in survival analysis which will be further explored by applying a relatively new variable selection technique called the Lasso.

Mr Robbertse and Mr Van Appel's research involves the estimation of parameters in interest rate models and the application thereof in the pricing of bonds, bond options and other interest rate derivatives. Some estimation methods perform better than others when factors such as sample size and choice of model are taken into consideration. Typical estimation methods used includes least squares estimation, maximum likelihood estimation, empirical likelihood estimation and the generalized method of moments. Some models have the pitfall of underestimating parameters in which case procedures such as the bootstrap and jackknife can be used to correct the bias of those parameters. Furthermore, in the context of certain interest rate models, explicit formulas for interest rate derivatives such as bonds or bond options cannot be obtained. In those cases numerical procedures such as numerical integration and Monte Carlo pricing can be used as an alternative. The majority of interest rate models all have a Brownian motion as driving stochastic process, so one may be fitting a normal distribution incorrectly to skewed data. Therefore, replacing this driving process with a more general stochastic process, namely a Lévy Process, they may be able to better model interest rate data which violates the assumptions of normality. Incorrect model selection or estimation method may have as a result that these products are under- or overpriced, leading to arbitrage opportunities in the market. Their aim is to find robust model(s) and method(s) to apply in the South African interest rate market and to determine the price sensitivity of interest rate derivatives based on the chosen model for the underlying interest rate process.

Mr Van der Walt and Ms Sonnekus are investigating some methods currently used to measure risk in the financial sector as well as new methods that can be applied on the South African markets. One of the problems faced by risk analysts is that most statistical methods are based on some assumptions, which generally cannot be justified in practice. Another problem is the lack of availability of suitable data to test the methods on. Previously some methods have blindly been adopted from overseas textbooks without taking into account the differences between the overseas markets and the South African markets. It is however important to investigate all the different risk measures used for overseas markets, not just the American markets. All financial institutions are currently looking for more accurate risk measures.

Dr Kaseke and Mr Malandala are investigating the use of conditional Copulas in estimating value at risk and in stochastic portfolio optimization. The recent financial crisis has had and continues to have an impact on the South African economy and in the world economy at large. In fact, the economy is still recovering but many questions related to the financial crisis are still without answers. There is a perception that risk was not adequately taken into account. It becomes important to measure and estimate the risk because investors are and will be always concerned with the risk on their investments. The primary objective of their research is to answer the following two questions: (i) how can the value at risk of a portfolio be estimated on the basis of selected exchange rates between the South African Rand quoted against the British Pound, Japanese Yen and US Dollar, and (ii), how can the risk be minimized or reduced to an acceptable and desire level. The expected outcome is believed that using conditional Copulas may provide better estimates of value at risk and that Copulas may be able to address drawbacks inherent in normality assumptions, non-linear dependence and fat tails of return distributions.

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