ABOUT iCORE

Mission

The mission of the Alberta Informatics Circle of Research Excellence (iCORE) is to attract and grow a critical mass of exceptional researchers in the field of informatics, that is, areas of computer science, electrical and computer engineering, physics, mathematics and other disciplines related to information and communications technology (ICT).

Target areas

iCORE is directing its support to areas in which Alberta has a chance to develop internationally recognized research teams. It is also focusing on areas in which Alberta companies are active, so that intellectual property and valuable knowledge workers resulting from iCORE's investment will have compelling reasons to stay in Alberta.

THE ROLE OF THE ALBERTA INFORMATICS CIRCLE OF RESEARCH EXCELLENCE

iCORE was established in October 1999 by the Government of Alberta to foster world-class university-based research that supports the ICT sector. This investment stems from a belief that strong fundamental research is at the core of a healthy economic sector, which in turn creates social, cultural and economic advantages for Albertans.

Focus on people

iCORE invests in people - the highest caliber research scientists who work on fundamental and applied problems in informatics. Around these leaders, world-class research teams are developed.

For more information on iCORE's strategy and areas on research focus, visit www.icore.ca

FLAGSHIP GRANT PROGRAMS

Chair and Professor Establishment (CPE) Grants

iCORE Chairs are awarded to exceptional researchers with outstanding research records that place them in the top five percent of their fields. iCORE Professors are mid-career researchers with outstanding potential whose record may not yet justify a Chair position.

Research teams funded may vary in size from a single Chair or Professor working alone to teams with ten or more members. iCORE funds can be used to cover the salaries of chairs, professors, research associates, postdoctoral fellows and graduate students, as well as some research operating and equipment costs. The research itself may range from fundamental to applied.

CPE grants are normally awarded for five years, represent one-half or less of the total budget, and are renewable on a competitive basis.

Industry Chair Establishment (ICE) Grants

iCORE Industrial Chairs are awarded to researchers undertaking high-caliber internationally competitive research. Industrial Chairs are always developed in conjunction with a sponsor company (or companies) that has demonstrated a willingness and ability to collaborate closely with the research team, and to exploit proposed research in Alberta. The program is also typically matched with NSERC awards.

Funded research teams may vary in size from one to ten or more members, and may include a Chair, professors, research associates, postdoctoral researchers, graduate students and research staff. The funds may also cover operating and equipment costs.

ICE grants are normally awarded for five years, represent one-third or less of the total budget, and are renewable on a competitive basis.

EMERGING CLUSTERS

NETWORKS AND RELATED INFORMATICS THEORY		START DATE
Wireless Communications	(Dr Norman C. Beaulieu)	2000-01
Advanced Information Processing Systems	(Dr Graham Jullien)	2000-01
Wireless Location Research	(Dr Gérard Lachapelle)	2000-01
Wireless Internet Modeling	(Dr Carey Williamson)	2001-02
High Capacity Digital Communications	(Dr Christian Schlegel)	2001-02
Number Theory and Cryptography	(Dr Hugh Williams)	2001-02
Wireless Science and Technology	(Dr Jim Haslett)	2002-03
NANOTECHNOLOGY		
Nanoscale Engineering Physics	(Dr Michael Brett)	2000-01
Nanoscale Engineering Physics	(Dr Mark Freeman)	2000-01
Nanoscale ICT	(Dr Robert Wolkow)	2002-03
Quantum Information Science	(Dr Barry Sanders)	2003-04
SOFTWARE SYSTEMS		
High Performance Artificial Intelligence	(Dr Jonathan Schaeffer)	2000-01
Software Engineering Decision Support	(Dr Guenther Ruhe)	2001-02
Reinforcement Learning	(Rich Sutton)	2003-04
Intelligent Oils Sands Mining Systems	(Hong Zhang)	2003-04

SUPPORT PROGRAMS

Graduate Student Scholarships (GSS)
- Designed to recruit exceptional graduate students
- Operates in conjunction with NSERC, Alberta Ingenuity and other major awards.
- Up to two hundred awards annually.

Visiting Professor (VP) Grants
- Designed to bring internationally recognized researchers to Alberta for six months to two years to develop partnerships and possibly recruit Chairs or Professors.

ICT Strategy Planning and Recruiting (ISPR) Grants
- Designed to support the interaction with potential candidates for the major award programs.
- Supports ICT conferences and workshops in the province in areas where a Chair or Professor award may be made.

The iCORE Lectures
- A lecture series with iCORE award holders held at a host university and broadcast live to the other universities in Alberta via the Alberta Video Classroom Network. *Also available as a webcast.*

Banff Summit
- An annual event commencing in 2004.
- Week-long think tank of Alberta and international ICT researchers
- Focused workshop bringing iCORE researchers and industry together to work on current issues in ICT research.

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Contents by Cluster

PREFACE

The premise for the creation of iCORE in 1999 was that an investme in top information and communications technology (ICT) researchers would stimulate an ever-widening circle of excellent research. This volume, the second annual Research Report, is testament to that vision. The quality and volume of research activity documented here is breathtaking. The research teams funded in the first year are setting a remarkable pace; newer teams are establishing themselves. The most recently awarded teams are joining the hundreds of researchers already in place.

The collective activity - this circle of research excellence - is a new phenomenon for Alberta. These researchers are developing many ICT research projects, leading and participating in international collaborations, and fertilizing laboratory research with commercial potential in Alberta. The last year alone has seen significant developments not only in the specialized target research areas for Alberta, but in the spillover effect this has had on Alberta's reputation for students in science and engineering.

Alberta universities now attract one quarter (24 percent) of all of the highest ranked graduate students in Canada in computing science and electrical and computing engineering, up from just six percent when iCORE first started. However, the most significant strides are in iCORE's central project - the development of emerging clusters in target areas where Alberta has a chance of reaching a critical mass of activity and achieving the resulting economic vibrancy. These achievements are documented in this report.

Brian Unger, President and CEO

INTRODUCTION: Building on Success

This research report represent the achievements of our iCORE Chairs, Professors and research teams over the past year. As these programs unfold we see the emergence of three clusters of research excellence. The first, and largest, cluster is in "networks, communications and informatics systems," covering basic to applied research areas from basic signal processing (Beaulieu) and devices (Schlegel, Jullien, Haslett) through to network design and systems management (Williamson), security (Williams) and applications in wireless location/navigation systems (Lachapelle). The second cluster, "nanotechnology and quantum computing," includes research into the physics of nanoscale materials and processes (Freeman, Wolkow) as well as quantum computing (Sanders, coming in September 2003), and their applications to new materials (Brett). The third cluster is broadly termed "advanced software systems" that includes fundamental research into new intelligent and high performance software systems via machine algorithms (Schaeffer) and software engineering (Ruhe), as well as machine learning (Sutton, coming in August 2003),

The clusters now in place have had an exceptionally productive year.

NETWORKS, COMMUNICATIONS AND INFORMATICS SYSTEMS

Signal Processing

This year, **Dr Norman Beaulieu** and his team have focused on the development of more efficient and robust antennae and more general wireless communications signal processing problems. The Wireless Communications team has:

- brought $915,405 of additional funding to the iCORE research program.
- had a remarkable number of journal and conference research papers published or accepted in the reporting period.
- Filed one Report of An Invention with the University of Alberta Industry Liaison Office.
- made strong contributions to the training of highly qualified personnel. One PhD thesis and two MSc theses were completed under his supervision in the reporting period. Currently, Dr Beaulieu is supervising six MSc candidates, ten PhD candidates and three postdoctoral fellows at the University of Alberta. In addition, he is supervising two PhD candidates at Queen's University.

Dr Beaulieu received distinguished recognition by being elected a Fellow of The Royal Society of Canada, and by being appointed to the Executive Committee of the Royal Society and he continues to serve in the reporting period as Editor-in-Chief of the IEEE Transactions on Communications.

Communication Channels

Dr Christian Schlegel's primary focus is on high-capacity digital communications through real-world communications channels, in particular, wireless data links. This year his team has:

- designed and constructed a prototype multiple-input multiple-output channel measurement system
- conducted initial channel measurements which confirm theoretical expectations as well as results obtained by other laboratories.
- Enhanced this system for real-time operations as well as full portability.

On the analog decoder research side, advances include:

- the design of a medium-sized product code analog subthreshold CMOS decoder that will enter the production phase this summer and testing later in the year.
- Initial measurements and projections based on simulations confirm that analog technology has the potential to outperform digital decoders by two orders of magnitude in power

consumption and space requirements, and thus can challenge current digital designs and possible displace them in the future.

Current efforts of team members are to prove feasibility with real input and output circuitry.

The HCDC laboratory has also:

- generated 30 technical publications which are currently at various stages in the publication process.
- Dr Schlegel has been appointed General Chair for the IEEE Communication Theory Workshop 2005, and Technical Program Chair for the 2005 International Symposium on Information Theory.

Networks, Communications and Informatics Systems: Devices and Systems

Dr Graham Jullien's laboratory conducts research into the implementation of information processing systems using advanced and emerging technologies. A major achievement this year has been to assemble the Centre for Innovative Wireless Integrated Microsystems (CIWIMS), and to define a CIWIMS Laboratory Cluster. The Cluster provides a stimulating environment in which the researchers skill set includes: wireless-RF; wireless-location finding; bio-sensors; system-on-chip processors; thin-film and fabrication-integration; health sciences. Current projects include: wireless networks; embedded systems and fault tolerant systems; and the modeling and simulation of circuits and structures in advanced and emerging fabrication technologies.

Highlights include:

- arithmetic techniques for applications as varied as low-power hearing instruments, 400M samples per second adaptive wireless base station filters, and extremely low noise digital processing circuits
- machine vision techniques for analyzing defects directly within the camera in real-time
- several novel video coding architectures for multi-media streaming.
- The Laboratory has a core personnel component of about 30 researchers and students, and workstations host more than 50 graduate students performing research on all aspects of integrated circuit design.

Research is conducted with the support of major Canadian industries, and the team is a member and lead client in the Canadian Microelectronics Corporation System-on-Chip Research Network, funded by a $40 million CFI grant, that is being used to bring the technology of system-on-chip design to all interested Canadian universities.

Dr Jullien was elected a Fellow of the IEE this year in recognition of his outstanding contributions to the area. Fellows of the IEEE constitute only 0.1% of all current members.

Dr Jim Haslett, as an iCORE Industrial Research Chair, is funded by TRLabs, iCORE and NSERC. He and his team are focused on developing, in conjunction with the TRLabs Wireless Research Center in Calgary, a sophisticated wireless RF Integrated circuit design and test capability. The research program began in May of 2002, and in the ensuing 11 months, a team of 12 graduate students and two postdoctoral fellows has been assembled by Dr Haslett to carry out the chair mandate. Close collaboration with staff scientists at TRLabs, and extensive collaboration with other researchers and industrial sponsors has resulted in an excellent list of accomplishments for the first year of the chair program. The student team currently consists of four PhD students, and nine MSc students.

Dr Haslett and the research team have been successful in bringing in significant external funds to complement the $600,000 annual chair budget.

- In the past 11 months, an additional $244,368 has been obtained by Dr. Haslett as principal applicant, to support the research program, excluding the student scholarships which amount to an additional $209,000 per year.
- Other funding has been obtained with Dr. Graham Jullien.
- During the year, 23 new RF ICs designed by the research group were fabricated through the CMC, and the results published in a variety of conferences and journals.
- Two new patent applications were filed through TRLabs.
- A national award and a local award were received by the students for some of the work.
- A number of new collaborative research

projects were initiated, and a team of 10 principal researchers, including Dr Haslett, is currently preparing a CFI grant application to provide additional infrastructure to support the research programs.

Wireless Location/Navigation Devices

Dr Gérard Lachapelle's research focuses on outdoor and indoor wireless location, high performance navigation and positioning using satellite and ground-based RF techniques, and fusion with self-contained sensors for personal navigation. This year he has:

- managed 10 major research projects ranging from indoor location using satellites to high precision positioning using satellite signals integrated with self-contained sensors and the development of a software Global Navigation Satellite System receiver.
- These research projects resulted in personnel training, publications and intellectual property transfer.
- Personnel training consisted in the completion of one MEng and four PhD students directly supervised or co-supervised by the chair, the hiring of four senior research associates and the supervision and co-supervision of 21 MSc and PhD candidates, including 10 that began during the reporting period.
- Eleven papers were published and five were accepted for publication in refereed journals, and 15 were presented at conferences.
- Intellectual property transfer consisted of licensing of software and in technology transfer through external contracts and grants valued at $350,000.
- New partnerships were established with ARINC, U.S.A., Tampere University of Technology, Finland, and the University of Carleton.
- In recognition of their efforts, numerous members of the team and collaborators received awards and have been invited to speak at events across Canada and abroad.
- Thanks to the success of the chairholder and his collaborators in securing external sponsors for the above research activities, another $1.6M was raised in funding.

Network and Communication System Software

Dr Carey Williamson leads a research team of a dozen members (graduate students and research staff), with interests in wireless networks, Internet technologies, and network performance. Much of the research is experimental in nature, with an applied focus on industrially relevant network and protocol performance issues. The highlights of this reporting year include:

- expanding the team to seven graduate students, three of whom hold major scholarships.
- * funding from Telus Mobility and iCORE for an Industrial Research Chair in Wireless Internet Traffic Modeling.
- authoring or co-authoring 16 research papers (2 journal, 6 conference, 8 submitted),
- developing intellectual property regarding wireless Web servers
- building Phase 1 of the CFI-funded Experimental Laboratory for Internet Systems and Applications (ELISA)
- receiving an undergraduate teaching award.

Security

Dr Hugh William's team in Algorithmic Number Theory and Cryptography has the goal of creating a recognized centre of excellence for education, research and industrial cooperation on computer security at the University of Calgary. Mathematical modeling secure encoders, cryptographic codes, and algorithm development are key interests for this team. At the end of March 2003, a number of key milestones were achieved:

- the establishment of the Centre for Information Security and Cryptography which was inaugurated July 17th, 2002.
- further progress toward getting the cryptography laboratory up and running, and successfully applying for a Mathematics for Information Technology and Complex Systems (MITACS) grant.
- continued with their high level of journal publications.
- Graduate student numbers are steadily increasing
- continuing work with other institutions in Canada, the United States and abroad.

NANOTECHNOLOGY AND QUANTUM COMPUTING

Nanotechnology

Dr Michael Brett and Dr Mark Freeman's Nanoscale Engineering Physics Initiative has concluded its second year of operation. Major research accomplishments this year included:

- experimental demonstrations of spatial and temporal control of magnetization dynamics in mesoscopic structures (and better understanding developed through numerical simulations)
- highly controlled growth of large-scale square spiral structures for photonic crystals.

Nanocore has also continued to play an instrumental role in the growth of nanoscience and engineering research in Alberta.

- Efforts to attract Dr Bob Wolkow to Alberta came to fruition, and he is now installed as the senior Chair targeted in the initial Brett/ Freeman original application, and also cross-appointed as a Principal Research Officer at National Institute of Nanotechnology (NINT).
- The "uptake" of Nanocore trainees to Alberta initiatives has begun, with Marek Malac hired by NINT, and Mirwais Aktary in negotiation with Raith Gmbh about setting up a North American office for their nanofabrication product line in Edmonton.
- Major funding for nanofabrication tools was secured (CFI + ASRIP $8.3M, Brett).
- The commercialization of the method for controlling the formation of spiral spatial and temporal control of magnetization dynamics in mesoscopic structures is progressing
- ChiralTF Devices Inc., the first Nanocore spinoff, is now formulating a business plan.
- Industry funding included $112,000 in cash from Micralyne, Read-Rite and Maxtor, and $232,000 in-kind from Micralyne and JDS Uniphase.

Brett and Freeman each made several prestigious appearances at international conferences. In professional service, a number of new appointments to national and international committees were accepted. Brett was recognized with a Canada Research Chair and Freeman received the University of Alberta Alumni Honour Award. Participation in the Canadian Institute for Advanced Research effort in nanotechnology increased, with Brett, Freeman and Wolkow now all associates of the nanoelectronics program. Brett and Freeman have each been announced as cross-appointments to the National Institute of Nanotechnology, an affiliation that should provide for future research collaboration opportunities.

Dr Robert Wolkow is Principal Research Officer at National Institute of Nanotechnology (NINT). The Nanoscale Information and Communications Technology group is in an initial start-up phase at the University of Alberta, and will be associated with the new National Institute of Nanotechnology (NINT) in Edmonton. Initial projects will include investigations into nanoscale structure and manipulation, instrument development, connections to nanostructures, directed growth, and theory.

ADVANCED SOFTWARE SYSTEMS

Algorithms and Interactive Entertainment

Dr Jonathan Schaeffer's research team on high-performance artificial intelligence systems research group specializes in artificial intelligence research, investigating new technologies for creating "intelligent" behaviour in a computer. Although the research spans many areas of artificial intelligence, including search, machine learning, and heuristic knowledge, historically the group has used games to demonstrate the ideas. Fundamental problems in artificial intelligence are being investigated in the context of computer programs that play chess, checkers, Go, and poker. Many of the game-playing programs have achieved a high level of performance and have challenged the best human players in the world.

- The team now consists of three professors, four affiliated professors, one postdoctoral fellow, 9 PhD students, and 16 Masters students supervised or co-supervised by the Chair. In addition, there are four programmer/analysts (two part-time), and a half-time secretary.
- In the past year the team strengthened ties with Electronic Arts of Vancouver (the largest games company in the world) and BioWare of Edmonton (the world leader in role-playing games). The new technology has been well received by both companies, with good prospects for integration into commercial products.

- For over 15 years, the team has been building tools to simplify the task of parallel programming. The third generation tool, CO2P3S, is now available on the web and actively promoted at major parallel computing conferences.
- Schaeffer and team members have been involved in research, infrastructure and operating grant awards valued at approximately $56 million.
- Schaeffer is the co-founder of BioTools Inc. (www.biotools.com), a bioinformatics company. BioTools has three successful commercial products: PEPTOOL (protein analysis), GENETOOL (DNA analysis), and CHROMATOOL (DNA/protein assembly). These products are used in over 1,000 research laboratories around the world.
- Chenomx is a spinoff from BioTools (www.chenomx.com). Chenomx has developed software technology to do fluid analysis, and has partnered with Varian and Breuker, the two largest NMR manufacturers in the world.
- Chenomx's product, ECLIPSE, is currently under evaluation by a major pharmaceutical company.
- BioTools and Chenomx are successes, but both have been hampered by a lack of venture capital. Together they employ over 20 people and have combined revenues of $1 million.

Software Engineering Decision Support

Dr Guenther Ruhe's team achievements over the last year have been the development of novel approaches and tools supporting early life-cycle decisions in software development. The most successful results were achieved in the area of software release planning under resource and budget constraints.

- Computational efficient evolutionary algorithms have been designed and implemented, providing a set of promising solutions. The final decision maker can chose out of those solutions, taking into account further implicit and time-dependent constraints.
- First steps towards developing a commercial product out of these results have been conducted.
- a new approach called Soft Requirements Negotiator has been developed that initially uses qualitative, and later quantitative information to provide decision support. The reported results are part of a broader effort to develop an integrated decision support system with intelligent components for knowledge retrieval, analysis and reasoning, multi-criteria decision aid, simulation and negotiation.
- During the reporting period, further progress has been achieved in creating a core team of researchers and in establishing or enhancing dynamic national and international collaborations.
- The team has started to prepare the 16th International Conference on Software Engineering and Knowledge Engineering, taking place in Banff in June 2004, an excellent opportunity to present research excellence to both academia and industry.

Thee summaries provide some highlights of the past year. Details are provided in the reports that follow, written by the researchers themselves.

NETWORKS AND RELATED INFORMATICS THEORY

Reprinted courtesy of the Government of Canada, Canada Research Chairs Program

CHAIRHOLDER PROFILES

Norman C. Beaulieu
iCORE - Canada Research Chair in
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Research Involves: Expanding the capacity and quality of service of wireless communication systems

Research Relevance: Ensuring the ability of communications networks to meet growing demands for wireless services and enabling new multimedia services

KEEPING UP WITH THE WIRELESS REVOLUTION

The proliferation of wireless telecommunications devices has put an enormous strain on the physical capabilities of this new technology. The number of cellular phone users has leapt from a mere 25,000 in 1984, to some 16 million a decade later. There were 30 million cordless phones in use across North America in 1992, a number that has since doubled. And global PCS services that were bringing in $2 billion in 1996, are estimated to have revenues of about $12 billion in 2001.

Norman Beaulieu is at the forefront of researchers responsible for ensuring that the capability of this technology will be able to keep pace with the demands of these dramatically expanding business and consumer markets.

Beaulieu specializes in the most fundamental aspects of the science of broadband wireless communications. He has also applied these theoretical insights to solving some of the most practical problems in the design of communications systems. And he has been successful. Beaulieu has overturned many of the traditional methods for handling this technology, revealing them to be too expensive and inaccurate to be retained.

This work won Beaulieu the honour of being elected as a fellow of the Institute of Electrical and Electronics Engineers at a relatively early stage in his career. He recently became the only Canadian Editor-in-Chief that the organization's influential research journal has ever had.

Beaulieu has made seminal contributions in several distinct aspects of the field, giving him a wide perspective on strategies for overcoming the current limitations of wireless telecommunications. He suggests that no single improvement will be as effective as several complementary improvements that address different features of the problem. As a recipient of a Canada Research Chair, he intends to investigate several such improvements, dealing with how interference is handled, how signals are processed, and the ability to predict in advance how much data will be travelling over a particular channel.

NOTICE OF APPOINTMENTS

IEEE TRANSACTIONS

Norman C. Beaulieu was appointed Editor-in-Chief of the IEEE Transactions on Communications on January 2000.

Transactions on Communications is the flagstaff publication of the IEEE Communications Society which has over 45,000 members. Regarded as "the source" for break throug communications theories and practical applications, this world-renowned, scholarly journal covers all aspects of physical-layer communications. At present, there are over 60 Area Editors and Editors on the editorial staff who process over 700 submitted manuscript per year. The journal has over 9000 subscribers.

Dr Beaulieu is the first individual in Canada to be appointed EIC of this journal.

STEACIE

Norman Beaulieu was awarded the NSERC E.W.R. Steacie Memorial Fellowship, the first electrical engineer to be so honoured in fifteen years, in 1999, with the citation:

Norman Beaulieu is a world authority in wireless communication theory who has discovered ingenious mathematicaapproaches to predict in advance how well new wireless and digital communications systems will perform. His methods are of keen interest to those who design cell phone networks, for example, who need to know if such problems as channel fading and data loss will affect users. In January, he was elected Fellow of the Institute of Electrical and Electronics Engineers (IEEE).

FELLOWSHIP IN THE ROYAL SOCIETY OF CANADA

Dr Norman C Beaulieu has been elected to the ranks of the Royal Society of Canada. Norman Beaulieu.

Fellowship in the Royal Society of Canada is considered Canada's most prestigious academic accolade to which scholars and scientists aspire. "These distinguished individuals have accomplished work of truly outstanding quality," said Howard Alper, President of the Royal Society of Canada. "They add enormous value to the extraordinary resource of talent and experience that constitutes the Society."

The citations for the awards describe Dr Beaulieu as "a scientific leader in the analysis and modelling of wireless communications systems. He has discovered ingenious mathematical solutions and models for a wide range of digital communications components and applications. International researchers have widely used his methods, models and results."

IEEE FELLOW

Dr Beaulieu was elected to IEEE Fellow on January 1, 1999 with the citation:

For contributions to the analysis and modeling of wireless data and digital communication systems.

DR NORM N.C. BEAULIEU

iCORE WIRELESS COMMUNICATIONS LABORATORY

iCORE Chair
Electrical and Computer Engineering
University of Alberta

Dr Norman C. Beaulieu is iCORE Chair of the Wireless Communications Laboratory. Two other researchers already at the University of Alberta are part of the research team - Dr Witold Kryzmien and Dr Ivan Fair - both of the department of electrical and computer engineering. iCORE has committed $700,000 for five years for a total of $3.5 milion to establish this research team.

EXECUTIVE SUMMARY

Professor Norman C. Beaulieu was awarded the first iCORE Research Chair, September 1, 2000, forming a team with existing University of Alberta Faculty Professor Witold A. Krzymieñ and Associate Professor Ivan Fair. The establishment of the iCORE Research Chair in Broadband Wireless Communications at the University of Alberta seeded the institution of the iCORE Wireless Communications Laboratory. Assistant Professor Xiaodai Dong and Associate Professor Chinthananda Tellambura joined the team in February 2002 and July 2002, respectively.

The Laboratory has collaborations with researchers at other institutions, with industry and with the iCORE High Capacity Digital Communications (HCDC) Laboratory. There are research collaborations with partners in New Jersey, Massachusetts, Missouri, Italy and Ontario.

Dr Beaulieu has brought $715,405.00 of other (not from iCORE) research funding to the Research Program. As co-investigator, Dr Beaulieu has held an additional $200,000.00 in research grants.

The Wireless Communications team had a remarkable number of journal and conference research papers published or accepted in the reporting period. In addition, one Report of An Invention was filed with the University of Alberta Industry Liaison Office.

The iCORE Chair has made strong contributions to the training of highly qualified personnel. One PhD thesis and two MSc theses were completed under his supervision in the reporting period. One PhD qualifying examination was held. In addition, five PhD thesis proposals and two MSc thesis proposals were completed. Currently, Dr Beaulieu is supervising six MSc candidates, ten PhD candidates and three post-doctoral fellows (PDF's) at the University of Alberta. In addition, he is supervising two PhD candidates at Queen's University.

Dr Beaulieu received distinguished recognition by being elected a Fellow of The Royal Society of Canada, and by being appointed to the Executive Committee of the Royal Society. In addition, Dr Beaulieu continued to serve in the reporting period as Editor-in-Chief of the IEEE Transactions on Communications.

The iCORE Wireless Communications Laboratory sponsored ten external invited speakers and twenty-three internal speakers in two seminar series.

In consequence of the achievements, awards, recognition and growth of the first thirty-one months, the iCORE Wireless Communications Laboratory is now well known in the international communications research community and is increasing international and national awareness of Alberta, iCORE and the University of Alberta.

RESEARCH GOALS AND OBJECTIVES

Wireless communications research has been given great impetus by the advent of cellular telephony, mobile satellite and portable personal communication services. The exponentially growing user demand for services together with the increasing demands for higher speed transmission of large amounts of data create the need for new technologies. In order to provide higher data transmission rates to more users without sacrificing the integrity of the received information, advances must be made in the transmission system components and the transmission system designs. In turn, achieving the best advances in wireless systems and components requires better modelling of the wireless channels, including the long-term, long-range prediction of the fading channel.

The overall goal of the proposed research is higher capacity in broadband wireless communication systems at lower cost. The primary thrust of this research is investigation into fundamental properties, limitations, and improvements in broadband wireless systems. A secondary thrust is the application of the research results to present and future systems. This two-pronged approach is consistent with the Chair's belief that strong fundamental research is vital to the understanding and improvement of technically challenging systems, while application of the fundamental research results is an important step in creating economic advantages for the supporting community.

RESEARCH PROJECTS

The research conducted in the iCORE Wireless Communications Laboratory is multifaceted; some topics under investigation are listed in the Research Team section below.

Dr Beaulieu's research and editorial activity led to his election as a Fellow of the Royal Society of Canada (FRSC) where he was one of eight of the 62 new Fellows of the Royal Society chosen to be profiled in its media release. In addition, he was invited to serve as Invited Distinguished Speaker at an international conference, and invited to write the introduction to the Classic Reprint of the paper "Linear Diversity Combining Techniques" by D. G. Brennan.

Research activity of Professor Krzymień and his graduate students supported through the iCORE Chair is currently focused on broadband high throughput packet data access to the Internet for mobile and nomadic users, employing OFDM (orthogonal frequency division multiplexing) and spread spectrum signalling, and MIMO (multiple-input multiple-output) antenna techniques. The work includes physical link layer issues such as adaptive modulation and coding, space-time coding, multiple access interference cancellation and long range channel state prediction, as well as medium access control (MAC) and radio resource management questions, such as hybrid ARQ (Automatic Repeat reQuest) and packet transmission scheduling algorithms. Dr Krzymień has done collaborative research with Nortel Networks and Ericsson Wireless Communications. His professional service to the communications research community includes being an Associate Editor for the IEEE Transactions on Communications, a member of the Editorial Board of Wireless Personal Communications - An International Journal (Kluwer), the Area Editor for Digital Communications / Signal Processing of the Intl. J. on Wireless & Optical Communications (World Scientific), and a member of Technical Program Committees for five international conferences. He also served as Session Chair for several major international conferences. Professor Krzymień is the principal investigator on an NSERC Strategic Grant "Enabling Technologies for Future High Throughput Packet Data Access" awarded in October 2002 for 5 years at $200,000 per year. The grant's team includes iCORE professors Beaulieu, Fair, Schlegel and Tellambura.

Professor Krzymień's current

IN 2002, DR BEAULIEU'S RESEARCH AND EDITORIAL ACTIVITY LED TO HIS ELECTION AS A FELLOW OF THE ROYAL SOCIETY OF CANADA (FRSC).

research activity encompasses the following main projects:

- "Enabling Technologies for Future High Throughput Packet Data Access", an NSERC Strategic Grant supported project.
- "Techniques for Efficient Digital Wireless Multiple Access", an NSERC Individual Research Grant project.
- "Space-Time Processing and Coding for Wideband CDMA and Future Wireless Access", a TRLabs supported project.
- "Multiple-Access Interference Cancellation for Efficient CDMA Wireless Communications", a TRLabs supported project.
- "High Bit Rate Packet Data Wireless Access on Single and Multi-Carrier Forward Links", a TRLabs supported project.
- "Advanced Receivers for Adaptive MIMO and Multi-Carrier Packet Data Access Systems", a TRLabs supported project.

Dr Fair and his graduate students are investigating efficient channel coding techniques for wireless communication systems. The three main thrusts of their work supported through the iCORE Wireless Laboratory include development of efficient turbo decoding techniques, new codes for MIMO systems, and coding techniques to reduce the peak-to-average power ratio in OFDM systems.

As Associate Chair for Undergraduate Studies and Acting Director of Computer Engineering in the Department of Electrical and Computer Engineering at the University of Alberta, Dr Fair has also played an active role in the evolution of the ECE curriculum and programs. Dr Fair was recently appointed an Associate Editor for IEEE Communications Letters, and continues to serve on program committees of a number of conferences and as a reviewer for several technical journals.

Research projects lead by Dr Fair that are currently being supported by the iCORE Wireless Laboratory include the development of:

- efficient turbo decoding techniques;
- error control codes for multiple-input multiple-output wireless systems;
- techniques to limit the peak-to-average power ratio in OFDM systems.

Professor Xiaodai Dong joined the Department and iCORE Wireless Communications laboratory in February 2002. Professor Dong serves as an Associate Editor for Modulation and Signal Design of the IEEE Transactions on Communications, and a member of the Technical Program Committee for the 2003 IEEE International Conference on Communications (ICC'2003). She provides extensive paper review services to a number of journals and conferences.

Professor Dong's research activities focus on the development of theory and applications that are essential to enabling high capacity broadband wireless communications systems. Specific interests include communication theory, adaptive modulation and coding, fading channels, multiple antenna systems, multi-carrier communications and ultra-wideband technology. To achieve this goal, research projects focusing on highly effective channel estimation schemes, link adaptation technologies, and ultra-wideband communication transceiver designs are currently under investigation.

Dr C. Tellambura is Associate Professor and iCORE Research Associate in the Department of Electrical and Computer Engineering, University of Alberta. He was recruited from Monash University in Victoria, Australia and joined the iCORE Wireless Communications Laboratory in July 2002. Dr Tellambura is known internationally for his work in communication theory and wireless systems. He is serving as Associate Editor for Multicarrier Systems of the IEEE Transactions on Communications and Associate Editor of the IEEE Transactions on Wireless Communications.

Dr Tellambura's research aims to develop coding techniques that will reduce the fluctuations of the OFDM signal amplitude and will reduce interference in OFDM systems. Some of the potential applications and significance of this research are:

- Digital subscriber loops, which use existing telephone lines to carry very high-speed data, use multicarrier modulation. High peaks can contribute to out-of-band interference and this may also couple to adjacent subscriber lines causing unacceptable interference.

- If OFDM is to be used for mobile telephony, the Doppler spread caused by the movement of the mobile creates a fundamental limit to performance. Improved coding techniques can alleviate this.
- Other applications include wireless local area networks, digital video broadcasting, digital audio broadcasting and wireless access for mobile satellite services and wireless data networks. New coding techniques and transmit-diversity for OFDM will enhance performance benefits

Some topics currently under investigation are:

- Peak Reduction in OFDM.
- Interference Cancellation in OFDM.
- Hybrid Selection/Maximal Ratio Diversity over Correlated Fading Channels.
- Novel Suboptimal Diversity Combining Receivers.
- A New Representation for Characteristic Function of a Lognormal Random Variable.
- Adaptive Modulation for OFDM.
- Space-time codes over Correlated Fading Channels.

RESEARCH TEAM

The laboratory consists of a team of Professors, Graduate Students and Post-Doctoral Fellows with two office Support Staff, three Summer Research Assistants, two Research Engineers and one Computer Systems Specialist.

TEAM LEADER	AWARDS
Norman Beaulieu	• Fellow of The Royal Society of Canada • Appointment to Executive Committee of The Royal Society of Canada • NSERC E.W.R. Steacie Memorial Fellow • IEEE Fellow • Canada Research Chair in Broadband Wireless Communications • Fellow of Engineering Institute of Canada (EIC)
RESEARCH TEAM	**TITLE**
Witold Krzymien	Professor ; Fellow of the Engineering Institute of Canada (EIC)
Ivan Fair	Associate Professor
Chinthananda Tellambura	Associate Professor
Xiaodai Dong	Assistant Professor
OTHER TEAM MEMBERS	**RESEARCH TOPIC**
Qiong Xie	Cellular Network Coverage
Robert Hang	VHDL Design

PDF - DR BEAULIEU	TOPIC
Julian Cheng	Exact Performance Analysis of DS-CDMA in Nakagami Fading
M. Oussama Damen	Space-Time Codes and Bandwidth Efficient Pulse Shaping
Seung Joon Lee	Multirate DS-CDMA for Multimedia Applications

PDF - DR BEAULIEU	TOPIC	AWARDS
Kevin Altman	Symbol Synchronization in Small Signal-to-Interference Ratio Environments	NSERC PGS-B, iCORE
Kareem Baddour	Autoregressive Simulation Methods for MIMO systems	
Yunfei Chen	Fading Channel State and Model Parameter Estimation	Alberta Ingenuity Scholarship
Julian Cheng	Exact Performance Analysis of DS-CDMA	
Ethan Davis	Signal Classification and Modulation Identification	
Sasan Haghani	Capacity of Fading Wireless Channels	Alberta Ingenuity Scholarship
Bo Hu	Performance Analysis of Ultra-Wideband Systems	Alberta Ingenuity Scholarship
Pavel Loskot	Hybrid Maximal Ratio/ S+N Selection Diversity	
Amir Rabiei	Non-Coherent Maximum Likelihood Estimation	
Kathiravetpillai Sivansan	Receiver Designs for Multiuser Detection	
Peng Tan	Interference Cancellation in OFDM	Alberta Ingenuity Scholarship
Bohdan Tomiuk	Channel Estimation Error in Maximal Ratio Diversity	

David Young	Novel Fading Models based on Physical Channels	
Xiaodi Zhang	Performance Analysis of H-S/MRC Systems	
MSC CANDIDATE - DR BEAULIEU	**TOPIC**	**AWARDS**
Lingzhi Cao	Pilot Symbol Assisted 16-QAM for High Capacity Wireless Systems	
Xiaofei Dong	Higher-Order Statistical Behaviour of Fading Channels	
Sasan Haghani	Hybrid Selection/Maximal Ratio Diversity for Two-Dimensional Signalling	
Jeremiah Hu	Tractable Models for Phase Distributions in Signal Fading	NSERC PGS-A, WH Johns Grad Fellowship, iCORE
Wenyu Li	Optimal Pilot Symbol Assisted Modulation	
Faruq Rajwani	Novel Closed-Form Approximations to Lognormal Sum Distributions	NSERC PGS-A, WH Johns Grad Fellowship
Qiong Xie	Minimax Approximation to Lognormal Sum Distributions	
Tim Poon	Optimal Receiver Designs for Co-Channel Interference Environments	NSERC PGS-A, iCORE, WH Johns Grad Fellowship
PHD CANDIDATE - DR KRZYMIEN	**TOPIC**	**AWARDS**
Jia Liu	Interference Cancellation Algorithms for Layered Space-time Wireless Links	TRLabs Scholarship

Shreeram Sigdel	Efficient Receiver Algorithms for Multiple-Input Multiple-Output (MIMO) Wireless Links Employing Adaptive Multi-Carrier Transmission	TRLabs Scholarship
Geoffrey Messier	Techniques for Improved CDMA Forward Link Performance in Realistic Propagation Environments	NSERC PGS-A, iCORE, TRLabs Scholarship
David Mazzarese	High Throughput Downlink Cellular Packet Data Access with Multiple Antennas and Multi-user Diversity	TRLabs Scholarship, FS Chia Scholarship
Robert Novak	Adaptive Multi-carrier Systems for High Bit Rate Downlink Wireless Packet Data Access	TRLabs Scholarship
Kay Wee Ang	Improved hybrid subtractive interference cancellation schemes	
MSC CANDIDATES -DR KRZYMIEN	**TOPIC**	**AWARDS**
Shuying Shen	Long Term Prediction of Small Scale Fading and Multi-user Interference in Single-carrier Single-antenna Packet Data Access Systems	NSERC PGS-A, iCORE, TRLabs Scholarship
Robert Elliott	Transmission Scheduling Algorithms for CDMA Packet Data Access Evolution	
PDF - DR FAIR	**TOPIC**	**AWARDS**
Yan Xin	PAPR Reduction in OFDM	Alberta Ingenuity Scholarship

PHD CANDIDATES - DR FAIR	TOPIC	AWARDS
Fengqin Zhai	Integration of Error Control and Constrained Sequence Codes	CWTA (Canadian Wireless Telecommunications Assn) Scholarship
Ge Li *(Co-supervised with Dr Krzymien)*	Low Density Parity Check (LDPC) Codes for MIMO Wireless Systems	TRLabs Scholarship
Chunlong Bai *(Co-supervised with Dr Krzymien)*	Hybrid Automatic Repeat Request (ARQ) Coding Schemes for Adaptive High Throughput Wireless Data Links Employing Multiple-input Multiple-output (MIMO) Antenna Systems	Alberta Ingenuity Scholarship, TRLabs Scholarship

MSC CANDIDATES - DR FAIR	TOPIC
Aaron Hughes	Integration of Error Control and Constrained Sequence Codes

SUMMER STUDENTS - DR FAIR	TOPIC	AWARDS
Vincent Sieben	Development of Convolutional Codes with Additional Spectrum Control	NSERC Undergraduate Award

PHD CANDIDATES - DR DONG	TOPIC
Mohsen Eslami	Link Adaptation for Multiple Antenna Systems

MSC CANDIDATES - DR DONG	TOPIC
Alfred Lee	Receiver Design of Ultra-Wideband Communication Systems

PHD CANDIDATES - DR DONG	TOPIC
Lei Xiao	Highly Effective Channel Estimation for Wireless Fading Channels

PHD CANDIDATE - DR TELLAMBURA	TOPIC
Luqing Wang	Reduction of High Peaks of OFDM Signals
MSC CANDIDATE - DR TELLAMBURA	**TOPIC**
Yunxia Chen	Performance of Diversity Systems in Correlated Fading Channels
SUMMER STUDENT - DR TELLAMBURA	**TOPIC**
Rees Machtemes	3rd and 4th Generation Wireless System Proposals
SUPPORT - DR FAIR	**POSITION**
Mark Wells	Editorial Assistant to the Editor-in-Chief of the IEEE Transactions on Communications
Sharon Walker	Administration
Walt Howard	Computer Systems Specialist

COLLABORATIONS

Research Collaboration
Dr Beaulieu's national and international research collaborations include:
1. Wireless Systems Research Department, AT&T Labs - Research, Middletown, New Jersey, U.S.A. (Moe Win, Jack H. Winters); Shannon Laboratories, AT&T Labs - Research, Florham Park, New Jersey, U.S.A. (Benjamin F. Logan); Department of Statistics, Rutgers University, Piscataway, New Jersey, U.S.A. (Lawrence A. Shepp): Research on hybrid selection/maximal ratio diversity combining digital receivers.
2. Electrical Engineering Department, University of L'Aquila, L'Aquila, Italy (Fortunato Santucci and Marco Pratesi): Research on new mathematical modeling of sums of lognormal random variables and applications to outage in slow frequency hopped time division multiple access (TDMA) spread spectrum (FHSS) cellular systems.
3. Department of Engineering Science, University of Modena, Modena, Italy (Maria Luisa Merani): Research on efficient generation of cross-correlated fading amplitude sequences for simulation of correlated branch diversity systems.
4. Department of Mathematics and Statistics, Queen's University, Kingston, Ontario, Canada (Fady Alajaji, Glen Takahara and Hongyan Kuai): Research on signal constellation mappings for non-uniform sources.
5. Department of Electrical Engineering, University of Missouri, Columbia, Missouri,

U.S.A. (Chengshan Xiao): Research on higher-order statistics of fading channel simulators and research on novel channel models and simulation techniques for line-of-sight fading channels.

Dr Krzymień and his students collaborate with the Institute for Communication Technology, German Aerospace Centre (DLR), Oberpfaffenhofen, Germany. The collaboration involves joint work in the area of spread-spectrum multi-carrier systems. The prime contact is Dr Stefan Kaiser. A visiting post-doctoral researcher from DLR, Dr Erik Haas, joined the group from May to August 2003. His visit was funded by DLR.

Professor Tellambura's research collaborations include:

1. Electrical Engineering Department, Virginia Tech, USA (A. Annamalai): Research on diversity systems and their performance in wireless environments. Joint research results will be published in a forthcoming book as well.
2. Electrical Engineering Department, University of Bergen, Norway (M. Parker): Research on peak power reduction for OFDM systems.

Other Collaborations

Dr Beaulieu continued to serve in the reporting period as Editor-in-Chief of the IEEE Transactions on Communications. Professor Beaulieu also served on the Editorial Board of The Proceedings of the IEEE and as Associate Editor for Communication Theory of the IEEE Communications Letters. Complementing his research journal activities, the iCORE Chair has been active in research conference organization. A highlight of this activity is the hosting of the International Association of Science and Technology for Development (IASTED) Wireless and Optical Conference (WOC 2002), held in Banff, Alberta in July 2002. The conference attracted 204 registrants from 24 countries including major participation from Canada, the United States and Korea. Under the leadership of the iCORE Chair, the WOC 2002 Conference grew 264% in submissions, 262% in registrations and 234% in the number of paper presentations over the WOC 2001 Conference. Other research conference organization activity includes service on the Technical Program Committee of the conference WIRELESS 2002 and service on the Technical Program Committee of the Global Telecommunications Conference GLOBECOM 2003, service on the Technical Program Committee of the International Telecommunications Symposium ITS 2002, service on the Prize Paper Committee of ITS 2002 and service as Session Chair for the International Conference on Telecommunications ICT'2003 and the IEEE International Symposium on Advances in Wireless Communications.

Dr Beaulieu served on key panels during the reporting period, including: the IEEE Vehicular Technology Society Fellow Evaluation Committee, the British Columbia Advanced Systems Institute research funding proposal review panel, the NSERC Circle Forum, an NSERC Workshop on Highly Qualified Personnel (HQP), the College of Reviewers of the Canada Research Chairs Program and an NSERC Industrial Research Chair Proposal Site Visit Committee.

Collaboration with Industry

Dr Beaulieu continued as Director of the Corporation of Eleven Engineering Incorporated, Edmonton, Alberta in the reporting period. He has been actively involved in technology and product planning as well as in the recruitment of highly qualified personnel.

Dr Krzymień's industry collaborations include:

1. Spatial Processing Technology Group, Harlow Laboratories, Nortel Networks, Harlow, UK. Prime contact: Dr Chris Ward. The Harlow group is an industrial partner on an NSERC Strategic Grant. The collaboration primarily entails the spatial processing aspects of the strategic project, but also includes link adaptation and multi-carrier transmission techniques.
2. CDMA Systems Performance Evaluation Group, Nortel Networks, Richardson, TX, USA. Prime contact: Dr David Paranchych. The collaboration is focused on shorter-term evolution of 3rd generation cellular systems enabling high throughput packet data access, and primarily involves design and evaluation of scheduling algorithms for best-effort packet data.
3. Ericsson Wireless Communications, San Diego, CA and Boulder, CO. Prime contact: Dr Anthony Soong. Collaboration involves exchange of technical information concerning design and performance evaluation of high throughput single-carrier wireless packet data systems employing adaptive transmission techniques.

Collaboration with High Capacity Digital Communications (HCDC) Laboratory

The iCORE Wireless Communications Laboratory has given funding to the iCORE High Capacity Digital Communications (HCDC) to provide a portion of the salary for a VHDL Design engineer, Robert Hang, for the HCDC lab. Projects include:

- Designing and simulating a multi-channel frequency tracking algorithm for a MIMO receiver.
- Designing and simulating a timing synchronization algorithm for a MIMO receiver.
- Implementing a MIMO receiver design in VHDL for use in the FPGA development board of the HCDC MIMO testbed.
- Assisting in a demonstration of the HCDC MIMO system to a potential industrial partner (L3 Communications, Inc.).
- Planning the design of the next phase of the MIMO project: the development of a joint packet communication testbed.

The HCDC MIMO team will be presenting research papers based on measurements obtained with the HCDC MIMO testbed at two IEEE conferences this summer and L3 Communications is now an industrial partner on the HCDC MIMO team.

Professor Beaulieu is providing scientific input to the MIMO project. In particular, he is collaborating with Professor Schlegel and a PDF on theoretical solutions to the determination of the capacity of MIMO systems.

iCORE Wireless Communications Laboratory Seminars

The iCORE Wireless Communications Laboratory has sponsored ten research seminars by invited external speakers from Utah, Waterloo, Kingston, Minnesota, Sydney, N.S., Turkey, California, Tokyo, Victoria, B.C. and France. In addition to providing the usual forum for scientific exchange, the seminar series was designed to introduce the speakers to the University of Alberta and iCORE.

Graduate Students' Seminar Series

The iCORE Chair's graduate students requested that the Laboratory agree to, and sponsor, a seminar series to be organized and presented by the graduate students. This seminar series has been very well attended by graduate students and faculty from the entire department. Twenty-three seminars were sponsored in the reporting period.

FUNDING

New Funds Acquired this year as Prime Investigator

In addition to iCORE funding of $700,000, the Chair received an Alberta Ingenuity Fund Institutional Establishment Grant of $180,000 over two years, an NSERC Research Grant in Wireless Communications and Digital Transmission for $66,000 per year, and an NSERC E.W.R. Steacie Memorial Fellowship for $90,000, accompanied by a Research Grant Supplement for $144,405. In addition, Dr Beaulieu received $200,000 per year for his Canada Research Chair (CRC) in Broadband Wireless Communications Systems, with an infrastructure grant of $125,000 from the Canadian Foundation for Innovation (CFI).

New Funds Acquired this year as Co-Investigator

An NSERC Strategic Grant was awarded in October 2002 in the amount of $200,000 per year for 5 years. The award, entitled "Enabling Technologies for Future High Throughput Packet Data Access", provides funding for principal investigator Dr Krzymien and co-investigators Drs Beaulieu, Fair, Schlegel, and Tellambura.

Other

Dr Tellambura received an NSERC Discovery Grant of $28,000 per year, titled "Orthogonal Frequency Division Multiplexing for Wireless Communications", for the period June 2002 to March 2006.

Dr Dong received an NSERC Discovery Grant titled "Highly Spectral Efficient Wireless Communication Systems" at a funding level of $22,850 per year for the period April 2003 to March 2007.

INTELLECTUAL PROPERTY

Activity this year, including revenue

Dr Beaulieu has filed a University of Alberta Report of an Invention: "Threaded Algebraic Space-Time Signal Constellations and Codes and Threaded Algebraic Space-Time Code Construction Methodology".

Dr Krzymieñ was granted two patents this year:

1. Q. Shen, W.A. Krzymieñ, "Closed-loop power control scheme for wireless communication systems", US Patent No. 6 529 709 (granted 4 March 2003; assigned to TRLabs).
2. W.A. Krzymieñ, S. Sun, "Spread spectrum time-division multiple access communication scheme", US Patent No. 6 493 334 (granted 10 Dec 2002; assigned to TRLabs).

Patents Received or Created over Lifetime

1. N.C. Beaulieu, "Methods, Systems and Devices for Generating Pulse Shapes," US and Canadian Patent Application, filed March 28, 2002.
2. A. Jalali, W.A. Krzymieñ, P. Mermelstein, "A medium access control scheme for data transmission on code division multiple access wireless systems", US Patent No. 5,828,662 (granted 27 October 1998; assigned to Nortel).
3. G.G. Messier, W.A. Krzymieñ, "Channel code decoding for the CDMA forward link", US (10/260,226; filed 27 September 2002) and Canadian (2,405,322; filed 26 September 2002) patent applications (assigned to TRLabs).
4. W.A. Krzymieñ, S. Sun, "Spread spectrum time-division multiple access communication scheme", Canadian patent application (no. 2,272,875; filed 26 May 1999, assigned to TRLabs).
5. Q. Shen, W.A. Krzymieñ, "Power control scheme", a Canadian patent application (no. 2,183,139; filed 12 August 1996, assigned to TRLabs).

Potential for Future Commercial Activity

The iCORE Chair and his graduate students and PDF's are conducting research on a number of topics that are of great relevance to practical wireless systems. There is potential for intellectual property arising in work on Space-Time Coding, Orthogonal Frequency Division Multiplexing (OFDM) and Diversity Receiver Designs.

Professor Krzymieñ's research activity spans the full range from design and evaluation of novel wireless systems based on the foundation of communications theory to their potential commercial applications, facilitated through his active industrial contacts. The general direction of that activity, best characterized under the general heading of "Enabling Technologies for Future High Throughput Packet Data Access" is of high interest to his industrial partners. In addition to his iCORE affiliation, Professor Krzymieñ is also very strongly linked with the activities of TRLabs, with which he has been closely affiliated since 1986. The TRLabs affiliation further facilitates effective contacts with numerous industrial and other commercial partners, and hence enhances the prospects for commercialization of his research results.

PUBLICATIONS

Refereed Journal Publications

1. G. Takahara, F. Alajaji, N.C. Beaulieu, and H. Kuan, "Constellation Mappings for Two-Dimensional Signalling of Non-Uniform Sources," IEEE Transactions on Communications, vol. 51, Mar. 2003, pp. 400-408.
2. N.C. Beaulieu, "Introduction to 'Linear Diversity Combining Techniques'," Invited Paper, Proceedings of the IEEE, vol. 91, Feb. 2003, pp. 328-330.
3. D.P. Weins, J. Cheng, and N.C. Beaulieu, "A Class of Method of Moments Estimators for the Two-Parameter Gamma Family," Pakistan Journal of Statistics, vol. 19(1), 2003, pp. 129-141.
4. D.J. Young and N.C. Beaulieu, "Power Margin Quality Measures for Correlated Random Variates Derived From the Normal Distribution," IEEE Transactions on Information Theory, vol. 49, Jan. 2003, pp. 241-252.
5. S. Haghani and N. C. Beaulieu, "Symbol Error Probability of Low-Order Orthogonal Signalings in Rayleigh Fading with General Diversity Combining," IEEE Communications Letters, vol. 6, Dec. 2002, pp. 520-522.
6. C. Xiao, Y.R. Zheng, and N.C. Beaulieu, "Second-Order Statistical Properties of the WSS Jakes' Fading Channel Simulator," IEEE Transactions on Communications, vol. 50, June 2002, pp. 888-891.
7. J. Cheng and N.C. Beaulieu, "Generalized Moment Estimators for the Nakagami Fading Parameter," IEEE Communications Letters, vol. 6, Apr. 2002, pp. 144-146.
8. X. Dong and N.C. Beaulieu, "Average Level Crossing Rate and Average Fade Duration of Low Order Maximal Ratio Diversity with Unbalanced Channels," IEEE Communications Letters, vol. 6, Apr. 2002, pp. 135-137.
9. S. J. Lee and J. Ahn, "Acquisition performance improvement by barker sequence repetition in a preamble for ds-cdma systems with symbol-length spreading codes," IEEE Trans. Veh. Technol., vol. 52, no. 1, Jan. 2003, pp. 127-131.
10. S. J. Lee, "A new non-data-aided feedforward symbol timing estimator using two samples per symbol," IEEE Communications Letters, vol. 6, no. 5, May 2002, pp. 205-207.
11. K.-D. Lee, Y.-H. Cho, S. J. Lee, and H.-J. Lee, "Optimal design of superframe pattern for DVB-RCS return link," ETRI Journal, vol. 24, no. 3, June 2002, pp. 251-254.
12. M. O. Damen, A. Safavi, and K. Abed-Meraim, "On CDMA with space-time codes over multipath fading channels," IEEE Transactions on Wireless Communications, vol. 2, Jan. 2003, pp. 11-19.
13. R. Hang, W.A. Krzymieñ, and C.L. Despins, "Improved MAC protocol for reverse link packet data transmission in wideband DS-CDMA," IEEE Transactions on Wireless Communications, vol. 2, no. 1, January 2003, pp. 162-174.
14. S. Sun, W.A. Krzymieñ, Q. Shen, and B. Darian, "Rapid access protocols for discontinuous transmission in DS-CDMA systems," Wireless Personal Communications - An International Journal, vol. 21, no. 2, May 2002, pp. 201-218.
15. A. Annamalai and C. Tellambura, "A direct approach to performance evaluation of generalized selection diversity systems over Nakagami-m fading channels," Wireless Communications and Mobile Computing, vol. 3, no. 1, Feb. 2003, pp. 99-116.
16. A. Annamalai and C. Tellambura, "A moment-generating function (MGF) derivative based unified analysis of incoherent diversity reception of M-ary orthogonal signals over independent and correlated fading channels," International Journal of Wireless Information Networks, vol. 10, no. 1, Jan 2003, pp. 41-56.
17. K. Sathananthan and C. Tellambura, "Partial transmit sequence and selected mapping schemes to reduce ICI in OFDM systems," IEEE Communications Letters, vol. 6, issue 8, Aug. 2002, pp, 313-315.
18. K. Sathananthan and C. Tellambura, "Coding to reduce both PAR and PICR of an OFDM signal," IEEE Communications Letters, vol. 6, issue 8 Aug. 2002, pp. 316-318.
19. A. Annamalai and C. Tellambura, "Analysis of hybrid selection/maximal-ratio diversity combiners with Gaussian errors," IEEE Transactions on Wireless Communications, July 2002, pp. 498-511.

Refereed Journal Publications Accepted

1. M.O. Damen and N.C. Beaulieu, "On Two High Rate Algebraic Space-Time Codes," IEEE Transactions on Information Theory, vol. 49, April 2003, pp. 1059-1063.
2. M.O. Damen and N.C. Beaulieu, "On Diagonal Algebraic Space-Time Block Codes," to appear as a full paper in IEEE Transactions on Communications.
3. M.O. Damen, N.C. Beaulieu, and J.-C. Belfiore, "Bandwidth Efficient Linear Modulations for Multiple Antenna Transmission," to appear as a full paper in IEEE Transactions on Information Theory.
4. M.O. Damen, H. El Gamal, and N.C. Beaulieu, "Linear TAST Constellations: Fundamental Limits and Near Optimal Constructions," accepted for publication as a full paper in IEEE Transactions on Information Theory.
5. E. Davis, N.C. Beaulieu, and M. Rollins, "A MAP Blind Bit-Rate Detector for Variable Gain Multiple Access Systems," to appear in IEEE Transactions on Communications.
6. C.C. Tan and N.C. Beaulieu, "Transmission Properties of Conjugate-Root Pulses," accepted pending revisions for publication in IEEE Transactions on Communications.
7. X. Dong and N.C. Beaulieu, "New Analytical Probability of Error Expressions for Classes of Orthogonal Signals in Rayleigh Fading," to appear in IEEE Transactions on Communications.
8. X. Dong and N.C. Beaulieu, "Level Crossing Rate and Fade Duration of MRC and EGC Diversity in Ricean Fading," to appear in IEEE Transactions on Communications, May 2003.
9. M.Z. Win, N.C. Beaulieu, L.A. Shepp, B.F. Logan, and J.H. Winters, "On the SNR Penalty of MPSK with Hybrid Selection/Maximal Ratio Combining over LLD Rayleigh Fading Channels," to appear as a full paper in IEEE Transactions on Communications.
10. J. Cheng and N.C. Beaulieu, "Precise Error Rate Analysis of Bandwidth Efficient BPSK in Nakagami Fading and Cochannel Interference," accepted pending revisions for publication as a full paper in IEEE Transactions on Communications.
11. N.C. Beaulieu and C. Cheng, "Efficient Nakagami-m Fading Channel Simulation," accepted pending revisions for publication as a full paper in IEEE Transactions on Vehicular Technology.
12. N.C. Beaulieu and M.L. Merani, "Generation of Multiple Rayleigh Fading Envelope Sequences with Specified Cross-Correlations," accepted pending revisions for publication in European Transactions on Telecommunications.
13. W.W. Choy, N.C. Beaulieu, and M.O. Damen, "A New Technique for Estimating the Error Probability of Decision Feedback Equalization," accepted pending revisions for publication as a full paper in IEEE Transactions on Communications.
14. Y. Song, S.D. Blostein, and J. Cheng, "Exact outage probability for equal gain combining with cochannel interference in Rayleigh fading," accepted for publication in IEEE Transactions on Wireless Communications.
15. H. El Gamal and M. O. Damen, "Universal space-time coding," IEEE Trans. Inform. Theory, vol. 49, May 2003.
16. F. Zhai and I.J. Fair, "Techniques for Early Stopping and Error Detection in Turbo Decoding," accepted March 18, 2003 for publication in IEEE Transactions on Communications, 25 manuscript pages.
17. C. Tellambura, A. Annamalai, and V. K. Bhargava, "Closed-form and infinite series solutions for the MGF of a dual-diversity selection combiner output in bivariate Nakagami fading," to appear in IEEE Transactions on Communications, 2002.
18. S. Loyka, C. Tellambura, A. Kouki, A. Annamalai, and F. Gagnon, "Comments on New method of performance analysis for diversity reception with correlated Rayleigh-fading channels," to appear in IEEE Transactions on Vehicular Technology.
19. A. Annamalai and C. Tellambura, "MGF-based mathematical framework for analysis of generalized selection diversity systems in wireless channels," to appear in IEEE Transactions on Vehicular Technology.

Refereed Conference Publications

1. S. Haghani, N.C. Beaulieu, and M.Z. Win, "Bounds to the Error Probability of Hybrid Diversity Two-Dimensional Signalling," IEEE GLOBECOM, Taipei, Nov. 17-21, 2002, pp. 1408-1414.
2. K.E. Baddour and N.C. Beaulieu, "Robust Doppler Spread Estimation in Nonisotropic Scattering Environments," IEEE Vehicular Technology Conference: VTC2002-Fall, Vancouver, Canada, Sept. 24-28, 2002 pp. 2459-2464.
3. S. Haghani and N.C. Beaulieu, "SEP of Low-Order Orthogonal Signalings with General Diversity Combining," IEEE International Symposium on Advances in Wireless Communications: VTC'02-Fall, Victoria, Canada, Sept. 23-24, 2002, pp. 133-134.
4. S. Haghani, N.C. Beaulieu, and M.Z. Win, "The Penalty of Hybrid Diversity with LLD Rayleigh Fading," IEEE International Symposium on Advances in Wireless Communications: VTC'02-Fall, Victoria, Canada, Sept. 23-24, 2002, pp. 87-88.
5. N.C. Beaulieu, "Modelling and Simulation of Wireless Channels," SIU Signal Processing and Communications Conference: SIU 2002, Pamukkale, Denizli, Turkey, June 13, 2002, p. 3. Invited Distinguished Speaker Seminar.
6. M.O. Damen and N.C. Beaulieu, "Concatenated Block Error Control Codes and Bandwidth Efficient Algebraic Space-Time Codes," Proc. 3G Wireless: 3Gwireless'2002, San Francisco, May 28-31, 2002, pp. 181-186.
7. J. Cheng and N.C. Beaulieu, "Error Rate of BPSK in Generalized Fading Channels with Co-Channel Interference," IEEE Vehicular Technology Conference: VTC Spring 2002, Birmingham, Ala., May 6-10, 2002, pp. 1786-1790.
8. C. Xiao, Y.R. Zheng, and N.C. Beaulieu, "Second-Order Statistics of an Improved Jakes' Fading Simulator," IEEE Vehicular Technology Conference: VTC Spring 2002, Birmingham, Ala., May 6-10, 2002, pp. 6-10.
9. M.F. Pop and N.C. Beaulieu, "Design of Wide-Sense Stationary Sum-of-Sinusoids Fading Channel Simulators," IEEE International Conference on Communications: ICC 2002, New York, Apr. 28-May 2, 2002, pp. 709-716.
10. K.E. Baddour and N.C. Beaulieu, "Accurate Simulation of Multiple Cross-correlated Fading Channels," IEEE International Conference on Communications: ICC 2002, New York, Apr. 28-May 2, 2002, pp. 267-271.
11. H. El Gamal and M.O. Damen, "Threaded algebraic space-time signals", in Proc. IEEE Information Theory Workshop, Bangalore, India, Oct. 20-25, 2002, pp. 65-68.
12. H. El Gamal and M.O. Damen, "SISO codes for MIMO channels", in Proc. 40-th Allerton Conference on Communications, Control, Computing, Urbana, Oct. 2-4, 2002, pp. 916-925.
13. H. El Gamal and M.O. Damen, "Threaded algebraic space-time codes", in Proc. IEEE International Symposium on Advances in Wireless Communications, Victoria, BC, Canada, Sept. 23-24, 2002, pp. 81-82.
14. H. El Gamal and M. O. Damen, "An algebraic number theoretic framework for space-time coding", in Proc. IEEE International Symposium on Information Theory, Lausanne, Switzerland, June 29-July 6, 2002, p. 132.
15. K.W. Ang and W.A. Krzymieñ, "Performance of the multi-stage variable group hybrid interference cancellation scheme with timing and phase errors", in the Proc. 2002 IEEE Semi-Annual Vehicular Technology Conference (VTC2002-Spring), Jeju, Korea, April 2003, paper S08C_04, 5 IEEE formatted pages.
16. D. Mazzarese and W.A. Krzymieñ, "High throughput downlink cellular packet data access with multiple antennas and multiuser diversity", Proc. 2002 IEEE Semi-Annual Vehicular Technology Conference (VTC2002-Spring), paper S05B_03, 5 IEEE formatted pages.
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CHAIRHOLDER PROFILES

Christian B. Schlegel
Canada Research Chair in High Capacity Digital Communications
University of Alberta
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Achievements:
Published close to 100 research papers, a popular research book entitled Trellis Coding (1997), and an invited chapter contribution to the Encyclopedia in Telecommunications; two more research books in production; has given many invited research seminars and Institute of Electrical and Electronic Engineers (IEEE) workshops; senior member of the IEEE Information Theory and Communication Societies.

Research Involves: Study of fundamental limits of communication systems, high-capacity, limit-achieving algorithms, and their implementations in hardware.

Research Relevance: Findings will help build intellectual talent in Canada that is needed to develop new and innovative wireless technologies, and assist Canadian industries to adopt the new high-capacity capabilities by developing them in a manner which is readily transferable out of the lab.

Coming to Canada from: University of Utah, U.S.

ACHIEVING HIGH-CAPACITY WIRELESS COMMUNICATIONS

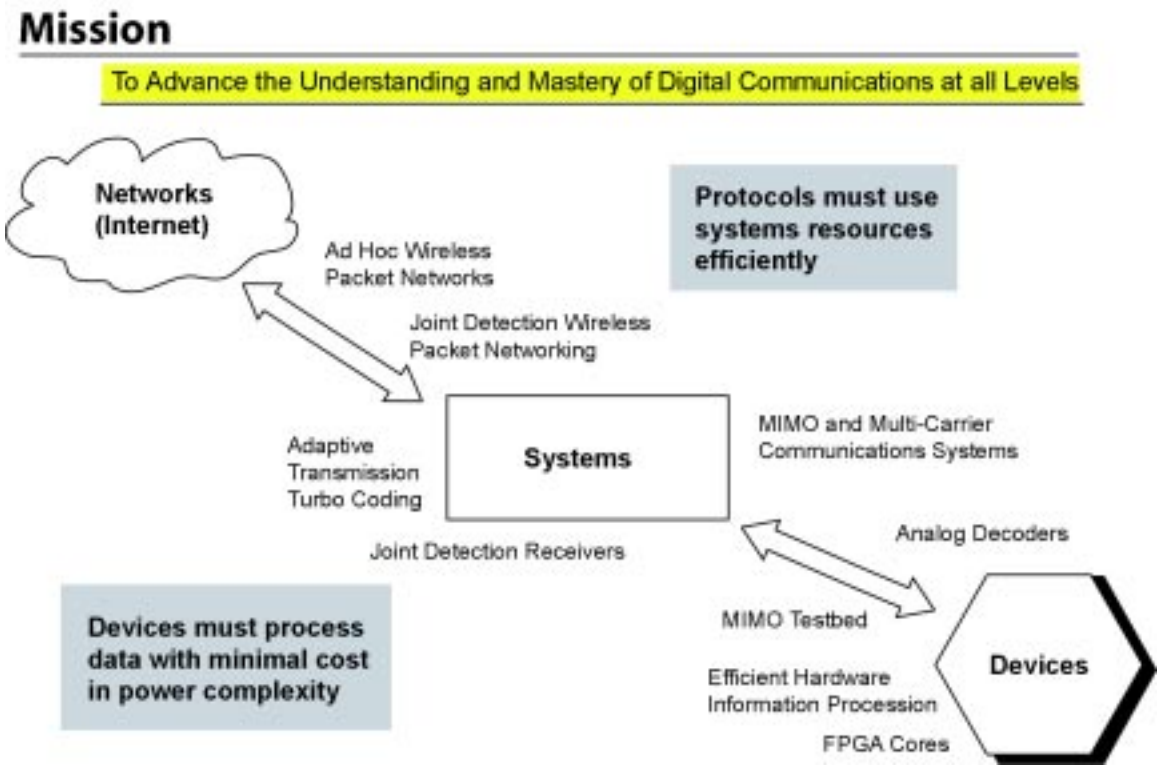
The growth of wireless communications over the past two decades has been nothing less than astounding. Furthermore, it is expected that wireless technology will continue to grow at this phenomenal rate. New and unexpected applications, such as wireless full-immersion virtual reality, may only be a few years away. With the gigantic data rates that such applications require, it will be essential to build digital data links which fully harness a channel's capacity.

Sophisticated theories prove that the capacity of wireless networks is essentially unlimited, but that very complex signal encoding and decoding methods, combined with complex transmitter and receiver systems, are required to harness this capacity. The success of future high-data rate information systems depends on a number of emerging core technologies at the frontier of digital communications research and development.

Dr Christian B. Schlegel is an internationally recognized expert in the theory and practice of digital communications systems design, analysis and implementation. The central focus of his

research as Canada Research Chair in High-Capacity Reliable Digital Communications will be on highly advanced, digital modulation, demodulation, coding and decoding methods, with the ultimate aim to build higher capacity wireless networks. He will work on error control coding technology (which renders an unreliable channel useable by avoiding transmission errors through the introduction of controlled redundancy), multiple antenna systems (required to increase data rates beyond current limits), interference control and mitigation technologies (addressing the serious problems of interference), high-speed, low complexity VLSI implementations (required to operate a data link), and analog circuit implementation of digital error control decoders.

Dr Schlegel's Chair will establish a High-Capacity Digital Communications Centre at the University of Alberta. The centre will provide a flexible and rapid design, prototyping and testing capability for new ideas in wireless communications research, and will benefit local and national industry through research results, highly trained human resources and access to experimentation facilities.



DR CHRISTIAN SCHLEGEL

HIGH-CAPACITY DIGITAL COMMUNICATIONS LABORATORY

Electrical Engineering
University of Alberta

Dr Christian Schlegel is an iCORE Professor of High Capacity Digital Communications, a position he holds in the department of electrical and computer engineering at the University of Alberta. iCORE has committed $350,000 per year for five years for a total of $1.75 million dollars to develop this research group at the University of Alberta.

EXECUTIVE SUMMARY

The primary focus of the High-Capacity Digital Communications (HCDC) Laboratory is the efficient transmission of digital data through real-world communications channels, in particular, wireless data links. Each such link has an inherent capacity, which forms a limit on the maximum rate at which digital data can be transmitted reliably over the link. Achieving these limits, and thus optimally harnessing a channel's inherent information carrying potential, is the goal of the projects of the HCDC Laboratory.

The channel to which most attention is presently given is the multiple antenna, a special form of a multiple-input multiple-output (MIMO) channel, which consists of antenna arrays at both the transmitter and the receiver instead of single antennas. It is known that this channel can, under favorable conditions, increase the capacity of a data link by a factor equal to the minimum number of antenna elements at the receiver or the transmitter.

During the 2002/2003 fiscal year the HCDC team designed and constructed a prototype MIMO channel measurement system and conducted initial channel measurements which confirm theoretical expectations as well as results obtained by other laboratories. This system is currently being enhanced for real-time operations as well as full portability.

On the analog decoder research side, the design of a medium-sized product code analog subthreshold CMOS decoder has been completed and will enter the production phase this summer and testing later in the year. Initial measurements and projections based on simulations confirm that analog technology has the potential to outperform digital decoders by two orders of magnitude in power consumption and space requirements, and thus can challenge current digital designs and possible displace them in the future. Current efforts of HCDC members are to prove feasibility with real input and output circuitry. The HCDC laboratory has also generated 30 technical publications which are currently at various stages in the publication process. Most of these publications target capacity approaching communications systems for multiple access communications, MIMO channels, or random access packet networking.

During this phase the HCDC laboratory has expanded its team by hiring seven new students and a VHDL design engineer, Mr. Robert Hang. Furthermore a new University of Alberta faculty member, Dr Stephen Bates, will join the department this fall and will be an associate member of the HCDC laboratory. Dr Bates specializes in packet traffic theory and has also extensive industry experience, where he was involved in building 10 Gbit Ethernet prototypes. Professor Schlegel has been appointed General Chair for the IEEE Communication Theory Workshop 2005, and Technical Program Chair for the 2005 International Symposium on Information Theory.

RESEARCH PROGRAM OVERVIEW

The focus of activities of the High-Capacity Digital Communications (HCDC) Laboratory, created by iCORE Professor Schlegel under iCORE funding, is the efficient transmission of digital data through a variety of currently popular transmission channels, most notably wireless channels. The goal is to transmit digital data with the least amount of resources, in terms of energy and bandwidth, and with the maximum amount of reliability. The laboratory's name, "high capacity," pertains to the capacity limits which were theoretically established by Claude Shannon in 1948, and which give each channel a maximum rate at which reliable communication is theoretically possible. Achieving this rate has been the research and development focus of many scientists and engineers over the past half century.

Among a large number of modern signal processing methods, error control coding is the single most important technique which allows communications engineers to approach this elusive limit. The main focus of our projects is consequently the efficient and judicious application of error control coding and supporting signal processing techniques to achieve a channel's inherent data carrying potential, that is, approach or achieve the capacity limit.

This question arises in a sense anew with each new channel that is being considered. The HCDC focuses on some novel channels as well as on more traditional transmission channels. Most important among those is the multiple antenna channel, which uses several transmit and receive antennas, also generically termed a multiple-input multiple-output (MIMO) channel. The promise of using multiple antennas is that of multiplying the channel's information carrying capacity by the numbers of antennas employed, without any additional requirement of bandwidth or power. This MIMO channel is currently a hot research topic for future ultra high-data rate applications as diverse as wireless localarea networks, cellular systems, ad-hoc wireless packet networks and even satellite systems.

Last year, our laboratory embarked on the design and construction of a hardware test platform which allows our researchers to measure the channel, evaluate its capacity potential, and test and implement transmission technologies of future applications. This effort is led by Professor Schlegel with the help of a hardware engineer, Paul Goud, who acts as the laboratory director and coordinates the design efforts of the various members of the laboratory. A first prototype implementation became operational in early 2003, and initial test channel measurements have been conducted which confirm theoretical results, as well as measurements conducted by a research team at Brigham Young University. This system is currently being enhanced to enable it to operate in real-time on a portable platform. Demonstrations to industry are planned for July in Calgary, and for August in Salt Lake City, Utah, to our first industrial partner, L3 Communications.

Research into efficient iterative receiver structures for code-division multiple access (CDMA) channels and MIMO channels has led to a number of academic publications, and the current theory and system designs have matured to a point where potential implementations are being discussed. Two new graduate students who concentrated on efficient packet communication at a number of research levels, have started to study packet traffic and system impacts of wireless networks equipped with future highly efficient joint receivers. Research work on turbo coding also forms a considerable portion of HCDC activities and Professor Schlegel's research monograph, "Trellis and Turbo coding," is nearing completion and a first draft has been handed into the publisher, IEEE/Wiley. Future extensions of these activities will include issues of channel acquisition and tracking and its efficient integration into iterative receivers. A concerted effort is under way together with our extended team members to address each major aspect of complete high-capacity digital communications systems and networks.

Our research efforts in the area of implementation of digital signal processing in analog VLSI

technology have gained speed with the completion of the design of a subthreshold CMOS analog message passing decoder for a medium-size product code. The design is currently submitted to Canadian Microelectronics Corporation (CMC) for fabrication in 0.25µm CMOS technology. Successful demonstration that this decoder operates close to the theoretically expected performance would demonstrate that analog processing technology has the potential to displace digital technology with circuits which are two orders of magnitude more power and space efficient. Prior to this chip, small analog decoders have been demonstrated to function according to expectations. If this larger chip also meets expectations, the viability of analog circuits to implement the large error control decoders required by future high-capacity communication systems will be demonstrated, and the team will then focus on the efficient design of interfacing circuitry, which currently consumes over 95% of the power of the chip.

An invention disclosure for the implementation of low-voltage alternate circuit for the computations modules of such analog processors has been filed with the University patent office. This contribution would allow designers to lower the supply voltage of chip to below 1V and thus achieve further power efficiency and other design gains.

Achievements over Past Year

The following is a list of achievements over the past 12 months.

1. Completion of the hardware MIMO channel measurement prototype and successful initial MIMO channel measurements which confirm expectations of both the MIMO channel potential as well as the system performance. A second project engineer has been hired to supervise and conduct the VHDL design for the measurement system as well as the future communications system testbed. The RF designs for up/down conversion have been completed by the Calgary based RF company SignalCraft. The completed RF designs have been thoroughly tested and found to be of very high quality.

2. Special dual-polarized patch antennas have been designed by our North Carolina State University partners and are currently being used to study the effects on MIMO capacity of polarization diversity in a highly scattered indoor transmission environment. Two initial conference publications on these measurements have been submitted and are accepted for publication and presentation.

Electro-magnetics professor C. Furse from the University of Utah has been invited for a visit and a potential link is being explored to feed our results into the design of future antennas for mobile handsets using MIMO technology.

3. Theoretical research in the areas of joint detection for CDMA channels, joint detection and integrated channel estimation for MIMO systems, and signaling strategies in random access wireless packet communication systems have been investigated on the theoretical plain, and a number of publications have been generated by Dr Schlegel and his graduate students dispersing these results. Major contributions include the design of a novel random access packet system, use of a joint detector at the receiver, and the complete analysis of iterative receivers for CDMA with low-complexity interference cancellation front-ends. While some major questions still remain unsolved, iterative receivers using linear front-end processing are now completely understood.4. The design and thorough analysis of an analog product code decoder in CMOS technology has been completed and pipelined for implementation and later testing. Several research papers on the design, novel analysis techniques based on importance sampling, and interface issues with decoder have been submitted and are in various stages of publication. This cosupervised project with Professor V. Gaudet has expanded through the hire of three new graduate students focusing on this new technology.

1. The HCDC webpage has been completely redesigned and is currently undergoing testing for completeness and ease of use. It is located at the University of Alberta web address www.ualberta.ca/hcdc.

Dr Schlegel has been appointed General Chair of the 2005 Communication Theory Workshop to be held in June 2005 in Park City, Utah, and as Technical Program Director of the prestigious International Symposium on Information

Theory, to be held in the fall of 2005 in Adelaide, Australia.

Objectives for Next Year

The objectives for next year are as follows.

1. Expansion of the current measurement testbed into the real-time version supervised by Mr Robert Hang, and demonstration thereof to local and US industry. To our best knowledge, such real-time MIMO measurement equipment is currently not available at any academic institution, where measurements are usually performed with off-line equipment after data collection.

The key innovation in this project is a novel low signal-to-noise ratio timing acquisition and tracking algorithm, which forms a vital function for future high-capacity communications systems.

2. Simulation, theoretical analysis, and implementation of a novel frequency compensation algorithm developed by HCDC members. This is a critical component for robust packet transmission systems.

3. Expansion of the hardware test-platform to make it ready for the implementation of novel communications systems and testing with real data communications in circuit and packet switched mode. The exact formulation of next year's goals will be debated at a late May brainstorming session with participation of Utah team members. The current hardware testbed effort will be channeled into two parallel research efforts: 1) dealing with the issue of multiple joint access using concurrent but completely asynchronous transmissions of data packets, and, 2) the expansion of the MIMO channel measurement testbed into a MIMO communications prototype testbed using layering techniques.

4. Complete characterization of the analog product decoder, construction of an adequate measurment setup, and dissemination of results. If the processing core behaves as expected, the design focus will shift towards the efficient interface design. Industry contacts will be pursued and Mr Christopher Winstead, the senior PhD student on this project, is expected to graduate with these results. A new PhD student, Mr Golam Mostafa, has been hired and will pursue the question of efficient interface technologies, possibly in conjunction with the iCORE group of Professor Haslett in Calgary, who specialize in analog RF technology.

5. On the MIMO channel side it is planned to study various acquisition and channel tracking methods, primarily using iterative decoding methods, for their suitability to achieve the channel capacity and their implementability in hardware. A particular focus will be given to mobile channels with rapidly time-varying characteristics in an effort to prove viability of MIMO technology for mobile applications. A primary direction of thrust will be the spread pilot embedding method pioneered by our extended team member Dr Farhang. After theoretical studies concerning channel estimation and tracking in conjunction with our colleagues at the University of Utah have come to a completion, the implementation of a pilot embedded channel estimation system will be considered. Embedded pilot channel estimation essentially forms a direct and logical extension of our current MIMO channel measurement signaling.

6. Completion of our theoretical studies on near-capacity communications over multiple access channels using CDMA and the effective use of error control codes in such systems is expected during this and possibly the next phase. This will then open the possibility to implement such receiver structures in future testbed implementations.

7. Our recently initiated studies in the area of efficient packet transmission systems using advanced joint receivers is expected to generate guidelines and results for highly efficient packet structures as well as communications protocols. Future implementations of high-density packet test networks is currently being discussed among the different team members.

8. With the arrival of Dr Bates as new member of the HCDC we will have one more FPGA hardware expert on board, and potential new directions that are being contemplated are the extension of high-capacity transmission systems to wireline channels, such as Ethernet.

RESEARCH TEAM

As of May 2003, the following are the team members of the HCDC Laboratory broken down into two groups: Leadership Team which comprises the permanent members of the research team and the Extended Team, which comprises members with limited-time association such as graduate students and academic visitors.

TEAM MEMBERS

TEAM LEADER	AWARDS
Christian Schlegel	Canada Research Chair in High Capacity Digital Communications
ASSOCIATE MEMBER	**TITLE**
Witek Kryzmien	Professor, supervision of lab engineers, advisory role, joint supervison of PhDs
Vincent Gaudet 50% with Dr Beaulieu	Professor, Specialty in Analog VSLI and Signal Processing
Robert Hang	VHDL Design Director
OTHER TEAM MEMBERS	**TITLE/TOPIC**
Lance Perez	Academic Visitor, University of Nebraska; FPGA Turbo Coding Algorithms
Alex Grant	Academic Visitor, University of South Australia; Multiple User Communications
Gianluca Lazzi	Joint Project, North Carolina State University; Dual-polarized Patch Antenna
Behrouz Farhang	Joint Project, University of Utah; Efficient Channel Estimation Procedures
Zhenning Shi	Joint Project, University of Utah; Joint Detection for Linear Multiple Access Channels
Zachary Bagley	Partner; Principal Engineer, L3 Communications, Utah; Iterative Filters for Receivers
Shayne Messerly	Joint Project (p/t); Hardware Design of the MIMO Receiver

PHD STUDENTS

PHD	TOPIC
Sheryl Howard	Efficient Coded Modulation using Iterative Receiver Principles
Christopher Winstead	Analog Decoder Implementations; First CMOS Analog Error Control Decoder
Sumeeth Nagarai	Wireless MAC Protocols
Roland Kempter	Capacity Limits of Random Packet Multiple Access, Joint Detection at the Receiver
Vishwa Rajaman	High-efficiency Hardware Implementations of Digital Data Processing Algorithms
Golam Mostafa	Analog Processing

UNDERGRADUATE STUDENTS

UNDERGRADS	TOPIC
Mimi Yiu	FPGA Test Setup, Analog Hamming Decoder Implementation
Nicholas Lauzon	Channel Measurements of Multiple Antenna Transmission

COLLABORATIONS

The HCDC maintains strong academic partnerships as well as liaisons to industry. Currently, the following partners are actively contributing to the program:

L3 Communications, Salt Lake City, Utah
This company has had a long-standing liaison with Dr Schlegel and is currently supporting hardware oriented research efforts by funding Mr Zack Bagley and Mr Shayne Messerly. Both engineers have developed VLSI systems for the transmission and reception stages of our hardware testbed. This cooperation is expected to continue next year. Mrs Bagley and Messerly will continue with their work of implementing an iterative layering processor in FPGA to be used to separate the data streams in our MIMO systems testbed. L3 communications will contribute to this project by purchasing an additional FPGA hardware test platform for $US 16,500 to be used by the Utah group.

North Carolina State University (NCSU)
Joint US NSF funding with NCSU is currently in place with the PIs, Dr Brian Hughes and Dr Gianlucca Lazzi. The topic of this joint research work is efficient space-time coding systems. The funding currently supports students at NCSU and Utah. Cooperation on the hardware testbed by duplicating the setup at NCSU have been discussed, but are currently on hold.

University of Utah
A cooperative link exists with the University of Utah where Dr Schlegel works with Dr Behrouz Farhang on the design of efficient and rapid equalization methods for multiple antenna systems. Drs Farhang and Schlegel jointly supervise two Utah PhD students and a Postdoctoral Research Fellow in this project. Additionally, the team is talking to the Utah Electromagnetics group about antenna designs for future hand-held terminals which could exploit MIMO capacities.

FUNDING

The University of Alberta provided $75,000 in start-up funding and $469,000 in kind for construction of the laboratory. ASRA contributed $125,000 as a separate research and infrastructure grant, in addition to the 329,4000 from iCORE funding.

Federal funding included $100,000 from Dr Schlegel's five-year CRC, accompanied by $125,000 as the CFI component of the CRC chair. An NSERC strategic grant, held jointly with PI Dr Krzymien, who is a member of TRLabs, and Drs Beaulieu, Tellambura, and Fair, provides HCDC with a further $40,000. A four year NSERC Discovery Grant has an annual installment of $31,100 and is held by the Chair.

Cooperation with L3 Communications is continuing with potential funding in the future. Currently L3 Communications funds a partner laboratory in Utah at $150,000/annum.

INTELLECTUAL PROPERTY

A patent on the low-voltage implementation of analog processing nodes has been filed with the University patent office and is currently under consideration for patent application. The technology of analog processing can gain around two orders of magnitude in both size and power efficiency, and thus could become fairly important in future portable communications devices.

Negotiations are currently held to clear IP issues regarding our cooperation with L3 communications in anticipation of intellectual property resulting from our joint work on MIMO receiver technology.

Patents

1. Q. Shen, W.A. Krzymieñ, "Closed-loop power control scheme for wireless communication systems," US Patent No. 6 529 709 granted 4 March 2003; assigned to TRLabs.
2. W.A. Krzymien, S. Sun, "Spread spectrum time-division multiple access communication scheme," US Patent No. 6 493 334 granted 10 Dec 2002; assigned to TRLabs.

PUBLICATIONS

Journal Publications

1. C. Winstead, J. Dai, S. Yu, C. Myers, R. Harrison, and C. Schlegel, "CMOS analog MAP decoder for (8,4) Hamming code," IEEE Journal of Solid State Circuits. (In Press).
2. C. Schlegel and A. Grant, "Differential space-time turbo codes," IEEE Transactions on Information Theory, (In Press).
3. V. Gaudet and G. Gulak, "A 13.3Mbps 0.35um CMOS analog turbo decoder IC with a configurable interleaver," ((In Press).
4. V. Gaudet and A. Rapley, "Iterative decoding using stochastic computation," Electronics Letters, vol. 39, no. 3, February 2003, pp. 299-301.
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2. A. Rapley, C. Winstead, V. C. Gaudet, and C. Schlegel, "Stochastic Circuits for iterative decoding," International Symposium on Turbo Codes, Brest, France, September 2003. (In Press).
3. C. Winstead, N. Nguyen, C. Schlegel, and V.C. Gaudet, "Low-voltage CMOS circuits for analog decoders," International Symposium on Turbo Codes, Brest, France, September 2003. (In Press).
4. C. Schlegel and Z. Shi, "Turbo Performance of a Low-Complexity CDMA Iterative Multiuser Detector," International Symposium on Turbo Codes, Brest, France, September 2003. (In Press).
5. P. Goud Jr, C. Schlegel, R. Hang, W. Krzymieñ, Z. Bagley, S. Messerly, M. Nham, W. Rajamani, "Indoor MIMO Channel Measurements Using Dual Polarized Patch Antennas," IEEE PACRIM '03, August 28-30, Victoria, BC, Canada. (In Press).
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7. C. Winstead and C. Schlegel, "Importance Sampling for SPICE-level verification of analog decoders," ISIT 2003, Yokohama, June 2003, p.103
8. C. Winstead, C. Schlegel, and V. C. Gaudet, "Analog Iterative Decoding of Error Control Codes," Canadian Conference on Electrical and Computer Engineering, Montreal, QC, Canada, May 2003, pp.1539-1542
9. B. Farhang-Boroujeny and C. Schlegel, "Efficient multicarrier realization of full-rate space-time orthogonal block-coded systems," Proc. ICC'03, May 11-15, Anchorage, AK, USA, pp. 2267 -2271.
10. P. Kota and C. Schlegel, "A wireless packet multiple access method exploiting joint detection," Proc. ICC'03, May 11-15, Anchorage, AK, USA.

11. C. Schlegel and Z. Shi, "Performance and Complexity of CDMA Iterative Multiuser Detection," Proc. of ITW 2003, Paris, France, pp. 111-114.
12. C. Winstead and C. Schlegel, "Analog decoding of product codes," ISIT 2002, June 30-July 5, Lausanne, Switzerland.
13. Z. Shi and C. Schlegel, "Asymptotic iterative multiuser detection of random coded CDMA," ISIT 2002, June 30-July 5, Lausanne, Switzerland.
14. S. Howard, C. Schlegel, L. Perez, F. Jiang, "Differential Turbo Coded Modulation over Unsychronized Channels," Proc. of International Conference on Wireless and Optical Communications (WOC 2002), July 17-19, Banff, AB, Canada, pp. 96-101.
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16. H. Zhu, Z. Shi, B. Farhang-Boroujeny, and C. Schlegel, "An Efficient Statistical Approach for Calculation of MIMO Channels," IASTED International Conference on Wireless and Optical Communications (WOC 2002), July 17-19, Banff, AB, Canada.
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19. C. Schlegel and L. Perez, "Turbo Coding: Principles and Applications," invited Tutorial, ICC 2002, April 28-May 2, New York, NY, USA.
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1. D. Haley, C. Winstead, C. Schlegel, and A. Grant, "Architectures for error control in analog subthreshold CMOS," Australian Communication Theory Workshop, 2003.
2. V. Gaudet, "Towards 1Gbps: analog iterative decoding," Analog Decoding Workshop, Munich, Germany, June 2002.
3. C. Winstead, J. Die, S. Yu, R. Harrison, C.J. Myers, and C. Schlegel, "Interfacing and Mixed-Signal Design for Analog Decoders," Proc. of Analog Decoding Workshop, Munich, June 2002.

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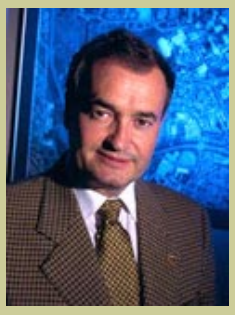
CHAIRHOLDER PROFILES



Gérard Lachapelle
Canada Research Chair in Wireless Location
The University of Calgary
Tier 1 - April 1, 2001
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Achievements: Johannes Kepler Award – The U.S. Institute of Navigation's highest honour, reserved for exceptional achievement

Research Involves: Establishing a new research group to develop super-accurate wireless location systems

Research Relevance: Provides new navigation tools and emergency services to cellular telephone users and the transportation industry

LOCATION IS EVERYTHING

Location. Location. Location. They're the three most important words in real estate—and now in wireless communication.

The cellular phone of the future will be expected to go beyond providing communication and Internet service. It will have to serve as a location beacon for the user. Developing super-accurate location technology is the objective of the newly created Wireless Location Research Group (WLRG) at the University of Calgary.

It's estimated that by 2003, there will be 800 million cellular phones in use worldwide. Concerns for public safety have resulted in a U.S. regulation requiring emergency 911 services for mobile telephone customers. The regulation calls for an accuracy of 100 metres, but that will be inadequate for those living in high-rises or working in office towers. These future services will require far more accurate location methods than are currently available.
Other demands for wireless location services include, precision control of agricultural planting equipment, structure monitoring and the need for 3-D marine navigation in constricted waterways. And trucking firms are demanding more accurate ways to keep track of their fleets.

The Global Positioning Satellite (GPS) system cannot adequately meet the needs of these future location-based services. (Signals from the satellite-based system frequently cannot easily penetrate treetops and buildings, and are only accurate to within 20 metres.) New super-accurate systems will soon be under development and testing thanks to funding provided by the Canada Research Chair in Wireless Communication.

The recipient of the Chair, Gérard Lachapelle is an internationally respected and awarded authority in the navigation community. During a career that has spanned 30 years, he has continually improved navigational methods and inspired students working with him to develop their own breakthroughs. Under his direction, the WLRG will embrace a multidisciplinary approach to discovering new wireless location systems.

The group will be looking at ways to enhance existing systems by augmenting them in a number of ways. GPS systems may one day be augmented by other satellite-based systems and by ground-based transmitters in high-density areas. The signals they transmit often bounce off buildings and other structures causing errors.

The research program is expected to attract great interest and support from the telecommunications industry. Surveys indicate that 70 percent of current Internet users want to go mobile and will demand services requiring the accurate wireless location technology.

DR GÉRALD LACHAPELLE

WIRELESS LOCATION RESEARCH GROUP (WLRG)

iCORE Professor
Geomatics Engineering
University of Calgary

Dr Gérard Lachapelle holds an iCORE Research Grant in Wireless Location at the University of Calgary. iCORE has committed $500,000 per year for five years for a total of $2.5 million dollars to develop this research group.

EXECUTIVE SUMMARY

This iCORE grant, which began in January 2001, focuses on research related to outdoor and indoor wireless location, high performance navigation and positioning using satellite and ground-based RF techniques, and fusion with self-contained sensors for personal navigation. The major performance parameters that are the focus of the research are availability, accuracy and reliability.

Strong collaboration with four faculty members at the University of Calgary and one at the University of Alberta, in addition to a wide range of external partnerships and sponsorships from outside organizations contributed much to the progress that was achieved on 10 major research projects ranging from indoor location using satellites to high precision positioning using satellite signals integrated with self-contained sensors and the development of a software Global Navigation Satellite System receiver. These research projects resulted in personnel training, publications and intellectual property transfer. Personnel training consisted in the completion of one MEng and four PhD students directly supervised or co-supervised by the chair, the hiring of four senior research associates and the supervision and co-supervision of 21 MSc and PhD candidates, including 10 that began during the reporting period. Eleven papers were published and five were accepted for publication in refereed journals, and 15 were presented at conferences. The chair holder made numerous invited oral presentations in Canada and abroad. Intellectual property transfer consisted of licensing of software and in technology transfer through external contracts and grants valued at $350,000. New partnerships were established with ARINC, U.S.A., Tampere University of Technology, Finland, and the University of Carleton. In recognition of their efforts, numerous members of the team and collaborators received awards.

Thanks to the success of the chair holder and his collaborators in securing external sponsors for the above research activities, another $1.6M was raised in funding, in addition to the iCORE grant of $0.5M. The objective to use the iCORE grant to leverage additional funds was exceeded.

Challenges in the first year of the grant included the search for specialized and high quality senior research personnel and the management of the team spread over five different areas during the start-up phase. The chair holder's group now occupies contiguous space in the Calgary Centre for Innovative Technology (CCIT) where they have had access to a modern navigation laboratory and antenna range since October 2002.

RESEARCH GOALS AND OBJECTIVES

The specific research objectives for this reporting period were as follows:

- Study the propagation properties of RF waves at 1.5 GHz through various materials for outdoor-to-indoor ranging purposes
- Study the feasibility of integrating self-contained MEMS sensors with RF techniques for personal location and navigation in urban canyons and indoors
- Continue the development of the multiple reference station technique MultiRef(tm) for GPS real-time kinematic positioning and proceed with the deployment of a 16-station test and demonstration network in Southern Alberta
- Continue investigations of ground-based cellular telephone CDMA location techniques
- Continue performance analyses of Galileo and combined GPS/Galileo systems, now that the European Union has made a firm decision to proceed with the deployment of that system
- Continue investigations related to the use of high sensitivity GPS receivers under outdoor and indoor signal masking conditions and design new applications
- Continue investigations related to various aspects of GPS, including receiver performance testing, development of reliability methods for GPS-based attitude determination and RTK methods
- Seek and exploit new opportunities related to location, positioning and navigation as they arise, e.g., participation in the U.S. DoD Joint Precision Approach and Landing Project (JPALS)

These objectives were achieved partly as a result of effective collaborations with other faculty members in the Department of Geomatics Engineering and outside collaborators and partners, and partly as a result of substantial additional external financing.

RESEARCH PROJECTS

The following 10 major projects were the focus of the chair holder's team during the reporting period:

a) RF Propagation:
The effects of building materials on UHF ranging signals were investigated to assess signal behavior as a function of materials, carrier modulation technique and signal strength. Signal behavior analysis included carrier and amplitude attenuation, related increased measurement noise, signal reflection and refraction, and effect of Fresnel zones. This fundamental research is necessary in order to understand the full potential and limitations of RF indoor location.

This work was done in collaboration with Professors Cannon and Klukas, Department of Geomatics Engineering. The project, supported by the Department of National Defence (DND), is part of a larger DND effort to assess the feasibility of performing high accuracy (2 m) personal positioning and guidance indoor using an integrated system. A technical report was submitted to DND and a paper submitted to a refereed journal.

b) Indoor GPS location:
This research activity is central to the activities of the research group. Investigations into the performance of high sensitivity equipment were continued. High sensitivity equipment uses longer signal integration time to increase the signal to noise ratio.The investigations were divided into two tasks, namely in-situ testing and hardware simulations. The in-situ testing consisted of performing static and kinematic measurements in selected environments to assess signal fade and noise, carrier phase, range and Doppler measurement quality, and related location availability and accuracy. Field testing under a wide range of forest environments was conducted outside Calgary, in Victoria, B.C., and Montréal,

Québec, partly shaded signal testing was conducted in downtown Calgary and on the University of Calgary campus, and indoor testing was conducted inside light residential and agricultural buildings in the Calgary area. These measurements were used to characterize the GPS signal channel and its stochastic properties under the environments tested. The second task consisted in investigating the possibility of reproducing, in a stochastic sense, the above field environments using a newly available hardware simulator. The latter, developed by Spirent Communications, U.K., in the early 2002 partly using GPS signal propagation channel characteristics developed in 2001 by the chair holder's research group, allows for a variety of signal characteristics to be modeled. Early results obtained in late 2002 and early 2003 indicate that such a method is indeed feasible. This result is very important, as it will allow high sensitivity GPS receiver manufacturers and cellular telephone service providers to conduct performance analysis and compliance testing under known and controlled conditions. Such compliance testing is required by the U.S. FCC and will likely be required by other regulatory agencies. GPS receiver deployment in cellular telephones is occurring at an estimated rate of 2M units per month in 2003.

This work was conducted in cooperation with Professors Cannon and Klukas, Department of Geomatics Engineering, Spirent Communications, U.K., and with the assistance of SiRF Technology Inc., CA. A paper presented by the University of Calgary/Spirent team at the GPS 2002 international conference received an award.

c) Outdoor/indoor vehicular and personal location and navigation using GPS integrated with self-contained sensors:

This activity focused on investigating self-contained MEMS sensor performance for vehicular and personal location and navigation and in designing novel methods and algorithms to integrate these together and with GPS. Investigations into the integration of high sensitivity GPS with a low cost rate gyro for vehicular navigation resulted in a 50% increase in availability in urban canyons. This system is, in turn, being used to develop an advanced traveller information system while ultimately increasing the road network capacity. Analysis into the performance and combination of various miniature low cost sensors for personal use resulted in numerous promising findings. For instance, a system consisting of an array of accelerometers and magneto-resistive sensors mounted on the user's footware was designed and tested to improve the relative location of the user moving outdoor or indoor. Thermal effects on accelerometers and gyros were investigated. Design work on the integration of GPS with these sensor types was initiated. A portable test multi-purpose system that includes a high performance integrated inertial navigation system/GPS to provide reference trajectories was designed. Limited testing in the field under various environments was conducted.

This work was conducted in cooperation with Professor El-Sheimy, Department of Geomatics Engineering, Professor K. Fyfe, Department of Mechanical Engineering, University of Alberta, and with some financial support from the industry, the Auto 21 National Centre of Excellence and the Department of National Defence.

d) High performance GPS and GPS/INS integration:

Methods to improve differential carrier phase GPS navigation and guidance accuracy and reliability performance were investigated, with emphasis on augmentation with a tactical grade inertial system. Statistical reliability theory was used to derive reliability measures for the integrated GPS/INS system. The methods and algorithms that resulted from this research were embedded in software package SAINT(tm) (Satellite And Inertial Navigation Technology).

This work was conducted in cooperation with Professor Cannon, Department of Geomatics Engineering. Financial assistance was received from the U.S. Navy through a contract with ARINC to test algorithms and methods during the latter part of the project.

e) Assessment of GPS/Galileo Performance:

Research into the accuracy, availability and reliability performance of the forthcoming European Union's Galileo system versus those of GPS and combined GPS/Galileo focused

on the use of multiple-frequency range and carrier phase observables. A method to simulate GPS and Galileo measurements in software with controlled error levels was completed. This methodology and algorithms developed were embedded into two software packages, namely SIMGNSS1(tm) and the SIMGNSS2(tm). The above simulated measurements were then used in other software developed by the research team to comparatively assess performance. This work will be useful to the research team in the years ahead to upgrade its GPS software to Galileo and GPS/Galileo.

This work was conducted in cooperation with Professor Cannon, Department of Geomatics Engineering. Financial assistance was received from the Canadian Space Agency as the work formed part of Canada's contribution to the overall Galileo effort.

f) High precision multiple reference station GPS real-time kinematic positioning and GPS meteorology:
Research on the use of a GPS reference network to improve real-time kinematic carrier phase positioning for users located in the network coverage area was pursued. Enhanced algorithms were embedded in MultiRef(tm), a software package developed during the past four years by the research team. A small scale, four-station test network deployed north of the University of Calgary was used to test the algorithms and software in real-time. Deployment of a medium scale (200 km x 200 km), 16-station network in Southern Alberta was initiated. The method was also tested on a 12-station GPS network located in the Campania region of Italy. Smoothing algorithms for a post-mission version of MultiRef(tm), namely MultiRefPM(tm), were also developed and tested. The post-mission version of this method is expected to be of interest to numerous private sector organizations. Investigations into using the above medium scale network to estimate atmospheric water vapour variations in real-time were initiated. This effort is expected to contribute to meteorological research in the long term.

The above research was conducted in cooperation with Professors Cannon and Skone, Department of Geomatics Engineering, the Universita' Degli Studi di Napoli Parthenope, Italy, and with the assistance of the Applanix Corporation, Toronto, and NovAtel, Calgary.

g) Wireless location using ground based systems:
Investigations into the use of cellular telephone networks to provide outdoor and indoor location were continued in cooperation with Dr Klukas, Geomatics Engineering, and focused on a IS-95 pilot signal hearability analysis, and non line-of-sight error mitigations for the time difference of arrival (TDOA) and angle of arrival (AOA) methods. Parameters such as the cellular channel propagation model and detection threshold were taken into account. Integration of these ground-based methods with differential barometry to deal with cell/user height differences and with GPS pseudorange measurements was also researched.

h) Initial development of a GNSS software receiver:
Initial research was started into the development of a GNSS software receiver capable of operating with the current GPS and the forthcoming Galileo system, GPS II and III. The fundamental design of the receiver was laid out and sub-divided into tasks that can be undertaken by different researchers. This project, which also includes the development of a software transmitter, is expected to last three years and will require some 15 person-years to complete. Components to become available throughout the next three years will be usable for a variety of research projects. The advantage of a GNSS software receiver will be the ability to develop and assess the behavior of advanced signal processing techniques to improve performance. This is the more important given that actual Galileo and GPS II and III signals will not be available for several years. This project is being conducted cooperation with Professor Cannon and is funded by the chair holder's iCORE grant and NSERC discovery grants at this time. However additional funding sources are being investigated.

i) Integration of a multiple GPS receiver system and self contained sensors for attitude determination
Such a system is used not only to determine position but also to determine the attitude parameters (roll, pitch and yaw) of the mobile

or stationary platform on which the integrated system is rigidly mounted. Low cost GPS receivers, antennas and rate gyros were integrated in software using an innovate series of algorithms to optimize availability and reliability. The effect of antenna phase centre instabilities and GPS data gaps were quantified, together with the advantages of the rate gyros.

j) Ship Multipath and Receiver reliability:
GPS receiver reliability is of great concern to marine organizations when GPS is used for precise applications such as shipping in constricted waterways and buoy tendering. A significant error source is multipath, caused by signal reflection from the ship infrastructure and surrounding water. Receiver response to this effect and other errors is a function of the receiver internal firmware. Ship multipath occurrence was measured during a four-day observation campaign on a ship and receiver response was analysed using a GPS simulator. This research was conducted with the support of the Canadian Coast Guard.

RESEARCH TEAM

TEAM MEMBERS

TEAM LEADER	AWARDS
Gérard Lachapelle	Fellow, Royal Society of Canada Canada Research Chair, Wireless Location Honorary Professorship, University of Wuhan, China
TEAM MEMBER/ COLLABORATOR	**TITLE**
Richard Klukas	Assistant Professor
Elizabeth Cannon	Professor, NSERC Steacie Fellowship 2002-2004
Susan Skone	Assistant Professor, NSERC UFA, 1999-2004
Naser El-Sheimy	Assistant Professor
OTHER TEAM MEMBERS	**RESEARCH TOPIC**
Ken Fyfe, U of A	Self-contained Pedestrian Navigation Systems
Jong Park, Korea Astronomical Observatory	GNSS High Precision Navigation
Bruno Scherzinger	Applanix Corporation, Adjunct Professor
Mark Petovello	GNSS and Integrated GNSS/INS
Aaron Morton	RF Propagation, Interference, and Digital Signal Processing
Glenn MacGougan	System Testing, Indoor Location, Navigation Laboratory

POSTDOCTORAL FELLOWS

PDF	TOPIC
U. Dogan	Visiting NATO scholar, until August 2002

PHD CANDIDATES

PHD	TOPIC	AWARDS
Samuel Ryan	Augmentation of GPS for Reliable Marine Navigation	Killam
Edvaldo Fonseca (external - Brazil)	Ionospheric Effects on GPS Transmission	
Giovanni Pugliano (external - Italy)	Multiple Reference Station GNSS RTK	
Kyle O'Keefe	Design of a Satellite-based Navigation System for Mars	PGS-B, iCORE
Paul Alves	High Performance Multiple Reference Station GNSS RTK	
Changlin Ma	Advanced Ground-based Techniques to Improve Wireless Location	
Chaminda Basnayke	GPS-based Transit Probe System	
Bo Zheng	GNSS Multipath Modeling and Software Receiver	
Oleg Mezentsev	GPS and Inertial Navigation Systems for Personal Outdoor/indoor Navigation	
Olivier Julien	Co-supervision with Professor Cannon	
Jussi Collin (external-Finland)	GPS and MEMS Sensors for Personal Outdoor/indoor Navigation	

Walid Abdel-Hamid	MEMS-based INS/GPS for Vehicular Positioning and Navigation	
Mohammad Rajabi	Digital Terrain Model Derivation from Satellite Imagery	
Roger Edwards (external - Univ. of Carleton)	GPS Interference	
Yong Ahn	High Performance Multiple Reference Station GNSS RTK	

MSC CANDIDATES

MSC	TOPIC	AWARDS
Yan Lu	Electrical Engineering	
Glenn MacGougan	Indoor Location with GPS	PGS-A, iCORE
Chaochao Wang	Attitude Determination with Multiple-antenna GPS Systems	
Lei Dong	GNSS RF Software Transmitter	
R. Stirling	Personal Outdoor/indoor Navigation using MEMS Sensors	PGS-A
Joseph Angelo	GNSS Interference	
Rob Watson	Indoor Location	
Dhar Karunanayake	GNSS	
Diep Dao	Integration of GPS and MEMS Sensors for Personal Outdoor/indoor Navigation	
Zhi Jiang	GNSS Software Receiver Development	
Ping Lian	Indoor Location	

UNDERGRADUATES

UNDERGRADS	TOPIC
Kees Lap Siu	Internship Student
Doug Langen	Internship Student
Lance De Groot	Internship Student

COLLABORATIONS

Active collaboration in the form of joint research projects and/or funded research projects took place with a variety of organizations. These include:

INSTITUTION	RESEARCHERS	NATURE OF COLLABORATION
Department of Geomatics Eng, Univ. of Calgary	R. Klukas, M. E. Cannon, N. El-Sheimy and S. Skone	GNSS and MEMS sensors
Department of Mechanical Eng, Univ. of Alberta	K. Fyfe, R. Stirling	Personal location using self-contained sensors
Department of Civil Eng, Univ. of Calgary	A. MacIver	Collaboration on use of GPS for vehicular traffic modeling
Department of Electronics, Carleton University	R. Edwards, J. Wight	GPS interference analysis
Dept of Electrical and Informatics Eng, University of Sherbrooke	J. de Lafontaine, F. Michaud	NCE Auto 21 collaborative vehicular driving systems and integrated systems
Universita' Degli Studi di Napoli Parthenope, Italy	G. Pugliano	Multiple reference station GPS RTK positioning
Tampere University of Technology, Finland	J. Takala	Personal location and navigation
Dept of National Defence, Defence Research Development Canada	J. Bird, N. Brousseau, M. Vinnins	Financial support for Tactical Indoor Positioning System and groud-based IS-95 wireless location development

INSTITUTION	RESEARCHERS	NATURE OF COLLABORATION
Canadian Coast Guard	S. Ryan	Ship GPS multipath assessment and receiver reliability
Dominion Radio Astrophysical Observatory, Penticton B.C.	P. Dewdney	Precise positioning for large adaptive reflector to be used in radio astronomy
Nokia Mobile Telephone Company, Finland	J. Collin, S. Turunen, J. Syrjarinne	Financial support, wireless location of cellular telephones
SiRF Technology Inc, U.S.A.	G. Turetzky	Collaborative technical support, high sensitivity GPS receiver assessment
Spirent Communications, U.K.	P. Boulton, A. Read	Common research on indoor location simulation enhancements
Univ. of Sao Paulo Polytechnical School	D. Blitzkow, R. Bueno	Collaboration on the use of precise GPS for bridge motion monitoring
ARINC/U.S. Navy, U.S.A.	F. Allen, M. Lage	Financial support, Joint Precision Approach and Landing System
NovAtel, Calgary	P. Fenton. T. Murfin	Technical support - Internet/ Modem capable GPS receivers for Southern Alberta RTK Network, Galileo assessment
Applanix Corporation	B. Scherzinger	MultiRefPM(tm) development and testing
Canadian Space Agency	n/a	GPS/Galileo performance assessment

FUNDING

The amounts reported below have been pro-rated for the 12-month reporting period, even if the grant or contract is multi-year and has a total higher value.

The amount in external R&D grants and contracts raised by the grant holder as prime investigator was $1.2M. In addition to iCORE funding of $500,000, Dr. Lachapelle received $200,000 from his Tier 1 Canada Research Chair, $65,000 from his NSERC Discovery Grant, $60,000 from the telecom industry, $150,000 from his CFI ISRIP, and $40,000 from the National Centres of Excellence Auto 21 project. Revenue from the Canadian Coast Guard is $23,000, plus $12,000 from a CFI project at the University of Victoria, $60,000 from ARINC and the US Navy, $98,000 from the Department of National Defense, and $5,000 from ATS.

Research teams involving the grant holder raised another $0.6M Revenue as a co-investigator includes $43,000 (with Dr. Cannon, from the Canadian Space Agency), NSERC Strategic Grants of $114,000 with Dr. El-sheimy et al and $90,000 with Dr. Cannon et al, $10,000 with Dr. Cannon from NRCan, $300,000 with Dr. Cannon et al from the CFI/CCIT equipment grant, $32,000 from Shell Canada with Dr. Tait et al, and $7,000 with Dr. Cannon et al from other industrial sources.

INTELLECTUAL PROPERTY

During Reporting Period

Some of the processes and algorithms developed during the reporting period and, in some cases, initiated previously, were embedded in software that were disclosed to University Technologies International (UTI). These new software packages consist of SAINT(tm)(Satellite And Inertial Navigation Technology), NDL(tm) (Navigation Development Laboratory), SimGNSS1(tm) (Software Simulator for Global Navigation Satellite Systems 1), and SimGNSS2(tm) (Software Simulator for Global Navigation Satellite Systems 2). In addition, the following software packages, developed previously, were maintained and enhanced: C3NAVG2(tm), FLYKIN+(tm), HEADRT+(tm) and MULTIREF(tm). The revenue generated by UTI during the reporting period was $75,000, down from $550,000 for the previous reporting period, due to a slowdown in the IT industry. The outlook for the next 12-month however looks better.

In addition to the above, some of the intellectual property developed by the grant holder was transferred to third parties (industry and Canadian and foreign government agencies through grants and contracts. The value of this activity during the reporting period was in excess of $300,000.

The total value of the IP transfer during the reporting period was therefore $375,000.

Potential for Future Commercial Activity

The chair holder and his colleagues continue to seek commercial opportunities for their existing and forthcoming intellectual property on an on-going basis, in the form of industrial research grants and contracts, licenses, and equity position in new commercial ventures. They will built on their past success and expertise to achieve this objective. UTI will continue to serve as the University licensing arm for these activities. Given the chair holder's extensive contacts with a broad range of organizations interested in his team's work, this type of commercial activities is expected to grow substantially during the next three years.

PUBLICATIONS

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2. C. Wang, and G. Lachapelle, "GPS Attitude Determination Reliability Performance Improvement Using Low Cost Receivers," Journal of Global Positioning Systems, vol. 1, no. 2, 2002, pp. 85-95.
3. G. MacGougan, G. Lachapelle, R. Klukas, K. Siu, L. Garin, J. Shewfelt, and G. Cox, "Performance Analysis of A Stand-Alone High Sensitivity Receiver," GPS Solutions, Springer Verlag, vol. 6, no. 3, 2002, pp. 179-195.
4. M. Olynik, M.G. Petovello, M.E. Cannon, and G. Lachapelle, "Temporal Impact of Selected GPS Errors on Relative Point Positioning," GPS Solutions, vol. 6, no. 1-2, 2002, pp. 47-57.
5. G. Lachapelle and G. Pugliano, "Posizionamento GPS Network RTK: il metodo MultiRefä," Bollettino della SIFET, N° 3, 2002, pp. 5-15.
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7. K. O'Keefe, S. Ryan, and G. Lachapelle, "Global Availability and Reliability Assessment of the GPS and Galileo Global Navigation Satellite Systems," Canadian Aeronautics and Space Journal, Canadian Aeronautics and Space Institute, vol. 48, no. 2, 2002, pp. 123-132.
8. S. Ryan and G. Lachapelle, "Augmentation of DGNSS With Dynamic Constraints For Marine Navigation," Lighthouse, Canadian Hydrographic Association, Ottawa, No. 61, 2002, pp. 17-25.
9. L.P. Fortes, M.E. Cannon, S. Skone, and G. Lachapelle, "Improving a Multi-Reference GPS Station Network Method for OTF Positioning in the St. Lawrence Seaway," Lighthouse, Canadian Hydrographic Association, No. 61, 2002, pp. 4-11.
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11. G. Lachapelle and P. Alves, "Multiple Reference Station Approach: Overview and Current Research," Invited Contribution, Expert Forum on VRS, Journal of Global Positioning Systems, vol. 1, no. 2, 2002, pp. 133-136.

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2. R. Klukas, G. Lachapelle, C. Ma, and G. Jee, "A GPS Signal Fading Model for Urban Centres," IEE Proceedings of Microwaves, Antennas and Propagation, 2003, in press.
3. N. Luo and G. Lachapelle, "Precise Relative Positioning of Multiple Platforms Using GPS Carrier Phase Ambiguity Constraints," IEEE on Aerospace and Electronic Systems, 2003, in press.
4. L. Fortes, L., M.E. Cannon, G. Lachapelle, and S. Skone, "Optimizing a Network-Based RTK Method for OTF Positioning," GPS Solutions, 2003, in press.
5. U. Dogan, P. Alves, G. Lachapelle, and S. Ergintav, "Testing a Multiple Reference Station GPS Network for Real-Time Carrier Phase-Based Positioning in the Marmara Region, Turkey" Survey Review, 2003, accepted for publication.

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7. G. MacGougan, and J. Liu, "Fault Detection Methods and Testing," Proceedings of GPS2002, The Institute of Navigation, 2002, pp. 2668-2678. (Best Student Paper Award)
8. C. Wang and G. Lachapelle, "GPS Attitude Determination Reliability Performance Improvement Using Low Cost Receivers," Proceedings of GPS2002, The Institute of Navigation, 2002, pp. 1064-1074.
9. P. Alves, G. Lachapelle, M.E. Cannon, J. Park. And P. Park, "Use of Self-Contained Ionospheric Modelling to Enhance Long Baseline Multiple Reference Station RTK Positioning," Proceedings of GPS2002, The Institute of Navigation, Alexandria, VA, 2002, pp. 1388-1399.
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13. J. Collin, G. Lachapelle, and J. Käppi, "MEMS-IMU for Personal Positioning in a Vehicle - A Gyro-Free Approach," Proceedings of GPS2002, The Institute of Navigation, Alexandria, VA, 2002, pp. 1153-1161.
14. C. Ma. R. Klukas, and G. Lachapelle, "An Efficient NLOS Error Mitigation Method for Wireless Location," Proceedings of TRLab Wireless 2002 Conference, Calgary, July 8-10, 2002, pp. 160-167.
15. W. Abdel-Hamid, A Noureldin, N. El-Sheimy and G. Lachapelle, "Performance Analysis of MEMS-based Inertial Sensors for Positioning Applications," Proceedings of International Workshop on System-on-Chip for Real-Time Applications, Kluwer Academic Publishers, pp. 440-450.

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2. G. Lachapelle, G. MacGougan, K. O'Keefe, and M. Petovello, Testing of the Force 22 GPS Receiver. Report prepared for Defence Research Establishment Ottawa, Department of National Defence, 2002, 95 pp.
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7. K. O'Keefe, G. Lachapelle, and M.E. Cannon, Large Adaptive Reflector Real Time Kinematic (LARTK) GPS Positioning Software. Final Report Prepared for the Dominion Astrophysical Observatory, Penticton, B.C., 2003, 25 pp.

Williamson Feature
ELISA

DR CAREY WILLIAMSON

BROADBAND WIRELESS PROTOCOLS, APPLICATIONS AND PERFORMANCE

Computer Science
University of Calgary

Dr Carey Williamson is an iCORE Professor in Broadband Wireless Networks, Protocols, Applications, and Performance. iCORE has committed $350,000 per year for five years, for a total of $1.75 million dollars for this program at the University of Calgary. Dr Williamson also holds an iCORE-Telus Industrial Research Chair in the area of Wireless Traffic Modeling and Simulation at the University of Calgary, for which he receives $100,000 a year from both Telus and iCORE for five years.

EXECUTIVE SUMMARY

Dr Carey Williamson leads a research team of about a dozen members (graduate students and research staff), with interests in wireless networks, Internet technologies, and network performance. Much of the research is experimental in nature, with an applied focus on industrially relevant network and protocol performance issues. The highlights of this reporting year include:

- expanding the team to seven graduate students, three of whom hold major scholarships
- receiving funding from Telus Mobility and iCORE for an Industrial Research Chair in Wireless Internet Traffic Modeling
- authoring or co-authoring 16 research papers (2 journal, 6 conference, 8 submitted)
- developing intellectual property regarding wireless Web servers
- building Phase 1 of the CFI-funded Experimental Laboratory for Internet Systems and Applications (ELISA)
- receiving an undergraduate teaching award.

RESEARCH GOALS AND OBJECTIVES

Two of the most exciting and fastest-growing Internet technologies in recent years are the World Wide Web and wireless networks. The Web has made the Internet available to the masses, through its TCP/IP protocol stack and the principle of layering: Web users do not need to know the details of the underlying communication protocols in order to use network applications. Wireless technologies have revolutionalized the way people think about networks, by offering users freedom from the constraints of physical wires. These technologies are available today, in laptop or handheld form, at relatively modest cost. Mobile users are interested in exploiting the full functionality of the technology at their fingertips, as wireless networks bring closer the "anything, anytime, anywhere" promise of mobile networking.

The research program focuses on unifying wireless technologies and the Web, exploiting the full

benefits of each. Necessarily, the research program is applied in nature, with a strong focus on experimental computer systems and performance research.

The general goals of the research program, as stated in the original proposal to iCORE, are:

- To identify performance problems and bottlenecks in the design and operation of protocols in wireless/Web-based communications systems;
- To propose and evaluate creative solutions to these performance problems;
- To promote larger-scale deployment of wireless Internet/Web infrastructure at the University of Calgary

RESEARCH PROJECTS

This section describes selected projects underway in my research group in 2002-2003. The number of projects discussed is small, for space reasons. The chosen projects are intended to reflect the variety of the network performance research carried out in the group, and complement the larger set of projects described in last year's annual report.

Wireless Web Servers

A natural step in the wireless Internet evolution is the convergence of technologies to form the "wireless Web": the wireless classroom, the wireless campus, the wireless office, and the wireless home. In fact, the same technology that allows Web clients to be mobile (i.e., wireless network interfaces) also enables the deployment of wireless Web servers.

While the market for mobile Web servers may not be obvious, they can play a useful role in short-lived networks. A short-lived network is created spontaneously, in an ad hoc fashion, at a particular location in response to some event (scheduled or unscheduled). The network operates for some short time period (typically minutes to hours), before being disassembled, moved, and reconstituted elsewhere.

A NATURAL STEP IN THE WIRELESS INTERNET EVOLUTION IS THE CONVERGENCE OF TECHNOLOGIES TO FORM THE "WIRELESS WEB".

There are several distinguishing characteristics of a short-lived network. Often, the location of the needed network is not known a priori. There may not be any existing network infrastructure, either wired or wireless, at the needed location. In addition, the time at which the network is needed may not be known. Deployment may need to be spontaneous, with unknown (but often bounded) operating duration. The number of users for the network is typically small (perhaps tens to hundreds), bandwidth requirements are moderate, and the geographic coverage area for the network is limited. More importantly, there is often a need for either data collection or data dissemination at the site of the network. In most cases, the data access requirement is for a "closed" set of specialized content, rather than general Internet content. Examples of deployment scenarios for short-lived networks are sporting events, disaster recovery sites, press conferences, conventions and trade shows, and classroom area networks. The potential for entertainment applications (e.g., media streaming, home networking, multi-player gaming) is also high. In many of these contexts, an ad hoc wireless network (with a wireless Web server as an information repository) provides a suitable solution.

In this project to date, the team has explored the feasibility of wireless Web server deployment in the context of classroom area networks. While the measurement experience to date with wireless Web servers in the "legacy classroom" environment has been modest (i.e., one graduate class with 13 students), the experiments in the Wireless Internet Performance Laboratory at the University of Calgary have more rigorously determined an upper bound on the practical achievable performance. In

particular, the research was focused on the performance capabilities of an Apache Web server running on a laptop computer with an IEEE 802.11b wireless LAN interface. The team studied in-room and in-building Web performance for a small number of Web client machines, also with wireless network interfaces. All mobile computers are configured to operate in ad hoc mode, since no existing network infrastructure is assumed. The clients download content from the wireless Web server. A wireless network analyzer collects and analyzes traces from the experiments, with traffic analysis spanning from the Medium Access Control (MAC) layer to HTTP at the application layer.

The experiments focused on the HTTP transaction rate and end-to-end throughput achievable in an ad hoc wireless network environment, and the impacts of factors such as number of clients, Web object size, persistent connections, transmit power, and wireless channel error rate. In general, the experimental results indicate that off-the- shelf hardware and software for wireless Web servers can provide tolerable user-level Web performance. However, the wireless bottleneck, network efficiency problems, and server power consumption issues may limit the performance and robustness of wireless Web servers in short-lived networks, at least with current technology.

This work has been carried out primarily by Research Associate Guangwei Bai and MSc student Kenny Oladosu. Technical assistance, when needed, has been provided by Martin Arlitt, Nayden Markatchev, and Tianbo Kuang.

Ongoing work targets the deployment of wireless Web servers at indoor University of Calgary home sporting events (e.g., volleyball, basketball) next winter. The challenges include not just Web content delivery, but also request scheduling, wireless media streaming, quality of service, TCP protocol performance, caching, security, and ad hoc routing. This single project unifies many of the topics on which the graduate students and research staff are currently working. An Intellectual Property agreement for the Wireless Web Servers project was signed with UTI at the University of Calgary this past year.

A paper describing research results to date has been submitted for possible external publication. It is still in the review process.

Web Traffic Characterization

In this past year, the team did a 6-month industrial research contract with SaskTel (Saskatchewan Telecommunications) in Regina. SaskTel is the primary telecommunications provider in the Province of Saskatchewan, and one of many Internet Service Providers in the province as well. The objectives of the project were:

- to develop a network monitoring tool for measuring Internet traffic on the 1 Gbps backbone link in SaskTel's provincial network
- to characterize the Web traffic generated by residential customers on SaskTel's network
- to provide recommendations for enhancing the effectiveness of SaskTel's existing Web caching infrastructure

This project was carried out primarily by Martin Arlitt, a Senior Research Associate on my iCORE research team. He was assisted by colleague Rob Simmonds in the development, testing, and debugging of the multi-threaded network monitoring software.

Since the project work was carried out under a non-disclosure agreement, the results of the project cannot be included here. However, the project was still extremely valuable, for three reasons. First, the lab maintained intellectual property rights to the network monitoring software that was developed for this project. The team is currently using the very same software in a (voluntary) project with Information Technologies at the University of Calgary, to help characterize campus-wide Internet traffic. With this software, the team is well prepared to do similar projects with any other telco or ISP that expresses interest in our tool. Second, the SaskTel network provided a very challenging environment for the testing and debugging of the network monitoring software. Several anomalies were noted (e.g., improperly encapsulated IP packets, TCP port number collisions at Web caching proxies), so the software had to be fixed to detect and handle these

properly. As a result, the software tool is more robust now than it would have been if developed only within our pristine test environment. Third, the proprietary data sets that we collected provided us with a current snapshot of "typical" Internet usage. The biggest surprise was the sheer volume and variety of peer-to-peer (P2P) file-sharing traffic seen on the network.

The latter observation has launched a new research front on peer-to-peer networking issues. Team member Martin Arlitt attended a CANARIE Networking Workshop in Ottawa this past year to learn more about P2P, and will play a lead role in our ongoing research on this topic.

CATNIP TCP

One of the experimental protocols developed in our research group last year was called CATNIP (Context-Aware Transport/Network Internet Protocol). The CATNIP protocol provides a "smarter" way for a Web server to send Web pages to a Web client, by indicating which TCP packets are the crucial ones that affect the user-perceived response time for Web page downloads. Network simulation and network emulation experiments with CATNIP TCP demonstrated its effectiveness in reducing both the mean and the variance of delays for Web page downloads.

The primary challenge tackled this year was to find the "path of least resistance" for possible deployment of CATNIP TCP on the Internet. In its original version, CATNIP TCP requires a 1-bit "packet priority" field in a reserved portion of the TCP packet header. Needless to say, this is an obstacle to its deployment on the Internet because of the need to modify all the routers to interpret this bit properly.

The compromise approach proposed is to leverage DiffServ (Differentiated Services), a stateless paradigm for providing Quality of Service (QoS) on today's Internet. The DiffServ traffic classes are supported by many of today's router vendors.

The CATNIP/DiffServ (CATNIP-DS) project was undertaken by team member Qian Wu, with some initial assistance from TeleSim team member Roger Curry. Qian has developed a scheme for mapping CATNIP packet priorities into DiffServ "codepoints" at the network edge. The approach then relies on network routers supporting DiffServ to make use of this codepoint information when handling packets.

Experiments to date have been carried out with network simulation, using ns-2. Simulation results have actually been quite disappointing, showing little or no benefits for CATNIP TCP on DiffServ. One reason is RED (Random Early Detection), a probabilistic packet discard algorithm used for active queue management in DiffServ routers. The probabilistic nature of RED is likely nullifying the effectiveness of intelligent packet marking at the edges of the network. The team is currently developing a much more comprehensive set of simulation experiments to fully understand this phenomenon, before moving on to network emulation and live Internet experiments with CATNIP-DS.

RESEARCH TEAM

The research team consists of five full-time research staff, and seven graduate students (one of whom is co-supervised).

TEAM MEMBERS

TEAM LEADER	AWARDS
Carey Williamson	Teaching Excellence-Honorable Mention

OTHER TEAM MEMBERS	TITLE/TOPIC
Martin Arlitt	Web Performance, Network Traffic Measurement, Workload Characterization
Guangwei Bai	Internet Traffic Modeling, Wireless Web Measurement
Tianbo Kuang	Wireless Traffic Measurement, Media Streaming
Qian Wu	Network Simulation, TCP/IP
Nayden Markatchev	

MSC CANDIDATES

MSC CANDIDATES	TOPIC
Mingwei Gong	Request Scheduling in Internet Web Servers
Abhinav Gupta	Location-Aware Ad Hoc Routing
Andreas Hirt	Wireless Network Security
Gwen Houtzager	Optimizing Web Proxy Cache Placement
Yujian (Peter) Li	Modeling Web/TCP Transfer Time
Kehinde (Kenny) Oladosu	Wireless Web Server Performance
Fang (Shelly) Xiao	Fairness Issues for Wireless TCP

COLLABORATIONS

At the University of Calgary, the research team continues to interact with the TeleSim research group coordinated by Rob Simmonds and Brian Unger. Collaboration with Rob Simmonds was crucial for a joint paper on Web server benchmarking using the IP-TNE (Internet Protocol Traffic and Network Emulator) for parallel WAN emulation. Collaboration with PhD candidate Cam Kiddle has resulted in a co-authored paper (Kiddle, Simmonds, Williamson, Unger) on fluid-flow approaches to network simulation.

Also at the University of Calgary, I have volunteered to assist with a CFI proposal to upgrade the general campus networking infrastructure and increase the deployment of wireless infrastructure on campus. Morven Wilson (Information Technologies) is the lead on this application.

COLLABORATION WITH INDUSTRY

Telus Mobility

In Summer 2002, I submitted a brief research proposal to iCORE regarding a possible industrial

research chair on Wireless Internet Traffic Modeling, to be jointly funded by iCORE, NSERC, and Telus Mobility. In Fall 2002, I received notice that I was awarded industrial funding from Telus Mobility ($100,000 per year, for two years), with matching funds from iCORE ($100,000 per year, for two years).

The conditions of the award indicated that an application for an NSERC Industrial Research Chair (IRC) should be submitted within the first year of the award, to obtain additional matching funds and to extend the chair position to five years. Over the past 6 months, I have been preparing my NSERC/Telus/iCORE Industrial Research Chair application to be submitted to NSERC. The bulk of the research proposal is finished, though the budget section and the university portion of the proposal are still in a state of flux. The full proposal should be submitted to NSERC in Summer 2003.

Two meetings with Telus Mobility took place during the past quarter. On an interim basis, research team member Qian Wu has been assigned to the "Wireless Network Capacity Planning" part of this project until a suitable new Research Associate can be recruited. Preliminary simulation results are expected in Summer 2003.

SaskTel

In this past year, the team did a 6-month industrial research contract with SaskTel in Regina. The collaborative research project on Web Traffic Measurement was completed in December 2002, with the final report submitted in January 2003.

Sun Microsystems

On behalf of Dr Dennis Salahub (VP Research) and the University of Calgary, Professor Ron Johnston (Department of Electrical and Computer Engineering) and I drafted a proposal for a Sun Microsystems Center of Excellence (COE) on Wireless Internet Technologies, to be situated in the ICT building at the University of Calgary. A meeting was held on campus with Sun representatives in 2002, but as yet no further information is known about the status of this proposal.

Intel

I have met with the local Intel representative Monty Ghitter to discuss a possible research project related to wireless Internet technologies. A project proposal was developed and submitted to Intel, with feedback anticipated in April 2003.

TRLabs

I also have had several meetings with John McRory at TRLabs regarding mutual research interests. I am planning to be part of their upcoming CFI proposal on Home Networking Technologies.I am planning to join TRLabs as an Adjunct Scientist in Spring 2003, and hope to have a TRLabs-sponsored graduate student (or two) in September 2003. I have volunteered to offer a tutorial (Wireless Internet: Protocols and Performance) at the TRLabs Wireless 2003 conference in July.

MULTIDISCIPLINE OR MULTI-INSTITUTIONAL PARTNERSHIPS

My primary multi-institutional partnership is with respect to the CFI-funded Experimental Laboratory for Internet Systems and Applications (ELISA), being constructed jointly between the University of Calgary and the University of Saskatchewan. While the official decision regarding the matching funds from the Province of Saskatchewan is still pending (anticipated in April 2003), the University of Saskatchewan has advanced "bridge funding" for Phase 1 of the ELISA lab on an interim basis.

Significant progress was made this year on the ELISA lab at the University of Calgary. First, the renovations for the ELISA server room in ICT 718A are now complete. These plans, coordinated by Brian Scowcroft, involved extra wiring (electrical power, network connections), plumbing (air conditioning), and equipment protection (Universal Power Supply, emergency shutoff). Second, network connectivity for the lab has been arranged. The network connection for the lab is a 1 Gbps Ethernet (copper) to the campus router. From there, Netera will provide the external connectivity to CA*net 4, and thus to the University of Saskatchewan. Third, the interim funding from the University of Saskatchewan was used to purchase some initial equipment for the ELISA lab. This equipment included laptops, wireless access points, rack-mounted PCs, a router/switch, and a data storage server. This equipment arrived in March, and is now operational in the lab.

Completion of the ELISA lab is expected in Summer 2003, once the Province of Saskatchewan matching monies are secured (anticipated April 2003) and all CFI funds released.

FUNDING

The initial iCORE research program budget assumes \$350,000 per year from iCORE for 5 years. These funds are complemented by support from the university (faculty positions, startup funds, graduate student support, lab space, in-kind contributions), research grants (NSERC, CFI), external scholarship support (NSERC, Alberta Ingenuity, iCORE), and industrial support. The total budget in the initial proposal averages $750,000 per year.

New Funds Acquired This Year as Prime Investigator

In September 2002, I was awarded funding from Telus Mobility for an Industrial Research Chair in Wireless Internet Traffic Modeling. This funding ($100,000 per year for two years)was matched by iCORE, bringing the total to $200,000 per year for two years. An application for an NSERC Industrial Research Chair is in preparation, to further complement this funding (an additional $100,000 per year) and extend it to five years.

The SaskTel research project generated $30,000 in external contract revenue, of which 30 percent was retained by the university for research overhead.

My individual NSERC research grant was up for renewal this year. I applied in October 2002, and received a notification of award in March 2003. My new Discovery Grant amount is $33,000 per year, for four years.

The Province of Alberta matching funds for the ELISA CFI lab were received this year. I was the principal investigator on this application. The amount awarded by ASRIP was $605,000. These funds are awaiting the go-ahead from the Province of Saskatchewan, and must be spent by the end of March 2004.

New Funds Acquired This Year as Co-Investigator

While the CFI award for the ELISA lab was officially announced in January 2002, I am showing the CFI award (\$1.2 million) in this year's budget, to be consistent with my original iCORE proposal. The co-investigators on the CFI proposal are Derek Eager and Rick Bunt from the University of Saskatchewan, and myself from the University of Calgary. The University of Saskatchewan is the lead institution on this proposal. I was the principal investigator, writing most of the proposal prior to my move to the University of Calgary.

INTELLECTUAL PROPERTY

As mentioned previously, a primary research theme this year has been on wireless Web servers, to evaluate their feasibility and performance. We contacted Richard May from InnoCentres and Geoff Moon from UTI regarding this innovation at a very early stage of the research, to evaluate commercial potential and protect intellectual property (IP) rights. The IP agreements clearly state that iCORE funding was the primary enabler behind this research idea.
UTI has completed the "due diligence" process with respect to this IP, and Richard May has had preliminary discussions with several parties regarding commercial potential for the idea. No revenue has accrued from this IP yet.

The other intellectual property item of interest is the network monitoring software developed by Rob Simmonds and Martin Arlitt for the SaskTel project. In many respects, this software is similar to the public-domain tool tcpdump, though our tool has been carefully designed and implemented for 1 Gbps Ethernet environments.

Three particular innovations in this software tool are the multi-threaded architecture developed by Simmonds (allowing the software to run effectively on a dual-processor network monitoring machine, reading packets at 1 Gbps) the customized statistical summaries developed by Arlitt (allowing it to run for long periods of time, while summarizing traffic for Web, peer-to-peer, and other networking applications), and the HTTP parsing code developed by Arlitt and Simmonds (allowing it to parse HTTP/1.0 and HTTP/1.1 headers in TCP packet payloads, revealing information about request sizes, response sizes, browser types, persistent connections, and Web object cacheability).

The tool also supports the capture of packet headers or full packet payloads, just like tcpdump. This software has been shared with SaskTel on a non-exclusive basis for their ongoing use. We have retained intellectual property rights for this software, allowing further development and use for our own research purposes.

PUBLICATIONS

Refereed Journal Publications

1. C. Williamson, R. Simmonds, and M. Arlitt, "A Case Study of Web Server Benchmarking Using Parallel WAN Emulation," Performance Evaluation, vol. 49, no.1-4, Sept. 2002, pp. 111-127.
2. M. Busari and C. Williamson, "ProWGen: A Synthetic Workload Generation Tool for Simulation Evaluation of Web Proxy Caches," Computer Networks, vol. 38, no.6, June 2002, pp. 779-794.

Conferences

1. C. Kiddle, R. Simmonds, C. Williamson, and B. Unger, "Hybrid Packet/Fluid Flow Net- work Simulation," to appear, 17th Workshop on Parallel and Distributed Simulation (PADS), San Diego, CA, June 2003, pp.143 - 152.
2. G. Bai and C. Williamson, "Workload Characterization in Web Caching Hierarchies," Proc. IEEE/ACM Intl. Symp. Modeling, Analysis, and Simulation of Computer and Telecommunications Systems (MASCOTS), Fort Worth, TX, Oct. 2002, pp. 13-22.
3. N. Markatchev and C. Williamson, "WebTraff: A GUI for Web Proxy Cache Workload Modeling and Analysis," Proc. IEEE/ACM MASCOTS Conference, Fort Worth, TX, Oct. 2002, pp.356-363.
4. T. Kuang and C. Williamson, "A Measurement Study of RealMedia Audio/Video streaming Traffic," Proc. SPIE ITCOM 2002, Boston, MA, July 2002, pp. 68- 79.

5. T. Kuang and C. Williamson, "RealMedia Streaming Performance on an IEEE 802.11b Wireless LAN," Proc. IASTED Wireless and Optical Communications Conference (WOC 2002), Banff, AB, July 2002, pp. 306-311.
6. G. Bai and C. Williamson, "Time-Domain Analysis of Web Cache Filter Effects," Proc. SCS Intl. Symp. Perf. Eval. of Comp. and Telecomm. Systems (SPECTS'02), San Diego, CA, July 2002, pp. 195-205.
7. C. Williamson and Q. Wu, "Context-Aware TCP/IP," Proc. ACM SIGMETRICS Conference, Marina del Rey, CA, June 2002, pp. 262-263. (abstract only)
8. R. Simmonds, C. Williamson, M. Arlitt, R. Bradford, and B. Unger, "Web Server Benchmarking Using Parallel WAN Emulation," Proc. ACM SIGMETRICS Conference, Marina del Rey, CA, June 2002, pp. 286-287. (NOTE: Poster paper. Extended abstract only.)

WILLIAMSON

INNOVATION ALBERTA

MICROSYSTEMS AND THE LAB ON A CHIP

Audio interview adapted and reprinted courtesy Innovation Alberta

Introduction: Microengineering and computer processing are transforming everyday procedures into Lilliputian marvels. Take the lab-on-a-chip concept, where blood samples can be analyzed instantly for health concerns. Or tiny implants that work on via a wireless network to repair damage to your body or improve your body functions. As one of a number of new iCORE chairs in informatics, Dr Graham Jullien brings together experts from disparate fields to develop microtechnology devices and procedures.

GJ: I was at the University of Windsor in southern Ontario for 31 years and the opportunity to come to Alberta arose, where there is funding infrastructure support for modern high technology. There is a lot of new opportunity here, a chance to interact with new people.

CC: AS THE ICORE CHAIR, WHAT WILL YOU BE DOING?

GJ: My mandate is to set up a world-class research lab in integrated micro systems. The official name of the lab is Advanced Technology Information Processing Systems. As you can probably imagine from that title, it pretty well leaves me to do a lot of different things and that's what I intend to do. I already know what some of those things are going to be. Others, I do not. We'll see what happens.

CC: WHAT IS LAB-ON-A-CHIP

GJ: Lab-on-a -chip is trying to reduce what used to be a set of laboratory tests done on the bench or in the lab, down to the level where you can hold one of these things in your hand or even lower than that, perhaps down to the level of just measuring these things over a few millimeters. What used to be a set of test tubes or electrophoresis slides are being brought down to a level where they are just a few millimeters in size. It involves an interaction of a lot of different disciplines, for example, the biochemistry disciplines associated with the original experimentation but also the microelectronic and microstructure disciplines that are being used to fabricate these particular devices.

CC: IT SOUNDS A BIT LIKE THE STUFF OF STAR TREK.

GJ: Science fiction does have a habit of eventually coming through, I suppose. We are a ways away from being able to wave a tricorder or something over the body and get an instant analysis, but we can get sort of biomedical analysis down a lot more efficiently by going to these smaller, smaller devices.

CC: WHAT OTHER APPLICATIONS ARE IN THE WORKS?

GJ: Biomedical analysis is normally where you find lab-on-a-chip being applied. However, I've worked for several years with colleagues back at Windsor on hearing instruments. We're working with a company, Jenome Corporation, in Burlington who have something like 70% of the world's silicon in the canal hearing aids. These are hearing aids that go right inside the ear. So we're not talking about hearing aids that sit around the ear or hanging on one's belt or whatever but hearing aids right inside the ear. Therefore, they have to be small and they have to be very low power and obviously they have to do a good job as well.

We been examining this sort of application and this has taken us to something called microelectromechanical systems which are small mechanical devices that are built at the level of millionths of an inch – the total device measuring in millimeters. One device in a hearing aid is a microphone. We've started to look at integrating those with the incredible amount of processing power that's now available on a little sliver of silicon. The integration of those sorts of microelectronic devices with microelectromechanical devices with the processing power of silicon also is leading us in Calgary, here now, to look at other applications of this.

There's another project that a colleague, Dr Mintchev, at the University of Calgary in the Electrical and Computer Engineering Department here. He's working with control problems with the colon that people generally don't want to talk about but these are major problems for people and he is actually looking at electrical stimulation procedures for helping people recover from these problems. We're looking to see if it feasible to implant micro devices right where they are needed to restimulate, for example, colonic muscles or stomach muscles. That might be a possibility. It might be possible to actually implant intelligent electrodes inside the body that can talk to each other over a wireless local area network.

CC: IT SOUNDS LIKE THIS INVOLVES MEDICAL DOCTORS AND RESEARCHERS AND TECHNOLOGISTS.

GJ: The trick here is to bring these disparate technologists together and I think that's what I can do. There are some incredible things that one can think of. Maybe this is science fiction. Maybe it can't be done. I don't know but, hey, let's have a shot at this.

DR GRAHAM A. JULLIEN

ATIPS iCORE LABORATORY

iCORE Chair
Electrical and Computer Engineering
University of Calgary

Dr Graham Jullien holds an iCORE Chair in Advanced Technology Information Processing Systems at the University of Calgary. iCORE has committed $800,000 per year for the first three years, then $600,000 per year for two years, for a total of $3.7 million dollars to establish this Chair.

EXECUTIVE SUMMARY

The ATIPS Laboratory conducts research into the implementation of information processing systems using advanced and emerging technologies. The ATIPS laboratory provides a knowledge link between these technologies and the chosen application areas in order to both facilitate their rapid exploitation and to uncover new linkages. Our long-term goal is to apply advanced and emerging technologies to targeted applications by being knowledgeable and innovative at all steps in the process. To achieve this requires a group of multidisciplinary researchers who are prepared to interact at levels of knowledge beyond their own immediate expertise.

A major achievement this year has been to assemble such a group, the Centre for Innovative Wireless Integrated Microsystems (CIWIMS), and to define a CIWIMS Laboratory Cluster. The Cluster will provide a stimulating environment in which the researchers will interact to work on projects that require a much wider set of skills than are normally required for working in one specific research area. We currently have a group of 10 principal researchers from a wide range of areas including: wireless-RF; wireless-location finding; bio-sensors; System-on-Chip processors; thin-film and fabrication-integration; health sciences. The ATIPS Laboratory provides skill-sets in the general area of System-on-Chip processors, but our projects are collectively quite wide-ranging in scope, and oriented towards the targeted areas of wireless devices for the health sciences.

Our current projects include: wireless networks; embedded systems and fault tolerant systems; and the modeling and simulation of circuits and structures in advanced and emerging fabrication technologies. Highlights include: arithmetic techniques for applications as varied as low-power hearing instruments, 400M samples per second adaptive wireless base station filters, and extremely low noise digital processing circuits; machine vision techniques for analyzing defects directly within the camera in real-time; several novel video coding architectures for multi-media streaming.

Established research projects in the area of wireless networks include novel high signal rate filters for base stations and wireless "platforms" from which a variety of low-power mobile wireless devices may be quickly developed. We have also explored the areas of embedded and fault tolerant systems. This is a fruitful area for our group and we have conducted wide-ranging research into: machine vision; hearing instruments; arithmetic techniques; video processors and circuit techniques; along with novel methods that apply fault tolerance to computational systems with relatively low overhead. Finally we have linked this work with the advanced and emerging fabrication technologies with which we currently construct our microelectronic circuits.

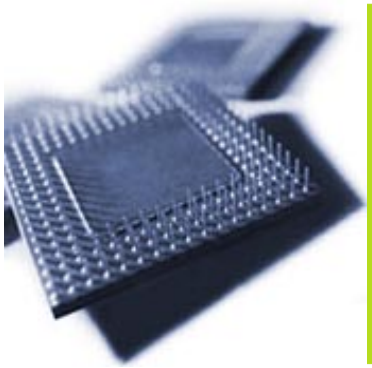
Our research is conducted with the support of major Canadian industries, and we are a member and lead client in the Canadian Microelectronics Corporation System-on-Chip Research Network, funded by a $40 million CFI grant, that is being used to bring the technology of System-on-Chip design to all interested Canadian Universities.

The ATIPS Laboratory has a core personnel component of about 30 researchers and students. The laboratory workstations host more than 50 graduate students performing research on all aspects of integrated circuit design.

Find out more at: http://www.atips.ca/

RESEARCH GOALS AND OBJECTIVES

The mission of the ATIPS laboratory is to investigate the use of advanced and emerging fabrication technologies to iCORE targeted applications in selected areas of information processing. The ATIPS laboratory provides a knowledge link between these technologies and the chosen application areas in order to both facilitate their rapid exploitation and to uncover new linkages.



OUR LONG-TERM GOAL IS TO APPLY ADVANCED AND EMERGING TECHNOLOGIES TO TARGETED APPLICATIONS BY BEING KNOWLEDGEABLE AND INNOVATIVE AT ALL STEPS IN THE PROCESS. TO ACHIEVE THIS REQUIRES A GROUP OF MULTIDISCIPLINARY RESEARCHERS WHO ARE PREPARED TO INTERACT AT LEVELS OF KNOWLEDGE BEYOND THEIR OWN IMMEDIATE EXPERTISE.

The original targeted areas, based on the initial interests of iCORE, were: a) wireless networks; b) embedded systems including fault tolerant processors; c) computing with nanotechnology. We have contributed to each of these areas in a variety of ways, but have also targeted biotechnology and health sciences as major application areas. We formed a consortium, the BioMedical Microsystems Group (BMMG), at the University of Calgary, and this interaction has led to the establishment of the Centre for Innovative Wireless Integrated Microsystems (CIWIMS) and the assembly of the CIWIMS Laboratory Cluster in the new CCIT (Calgary Centre for Innovative Technology) building on campus. CIWIMS includes, among its principals, three iCORE Chairs (Jullien, Haslett, Lachapelle), a Steacie Fellow (Cannon), and a CRC Chair (Okoniewski). In addition the group includes Dr Kaler, the Director of the Calgary Institute for Nanotechnology (CINT), with strong ties to the National Institute for Nanotechnology (NINT) at the University of Alberta, and two very promising young faculty members (Badawy, an ATIPS Laboratory member and Budiman, a thin film specialist from the Mechanical and Manufacturing Engineering Department). The health sciences are represented by two outstanding scholars (Sheldon and Pilarski) from the Medical Faculties at, respectively, the University of Calgary and the University of Alberta. The ATIPS Laboratory also has close ties with the Department of Mathematics at the University of Calgary; in particular the cryptography group led by iCORE Chair, Prof. Hugh Williams. Dr V.S. Dimitrov (ATIPS iCORE Associate) and Dr G. Jullien are members of the Centre for Information Security and Cryptography (CISAC), founded by Prof. Williams; Dr Dimitrov has been elected to the board of CISaC as the Faculty of Engineering board member.

Wireless Networks

A research project on adaptive filters is being conducted in cooperation with TRLabs, Calgary. The application is an experimental 1.2Gbps wireless LAN (local area network) operating at a frequency of 17Ghz. The system is asymmetrical, which means that most of the processing power is contained in the fixed base-station with very little (mostly analog) circuitry contained in the mobile units. This project is involved with the application of special number theoretic techniques to the implementation of high-speed quadrature signal adaptive filters. A novel processor design has been been tested on a custom FPGA (Field-Programmable Gate Array) simulator, developed by TRLabs (Calgary), at somewhat lower speeds than required for the final design. An IP Core (proprietary processor block) in 0.18µ CMOS is being designed to operate at the planned throughput of 400M samples per second.

A new research project on System-on-Chip low-power wireless platforms was started in 2002. The work involves developing versatile wireless enabled integrated circuit design structures (platforms) to which custom functionality can be added. This research is being conducted as part of the University of Calgary lead-client status for the Bluetooth IP core and IP core authoring threads associated with the CMC SoC Research Network (SOCRN). This work also forms part of a tutorial to be presented at the 2003 ISCAS.

Machine Vision

We have conducted a long-term project on multiple camera defect detection on rolling conveyor processes. The systems use multiple synchronized cameras in order to cover large width conveyors with pixel sizes in the tens of microns. Our current work involves the use of line-scan TDI (Time Delay and Integration) CCD (charge-coupled device) sensors, with video stream FPGAs, We have recently demonstrated the ability to self-synchronize the CCD sensors with the image velocity using only the output of the sensor (prior to this development it was necessary to use optical shaft encoders connected to the conveyor). The control of the synchronization has been coupled with defect detection algorithms implemented in the on-line FPGAs, to produce a very versatile set of techniques for defect detection in heavily textured backgrounds. This work involves close interaction with an industrial sponsor (DALSA Inc.).

As part of our work on machine vision we have recently investigated the use of plenoptic cameras for single camera depth recovery. A customizable plenoptic camera simulator, using backward ray tracing with stochastic sampling, was developed in 2002. This simulator will enable our research group to test any plenoptic camera configuration for depth recovery purposes. The simulator has been successfully tested against standard camera-lens configurations and we are now looking at potential plenoptic configurations for building a custom test camera system.

Hearing Instruments

This work is sponsored by our industrial partner, Gennum Corporation, and is related to the application of special architecture, arithmetic and circuit techniques to producing very low-power programmable digital implementations. CIC devices are particularly challenging to digitize because of the extremely small size and power dissipation required. Our goal is to continue and extend this work to embrace our wider interests in microconvergent systems.

In 2002 a hearing instrument filterbank processor was designed, fabricated in 0.18µ CMOS, and tested. The processor uses a 2-D 2-digit Multi-Dimensional Logarithmic Number System (MDLNS) to implement the filterbank. A binary to MDLNS converter, using a completely new conversion technique, was also implemented on the chip. The chip has been successfully tested and the technique is now being examined by our sponsor for potential commercialization.

We have also recently commenced a project on developing an asynchronous MDLNS processor architecture in order to further lower the power dissipation, and to reduce the effects of switching noise due to clocking. A complete asynchronous architecture for the MDLNS processor has been developed, including an asynchronous control system for realizing handshaking protocols. Full-custom integrated circuit cells have also been developed for future fabrication of a test chip.

Next generation hearing

instruments will be based on the directivity obtainable with microphone arrays. In a joint project with the University of Windsor and Gennum Corp. we have developed designs for MEMS microphone arrays, special MEMS sockets for integrating the MEMS arrays with integrated circuit processors, and techniques for using them in acoustic beam steering. We are currently converting the original designs into process steps for implementing at the University of Alberta NanoFab. This work will be among the first of our microconvergent research projects.

Arithmetic techniques

One of our long-term strengths is the investigation of alternative techniques for number representation in order to reduce the complexity and improve the performance of real-time digital signal processing systems. We define performance in terms of cost functions containing: time delay; resource utilization (e.g., silicon area or FPGA logic blocks); power dissipation; system noise (particularly with mixed-signal designs that use noise sensitive analog circuitry); and design time (with particular emphasis on SoC design reuse using parameterizable processor blocks).

In a direct link between arithmetic architectures and deep-submicron (DSM) technologies, we have been working on a variety of multiplier structures in terms of the effect of interconnect wiring on their performance. We have recently established optimum multiplier architectures for a variety of DSM technologies.

We are currently investigating the application of a multidimensional logarithmic number system that has been in development by our group for the past three years. It is based on earlier work on a double-base representation pioneered by our research group at the University of Windsor. We have developed a complete theory for this new number representation and have applied it to several application areas.

Many digital signal-processing computations are based on coefficients that are irrational (particularly transforms such as DFT, DCT and also some wavelets). In implementing these computations, we invariably introduce errors because of the need to represent the coefficients with finite precision. Our group has recently investigated mapping techniques, based on the use of algebraic integers, which allow the manipulation of such coefficients without any error. So far, we have applied our technique to DCTs and wavelets, with applications to video compression.

An increasing concern in DSM technologies is the noise generated by the very short switching transients in digital circuitry. In systems that combine sensitive analog circuitry (for example circuitry associated with sensors), this switching noise can be a major problem. We have taken a completely different approach to this problem by defining arithmetic systems that compute with digital precision but only use standard analog circuits. We have recently developed two such systems; one is based on cellular neural networks (non-linear analog circuits in a 2-D array); the other is based on a natural analog representation of multi-digit numbers - continuous valued digits. We are currently developing test circuitry to further evaluate these arithmetic systems.

Video Processors

Streaming video has become ubiquitous on the internet. Given typical internet bandwidths to the consumer, there is a need to greatly compress the video data in order to provide streaming capabilities without interruption (current techniques compress by about 2-orders of magnitude). Our interests are in the efficient implementation of current compression standards, including Discrete Cosine Transforms (DCTs) and Discrete Wavelet Transforms (DWTs), and the development of new standards. ATIPS team member, Dr W. Badawy, is a Canadian representative on the MPEG-4 standards committee.

We have used the algebraic integer work from our arithmetic investigations to implement error-free DCTs and have extended this concept of multidimensional algebraic integers Daubechies DWTs. A DCT chip is currently undergoing testing in order to verify the simulated performance.

We have also explored novel video and image coding architectures, for the MPEG4 and JPEG2000 standards, using more conventional arithmetic techniques. For these architectures we have implemented both DWTs and DCTs. One of the DWT designs was submitted to the MPEG4 (Part 9) Committee, and another design, based on

Distributed Arithmetic (DA), was proposed in which the performance improved on the best existing architectures by 40%. A new DCT time distributed architecture was proposed and successfully implemented using FPGAs. This design was also submitted to the MPEG (Part 9) committee and was accepted as a reference architecture and code for an MPEG4 hardware profile.

Circuit Techniques

Where necessary we look at designs at the transistor level. In the past this has included special dynamic logic circuitry and minimized transistor tree structures. Our current interests are in the use of non-linear analog circuits implementing Cellular Neural Network (CNN) array architectures. CNN arrays allow digital computation with very low system and cross-talk noise (three orders of magnitude below CMOS) because of the continuous dynamics of the interconnected non-linear analog cells. We are exploring a variety of number representations including standard binary, signed digit (using bi-directional current circuits) and DBNS. Dr J. Haslett, TRLabs/iCORE/NSERC Industrial Research Chair in Wireless RF Integrated Circuit Design, is co-supervising a student in this work and our results are being prepared for publication.

Fault Tolerant Systems

Fault tolerance is important for systems that have to operate reliably over long periods of time. Fault tolerance may also become important as fabrication densities increase to the point where the potential of soft faults increases. We have recently developed low overhead (about 30%) fault tolerant computational arrays based on the MRRNS system; this representation is also used to implement the adaptive filter for the TRLabs experimental LAN, and we plan to add fault tolerance to the base station adaptive filter during the next year.

Advanced Technologies and Computing with Nanotechnology

Our interests in advanced CMOS technologies are in the development of novel designs, from system level to transistor level. With this vertical approach we encounter a variety of design challenges. As technologies advance, device densities increase and each level in the design hierarchy brings its own problems and requires different solutions. The amalgamation of these design solutions and advanced technology modeling constitute System-on-Chip design. In the past few months we have set up a design laboratory, with both physical and electronic security, to enable our team to explore and develop SoC designs with third party IP blocks and advanced tools from the Canadian Microelectronics Corporation. We have also started to look at design reuse as a powerful tool for our own novel and custom designs.

The technology that has brought us advanced integrated circuits is also responsible for other microstructure-based technologies, including MEMS, microfluidics, RF-wireless components, and photonic devices. These technologies are, in the main, disparate but very useful microsystems can be built using the microconvergence of these technologies. We have assembled a consortium of researchers to examine the application of wireless enabled microconvergent systems, with particular applications in biotechnology and the health sciences. We have already developed several bio-MEMS blocks and have started to develop a low-power SoC bio-platform including a novel "lexel" array that is to be used as a dielectrophoretic cell analysis technique.

Computing with Nanotechnology

Our interests in the use of nanotechnology for computing are somewhat different to the burgeoning research into quantum computing. We are interested in exploring nanotechnologies that will provide a fairly smooth design space transition from design techniques used for conventional FET based circuitry. We have initially targeted Quantum Cellular Automata (QCA) technology for our studies, since it has been rated by several research organizations in the top 6 of nanocomputing technologies that have the most promise for commercial fabrication. The arrays of quantum dots that make up each QCA cell can also operate in a 2-state mode, which provides a smooth design transition from the low/high impedance states of FET channels that are used to implement 2-state logic in conventional designs. We have had considerable initial success with a unique CAD tool (QCADesigner) for quantum cellular automata (QCA) architectures. The tool is unusual

in that, although the technology is rather speculative at the moment, we have sufficient modeling information with which we can develop and simulate architectural blocks that we typically find in processor architectures built with standard integrated circuit fabrication technology. We have built the tool using a simulator jointly developed with the research group at the University of Notre Dame in Indiana - the group that initially proposed QCA technology. QCADesigner received the Micralyne Microsystems Design Award at the 2002 CMC Workshop. The tool has been used, by our group and many other researchers, to design new structures for potential QCA architectures. Springer has invited our group to write a textbook on the technology, QCADesigner and our new structures.

RESEARCH TEAM

Part of the ATIPS research program is being conducted by students at Dr Jullien's previous institution, the University of Windsor. These students are funded from Micronet grants.

TEAM MEMBERS

TEAM LEADER	AWARDS
Graham Jullien	Elected IEEE Fellow
TEAM	**TITLE**
Vassil Dimitrov	iCORE Research Associate; Number representations, Digital signal processing
Wael Badawy	ATIPS Team Member, VLSI Architectures, SoC, Image recognition, Low-power design
OTHER TEAM MEMBERS	**RESEARCH TOPIC**
Jonathan Eskritt	ATIPS Lab Manager
Paul Hobal	ATIPS WebMaster and Publicity

POSTDOCTORAL FELLOWS

PDF	TOPIC
Peiyu Zhang	Bio MEMS, Optical MEMS, MEMS Processes, Clean Room procedures
Wenjing Zhang	Data Stream SoC Architectures, VLSI Design, Integrated Circuit Test, Neural Networks

PHD CANDIDATES

PHD	TOPIC	AWARDS
Ibrahim Baykal	Defect Detection using in-Camera Video Stream Processing	
Jonathan Eskritt	Applications of MDLNS	
Minyi Fu	Applications of Algebraic Integers in New Architectures for Video Codecs	
Tamer Ibrahim	Very low-noise Arithmetic Processing Unit	Ontario Graduate Scholarship
A. Makki	Beam-Steered Hearing Instruments	
Roberto Muscedere	Difficult Operations in Double-Base Number Systems	
Konrad Walus	Quantum Cellular Automata	NSERC PGS-A, iCORE

MSC CANDIDATES

MSC	TOPIC	AWARDS
Mehboob Alam	SoC Implementation of Video Codecs	
Mohamed Amtoun	Depth Recovery in Plenoptic Cameras	
James Doherty	Transcutaneous Powering of an Implantable Stimulator	Alberta Ingenuity Fund
Ryan Glabb	Low-power System-on-Chip Platforms	
Paul Horbal	Adiabatic logic for ROM-Based Architectures	
Jeffrey Keilman	Lexel Arrays for Cell Manipulation using Dielectrophoresis	NSERC PGS-A, iCORE

Jennifer Li	An MDLNS Filter-bank for a Low-power Digital Hearing Instrument	
Pedram Mokrian	Multiplier Design in Deep Sub-micron Technologies	
Arash Razavi	Plenoptic Camera Simulation	
Mohammed Sayed	Embedded Memory Architectures for MPEG-4 Motion Estimation	
Gabriel Schulhoff	Modeling Quantum Dots on a Computer Cluster	
Jeff Tracey	Optimized Arithmetic Cells for SoC IP Blocks	
Jiansong Wu	Asynchronous Hearing Instrument MDLNS Processors	
Jonathan Yeboah	CNN Analog Arrays for Low-Noise Digital Adder Design	

UNDERGRADUATES

UNDERGRADS	TOPIC
Ian Steiner	MRRNS Complex Arithmetic Adaptive Filter
Adesh Garg	MRRNS Complex Arithmetic Adaptive Filter

COLLABORATIONS

RESEARCH COLLABORATION

University of Windsor, Ontario: G.A. Jullien has a formal association with the Research Centre for Integrated Microsystems. Research colleagues are M. Ahmadi and W.C. Miller and we are co-applicants on a $53,000 Micronet grant (principal applicant M. Ahmadi - S.1.WI). M. Ahmadi is also a co-applicant on a $203,000 Micronet Grant (S.2.CAL - G.A. Jullien principal applicant). G. Jullien currently supervises or co-supervises six graduate students (three other graduate students supervised or co-supervised in 2002 have since graduated). Our area of research is in hearing instruments, MEMS, and signal processors.

Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier, France. G.A. Jullien and V.S. Dimitrov, have a strong research association with Dr L. Imbert (CNRS Researcher) and Dr J-C. Bajard (Director of the Dept. Fundamental and Applied Informatics). Dr Imbert was employed as a postdoctoral fellow in both Windsor and Calgary, and G. Jullien has visited Dr Bajard at Montpellier and also his previous laboratory in Marseilles. We currently have a joint French-Canadian research grant application under review (applicant V.S. Dimitrov). Our areas of research are computer arithmetic, cryptography, and fault tolerance. A joint paper has been accepted for publication this year.

Helsinki University of Technology. Dr V.S. Dimitrov has strong ties with GETA (Graduate School in Electronics, Telecommunication and Automation). He was a consultant there from 1997-2000 and has taught short courses at GETA from 1998 to the present. G. Jullien has also taken part in one of the earlier short courses. (http://wooster.hut.fi/geta/courses/graham/index.html). The areas of research are DSP, number theoretic techniques and cryptography.

The Queen's University, Belfast. G. Jullien has had ties with 2 colleagues in the Department of Electrical and Electronics Engineering at Queen's for several years. Dr J. McCanny CBE, FRS, FIEEE, interacts with Dr Jullien in the area of systolic arrays and IP cores for signal processing. Recent discussions have taken place regarding the acquisition of IP cores from Amphion Inc, where Dr McCanny is CTO. These discussions have involved CMC and the SOC Research Network. Dr McCanny was one of the plenary speakers at the IWSOC workshop at Banff, where G. Jullien was the general chair. He also acted as a consultant to the ATIPS Lab. in 2002. The other colleague is Dr J. Woods in the area of rapid prototyping and FPGAs. Dr Jullien was invited to Queen's as a distinguished scholar in 1999, and Dr Woods is being invited as a consultant to the ATIPS Laboratory in October, 2003.

The University of Lousiana at Lafayette. Dr Jullien has had ties with the Centre for Advanced Computer Studies (CACS) since the late 80's. The chair of both the Departments of Electrical and Computer Engineering and Computer Science, Dr M. Bayoumi, is a former student of Dr Jullien, and Dr Badawy received his PhD under Dr Bayoumi's supervision. Dr Jullien has acted as both consultant and distinguished lecturer at CACS and Dr Bayoumi will be visiting the ATIPS Lab this year as a consultant. The research area of interest is in digital video processing and integrated circuit design.

The University of Texas at Austin. Dr Earl Swartzlander, of the Dept.of Electrical and Computer Engineering, has had strong ties with DrJullien's research group over the past 17 years. Dr Swartzlander and Dr Jullien have been involved in the organization of several conferences in the area of array processing and computer arithmetic, and Dr Swartzlander was a plenary speaker at the IWSOC in 2002. They have had previous joint papers together in the area of transistor level circuits for computer arithmetic.

The University of Grenoble, Spain. Dr Antonio Garcia, ECE. Dr Garcia was a research associate in G. Jullien's laboratory in the late 90's, and they have continued to work together on parallel processors using modular arithmetic. A joint paper was presented this year.

The University of Wisconsin, Madison. Dr Jullien has collaborated on conference organization and a special journal issue with Dr M. Schulte, Dept. ECE. The special issue was based

on the 2001 ASAP conference, and Dr Schulte is the technical chair for the 2003 Asilomar Conference on Signals, Systems and Computers, for which Dr Jullien is the general chair.

Other collaborations. For brevity we list other university collaborations together in this section with contacts and research areas. All collaborations have resulted in visits to discuss research projects. University of Newcastle, UK - Dr N. Coleman (logarithmic processors). University of Cardiff, Wales - Prof. N. Burgess (residue number systems). Penn State, US - Prof. W.K. Jenkins, Chair ECE (computer arithmetic). UCLA, Dept. Computer Science - Prof. M. Ercogovac, Chair (computer arithmetic). University of Florida, Gainesville - Dr F. Taylor, ECE (real-time architectures). Edith Cowan University, Perth, Australia - Dr K. Eshraghian, Head of School and Foundation Professor of Computer, Communication and Electronic Engineering (VLSI design, processor architectures). Universita' degli Studi di Trento - Dr Andreas Caranti, Dept. Math. (number representations, cryptography). Notre Dame University, Indiana - Dr Craig Lent, Microsystem Group (Quantum Cellular Automata).

COLLABORATION WITH INDUSTRY

DALSA Inc.

Dr Jullien has had a long-term research interaction with DALSA Inc. He has known the CEO of DALSA, Dr S. Chamberlain since they both served on the NSERC Grant Selection Committee in the mid-80's (they both chaired the committee in contiguous years). Dr Jullien pioneered the concept of in-camera defect detection in 1990 while working on a contract for DALSA. This idea was patented in 1995 (J.W. Roberts, J.G. Elias, G.A. Jullien, 1995, "High Speed Defect Detection Apparatus having Defect Detection Circuits Mounted in the Camera Housing," United States Patent, No. 5,440,648, Aug. 8.) and has resulted in sales exceeding $20M over the past decade. The concept was transferred to a university project supported by Micronet with industrial funding from DALSA (approximately $500,000 over the past decade including matching funds). Dr Jullien has served on the Board of Directors of DALSA since 1992. The company went public in 1996.

Gennum Corp.

Dr Jullien's laboratory at the University of Windsor, and now extended to the University of Calgary, has been working with Gennum Corp. since 1994. The initial work, which is still on-going, was in the area of video signal processing (for broadcast quality TV signal processing). Since 1998 our group has worked with Gennum Corp. on hearing instrument processors. Since 1994, Gennum has contributed over $700,000 (including matching funds) to our research.

TRLabs

We have included TRLabs in this section since part of its funding comes from industry. TRLabs has sponsored the ATIPS Laboratory since its inception. Currently, an intern student is partially supported from TRLabs funding (see the Research Projects section), City of Calgary. Dr Badawy has been applying his novel work on vision systems to the development of an Active Camera Tracking System for Traffic Analysis. The City of Calgary is contributing $120,000/year and also allowing special access to traffic lights and infrastructure.

IPROS

This start-up company in Toronto invited Dr Dimitrov to be on its advisory board. The company is working on building SoC cores for the efficient implementation of complex arithmetic processors, for applications in smart antennas for the communications market.

We have several other industrial contacts as follows: Qinetiq, UK, this used to be a UK Government institution (the Royal Signals and Radar Establishment), but has now been privatized. We have connections with Dr J. McWhirter, FRS, Dr I. Proudler and Dr R. Walke in the area of array processors for DSP. Dr McWhirter will be the plenary speaker at the 2003 Asilomar Conference, and will also act as a consultant to the ATIPS Lab. in October 2003 We have recently made contacts with the following local industries: Smart Technologies Inc., SiWorks, and Non-Elephant Encryption Systems. We are also interacting with the Innocentre and organize an annual Lunch'n Learn meeting to introduce local industry to the projects and capabilities of the ATIPS Laboratory.

MULTIDISCIPLINE OR MULTI-INSTITUTIONAL PARTNERSHIPS

Micronet R&D (NCE)

Dr Jullien was one of the founding members of Micronet, one of the first 14 Networks of Centres of Excellence, and one of only five to be funded through the full 14 year life-span of networks in the NCE program. Dr Jullien sits on the Board of Directors, the Steering Committee, and the Coordinating Committee of Micronet. Micronet R&D is comprised of 17 universities, 44 companies and two federal organizations, all in Canada. The research personnel contributed by the universities includes 71 faculty members and 363 graduate students and other research personnel. For 2001-2002, the total income of the network was $4,306,000 with approximately 32% being contributed by industry. Dr Jullien leads a project which was funded at $213,000 in 2002 (made up from Micronet base funding, industrial contributions and funding from the NSERC eMPOWR Innovation platform). This is one of the largest of the more than 50 projects funded by Micronet. In addition, Dr Jullien is a co-applicant in a second project from the University of Windsor, funded last year at $53,000. Until 1998, Dr Jullien was also the principal investigator in this second project.

Canadian Microelectronics Corp. (CMC) provides microsystem design tools, and fabrication and information services to 44 Canadian Universities, and Colleges. It has 25 Canadian Companies as members and is strongly linked to industry organizations and has a senior government official on the Board. Dr Jullien has been a member of CMC since 1985 (less than a year after it was founded). He served as Member Representative for the University of Windsor until 2000. He was on the Board of Directors from 1989-93 (vice-chairman of the Board in 1993) and rejoined the Board in 2001. He is one of 10 principal researchers in the System-on-Chip Research network, funded by a $40M CFI grant. Drs. Badawy and Jullien are lead clients for the IP blocks that were purchased from the CFI funds, and the IP block authoring suite being developed by a sub-committee of the Technical Advisory Committee. A secure laboratory has been set up in the CCIT building to handle commercial IP blocks in the development of SoC platforms.

The Centre for Information Security and Cryptography. Prof. Hugh Williams, iCORE Chair in Cryptography, Department of Mathematics at the University of Calgary has established CiSAC to bring together a multidisciplinary interest group in the area of cryptography and quantum computing. Drs. Dimitrov and Jullien are members of this centre and Dr Dimitrov also sits on the board of CiSAC as the Engineering Representative.

FUNDING

Our work is supported, in addition to iCORE, by NSERC, the Canadian Microelectronics Corporation, Micronet R&D (NCE), and several prominent microelectronic industries.

In addition to the iCORE funding of $800,000, the budget includes $80,000 from an NSERC Discovery grant and $213,000 from the Micronet NCE project (includes Micronet base funding, industrial contributions and NSERC eMPOWR funding).

New funds acquired as co-investigator include $53,000 from Micronet NCE, with M. Ahmadi as principal investigator, and $400,000 from the Canadian Microelectronics Centre for the SoC Research Network.

INTELLECTUAL PROPERTY

Since the ATIPS Laboratory became operational in mid-2001, we have been in close contact with University Technologies International, wholly owned by the University of Calgary, and have been encouraged to protect any substantial IP that is developed as part of research projects undertaken in the ATIPS laboratory. ATIPS accepts this encouragement in the case of substantive intellectual property opportunities.

Activity this year, including revenue

There has been no revenue from intellectual property this year since we have only just started IP protection procedures. ATIPS is recording the following activities connected with IP protection and development:

i) Optimal base 2-D logarithms for very efficient FIR filter implementations - submitted to UTI for patent consideration. (Dimitrov-Jullien)

ii) Double-base sparse representations for applications in Cryptography- submitted to UTI for patent consideration. (Dimitrov-Jullien).

iii) Self-Synchronization algorithms for time-delay and integration (TDI) line-scan cameras for machine vision applications - submitted to UTI for patent consideration. (Jullien)

iv) Lexel arrays for arbitrary electric field generation with applications to cell motion and identification using dielectrophoresis - submitted to UTI for patent consideration. (Jullien-Kaler).

v) Trade Names LEXEL and PLEXEL submitted to UTI for registration. (Jullien-Kaler).

vi) Two other trade names have been registered with UTI; GrApp and WebConcorde. These are associated with a software package developed for hosting technical conferences and paper/review submissions on the web. (Badawy)

vii) A potential startup company on Vision Systems has been registered with InnoCentre for the purpose of attracting venture funding. (Badawy)

PUBLICATIONS

Refereed Journal Publications

1. V.S Dimitrov and G.A. Jullien, "Multidimensional Algebraic-Integer Encoding for High Performance Implementation of the DCT and IDCT," Electronics Lett., vol.39, no. 7, 2003, pp. 602-603.
2. W. Badawy, M. Talley, G. Zhang, M. Weeks, and M. A. Bayoumi, "Low power very large scale integration prototype for three-dimensional discrete wavelet transform processor with medical applications," The SPIE Journal on Electronic Imaging, Vol. 12, No. 2, April 2003, pp. 270-277.
3. K. Wahid, V.S. Dimitrov, G.A. Jullien, and W. Badawy, "Error-free computation of Daubechies Wavelets for Image Compression Applications," Electronics Lett., vol.39, no. 5, 2003, pp. 428-429
4. Arash Shoarinejad, Sue Ann Ung, and W. Badawy, "Low power single-bit full adder cells," The Canadian Journal on Electrical and Computer Engineering, Vol. 28, No. 1, January 2003 pp. 3 - 9.
5. Wael Badawy and Magdy Bayoumi, "A Parallel Multiplication-Free Algorithm and Architecture for Affine-based Motion Compensation," The SPIE Journal on Optical Engineering, Vol. 42 No. 1, January 2003 pp. 255 - 264.
6. A. Saed, M. Ahmadi, and G.A. Jullien, "A Number System with Continuous Value Digits and Modular Arithmetic," IEEE Trans. on Computers, vol. 51, no. 11, 2002, pp. 1294-1305.

7. J.M.A.Tanskanen, and V.S. Dimitrov, "Round-off Error-Free Fixed-Point Design of Polynomial FIR Predictors and Predictive FIR Differentiators," Digital Signal Processing, vol. 13, 2002, pp. 42-57.
8. Hesham Ahmed, Walied Moussa, Wael Badawy, Medhat Moussa, "Applying FEA to Investigate the performance of Electrostatic Comb-Drive Actuators Utilized by on-a-chip systems", The Canadian Journal on Electrical and Computer Engineering, Vol. 27, No. 4, October 2002, pp. 195 - 200.
9. A. Garg, G.A. Jullien, G.H. McGibney, and J.W. Haslett, "A Modulus Replication Complex Adaptive Filter IP Core," Canadian Journal of Electrical and Computer Engineering, vol. 27, no. 4, 2002, pp. 177-181.
10. M. Sayed and W. Badawy, "A Novel Low Power Embedded Memory Architecture for MPEG-4 Applications with Mobile Devices," Canadian Journal on Electrical and Computer Engineering, vol. 27, no. 4, 2002, pp. 171-175.
11. W. Badawy, "System on Chip: the future of System Integration," Canadian Journal on Electrical and Computer Engineering, vol. 27, no. 4, 2002, pp. 149-154.
12. H. Safiri, M. Ahmadi, G.A. Jullien, and W. C. Miller, "A New Algorithm for the Elimination of Common Subexpressions in Hardware Implementation of Digital Filters by Using Genetic Programming," Journal of VLSI Signal Processing, vol. 31, no. 2, 2002, pp. 91-100.
13. W. Badawy and M. Bayoumi, "A Low Power VLSI Architecture for Mesh-based Video Motion Tracking," IEEE Transactions on Circuits and Systems II, vol 49, July 2002, pp. 488-504.
14. W. Badawy and M. Bayoumi, A Multiplication-Free Algorithm and A Parallel Architecture for Affine Transformation," The Journal of VLSI Signal Processing-Systems, Kluwer Academic Publishers, Vol 31, No 2, May 2002, pp. 173-184.
15. W. Badawy and M. Bayoumi, "Algorithm-Based Low Power VLSI Architecture For 2d-Mesh Video Object Motion Tracking", IEEE Transaction on Circuits and Systems for Video Technology, Vol 12, No. 4, April 2002, pp. 227-237

Accepted publications by refereed journals

1. L. Imbert, V.S. Dimitrov, and G.A. Jullien, "Fault-tolerant Computations over Finite Rings with Applications in Digital Signal Processing," IEEE Trans. on Circuits and Systems (paper TCAS1-0171, 2003, in press - 11 journal pages).
2. V.S. Dimitrov and G.A. Jullien, "Loading the Bases: A New Number Representation with Applications," invited article for IEEE Circuits and Systems Magazine, No. 2, July 2003 (in press).Alfred C. H. Yu and Wael Badawy, "A Novel Video Object Extraction Algorithm for Real-time Mesh based Motion Tracking Applications," IEEE transaction on Circuits and Systems for Video Technology, (in press).
3. W. Badawy and M. Bayoumi, "A Low Power VLSI Architecture for Mesh-based Video Motion Tracking," The Journal of VLSI Signal Processing-Systems, Kluwer Academic Publishers, (in press - invited).

Refereed Conferences

1. A. Vetteth, K. Walus, G.A. Jullien, and V.S Dimitrov, "RAM Design Using Quantum-Dot Cellular Automata," Proc. 2003 NanoTechnology Conference, San Francisco, February 23-27, 2003, pp. 160-163.
2. P. Zhang and G.A. Jullien, "MEMS-based Micro-needle Structures for Biomedical Applications," Proc. 2003 NanoTechnology Conference, San Francisco, February 23-27.
3. K.A.Wahid, V.S Dimitrov, G.A. Jullien and W. Badawy, "An Analysis of Daubechies Discrete Wavelet Transform Based on an Algebraic Integer Encoding Scheme," IEEE Workshop on Digital and Computational Video, Clearwater, November 2002, (in press).
4. K.A. Wahid, V.S Dimitrov, G.A. Jullien, and W. Badawy, "An Algebraic Integer Based Encoding Scheme for Implementing Daubechies Discrete Wavelet Transforms," Proc. Asilomar Conference on Signals, Systems and Computers, (2002, in press - 5 pages).

5. A. Vetteth, K. Walus, V.S. Dimitrov, and G.A. Jullien, "Quantum-Dot Cellular Automata Carry-Look-Ahead Adder and Barrel Shifter," IEEE Emerging Telecommunication Technologies Conference, Dallas, September 23-24 2002, CD-ROM paper 2-I-4 (5 pages).
6. D. Gonzalez, A. Garcia, G.A. Jullien, J. Ramirez, L. Parrilla, and A. Lloris, "A New Methodology for Efficient Synchronization of RNS-based VLSI Systems," 12th IEEE International Workshop on Power And Timing Modeling, Optimization and Simulation, Spain, September, 2002.
7. I.C. Baykal and G.A. Jullien,"Detection of Defects in Textures with Alignment Error for Real-Time Line-Scan Web Inspection Systems," Proc. IEEE Mid-West Symposium on Circuits and Systems, August 2002, vol. 3, pp. 292-295.
8. V.S. Dimitrov and J.M.A Tanskanen,"Probabilistic design of long error-free fixed-point polynomial predictors and differentiators," IASTED International Conference on Signal and Image Processing, Kauai, August 2002, pp. 394-398.
9. G.A. Jullien, H. Li, R. Muscedere, and V.S. Dimitrov, "The application of 2-D logarithms to low-power hearing-aid processors," IEEE Mid-West Symposium on Circuits and Systems, vol. 3, 2002, pp. 13-16.
10. V.S Dimitrov, G.A. Jullien, and K. Walus, "Digital filtering using the multidimensional logarithmic number system," Proc. 47th Annual SPIE conference, Seattle, July 2002, (invited).
11. R. Muscedere, V.S Dimitrov, G.A. Jullien, and W.C. Miller, "Efficient Conversion From Binary to Multi-Digit Multi-Dimensional Logarithmic Number Systems using Arrays of Range Addressable Look-Up Tables," International Workshop on Application Specific Array Processors, San Jose, July 17-19, 2002, pp. 130-138.
12. M. Alam, W. Badawy, and G.A. Jullien, "A novel pipelined threads architecture for AES encryption algorithm," IEEE International Conference on Application-Specific Systems, Architectures and Processors, 2002, pp. 296 -302.
13. S. Chowdhury, M. Ahmadi, G.A. Jullien, and W.C. Miller, "MEMS Socket Interface For Soc Connectivity," 2nd IEEE Workshop on System-on-Chip for Real-Time Applications, Banff, July 2002, pp. 309-318.
14. A. Garg, G.A. Jullien, G.H. McGibney,* and J.W. Haslett, "Modulus Replication Complex Adaptive Filter IP Core," 2nd IEEE Workshop on System-on-Chip for Real-Time Applications, Banff, July 2002, pp. 430-437.
15. M. Alam, D. Onen, W. Badawy, and G.A. Jullien, "VLSI Prototyping of low-complexity wavelet transform on FPGA," IEEE Canadian Conference on Electrical and Computer Engineering, vol. 1, 2002, pp. 412-415.
16. M. Alam and W. Badawy, "VLSI Architecture Prototyping of Pipelined IIR Digital Filter" IEEE Canadian Conference on Electrical and Computer Engineering, vol. 2, 2002, pp. 1031-1035.
17. H. Li, G.A. Jullien, V.S Dimitrov, M. Ahmadi, and W.C. Miller, "A 2-Digit Multidimensional Logarithmic Number System Filterbank for a Digital Hearing Aid Architecture," Proc. IEEE Int. Symp. on Circuits and Systems, vol. 2, 2002, pp. 760-763.
18. R. Muscedere, I.C. Baykal, and G.A. Jullien, "On the use of Hash Functions for Defect Detection in Textures for In-Camera Web Inspection Systems," Proc. IEEE Int. Symp. on Circuits and Systems, vol. 5, 2002, pp. 665-668.
19. S. Chowdhury, M. Ahmadi, G.A. Jullien, and W.C. Miller, "A MEMS Socket System for High Density SOC Interconnection," Proc. IEEE Int. Symposium on Circuits and Systems, vol. 1, 2002, pp. 657-660.

Accepted papers at Refereed Conferences

1. A. Garg, I. Steiner, G.A. Jullien, J.W. Haslett, and G.H. McGibney, "A High Speed Complex Adaptive Filter for an Asymmetrical Wireless LAN Using a New Quantized Polynomial Representation," to be presented at the IEEE Int. Symp. on Circuits and Systems, Bangkok, May 2003.

2. Y. Wei, W. Badawy, "A NEW Moving Object Contour Detection Approach", to be presented at the 2003 IEEE international workshop on Computer Architectures for Machine Perceptions, May 12-14, 2003, New Orleans, USA.
3. Y. Wei and W. Badawy, "A Novel Zoom Invariant Video Object Tracking Algorithm (ZIVOTA)," to be presented at the 2003 IEEE Canadian Conference on Electrical and Computer Engineering, Montréal, Canada, May 4-7, 2003.
4. X. Liu and W. Badawy, "A Novel Error Control Scheme For Video Streaming Over IEEE802.11 Network," to be presented at the 2003 IEEE Canadian Conference on Electrical and Computer Engineering, Montréal, Canada, May 4-7, 2003.
5. P. Aggarwal, K. V. I. S. Kaler and W. Badawy, "Design and Implementation Of MEMS Based Micro-Needles For Biomedical Applications," to be presented at the 2003 IEEE Canadian Conference on Electrical and Computer Engineering, Montréal, Canada, May 4-7, 2003.
6. Alfred Yu and Wael Badawy, "On Reducing The Size Of Structured Meshes With A Novel Video Object Extraction Algorithm," to be presented at the 2003 IEEE Canadian Conference on Electrical and Computer Engineering, Montréal, Canada, May 4-7, 2003.
7. W. Khan, V.S Dimitrov, and G.A. Jullien, "Error-Free Arithmetic for Discrete Wavelet Transforms using Algebraic Integers," to be presented at the 16th IEEE Symposium on Computer Arithmetic (ARITH16), Spain, June 15-18, 2003.
8. M. Alam, C. A. Rahman, W. Badawy, and G.A. Jullien, " Efficient Distributed Arithmetic Based DWT Architecture for Multimedia Applications," to be presented at the 3rd IEEE Int. Workshop on System-on-Chip for Real-Time Applications, Calgary, June 30 - July 2, 2003.
9. Mohammed Sayed and Wael Badawy, "A New Class of Computational RAM Architectures for Real-Time MPEG-4 Applications," to be presented at the 3rd IEEE Int.l Workshop on System-on-Chip for Real-Time Applications, Calgary, June 30 - July 2, 2003.
10. J.R. Keilman, G.A. Jullien, and K.I.V.S. Kaler, "A SoC Bio-analysis Platform for Real-time Biological Cell Analysis-on-a-Chip," to be presented at the 3rd IEEE Int.l Workshop on System-on-Chip for Real-Time Applications, Calgary, June 30 - July 2, 2003.
11. M. Alam, W. Badawy, and G.A. Jullien, "Time Distributed DCT Architecture for Multimedia Applications," to be presented at the IEEE International Conference on Consumer Electronics (ICCE), Los Angeles, California, June 17-19, 2003.
12. P. Mokrian, G.A. Jullien, and M. Ahmadi, "Interconnect effects in deep submicron implementation of high performance arithmetic architectures," Advanced Signal Processing Algorithms, Architectures, and Implementations XIII, SPIE Annual Conference, August 2003.
13. K. Walus, G.A. Jullien, V.S Dimitrov, and A. Budiman, "Computer Arithmetic Structures for Quantum Cellular Automata," invited paper to be presented at the 2003 Asilomar Conference on Signals, Systems and Computers, Pacific Grove, CA, Nov. 9-12, 2003.

Books

1. W. Badawy, and G.A. Jullien, (eds.), System-on-chip for real-time applications: Concepts, Architectures and Implementations, Kluwer Academic Publishers, 2002, ISBN: 1-4020-7254-6.

Other

Special Issues

1. G.A. Jullien, G.A. and M. Schulte (Guest Editors), "Special Issue on Application-specific Systems, Architectures, and Processors," J. of VLSI Signal Processing, vol. 32, no. 2, 2002, pp. 75-184.

National Workshops

1. K. Walus, V. Dimitrov, G.A. Jullien, and W.C. Miller, "QCADesigner: A CAD Tool for an Emerging Nano-Technology," to be presented at the 2003 Micronet Annual Workshop, Toronto.

2. M. Amtoun, A. Razavi, M. Ahmadi, G.A. Jullien, and W.C. Miller, "Analysis and Simulation of a Single-lens Plenoptic Camera for Depth Extraction," to be presented at the 2003 Micronet Annual Workshop, Toronto.
3. J. Doherty, G.A. Jullien, and M.P. Mintchev, "Transcutaneous Powering of an Implantable Stimulator for Re-creation of Impaired Gastrointestinal Motility," Biomedical Engineering Workshop, Banff, November 2002.
4. J. Keilman, G.A. Jullien, and K.V.I.S. Kaler, "Design of an Arbitrary Electric Field Generator for use with a Dielectrophoretic Based Laboratory-on-a-Chip," Biomedical Engineering Workshop, Banff, November 2002.
5. K. Walus, R.A. Budiman, and G.A. Jullien, "Effects of morphological variations of self-assembled nanostructures on quantum-dot cellular automata (QCA) circuits," Frontiers of Integration, An International Workshop on Integrating Nanotechnologies, Edmonton, October 28, 2002.
6. K. Walus, A. Vetteth, G.A. Jullien, and V.S. Dimitrov, "Design and Simulation of Quantum Dot Cellular Automata," CMC Symposium On Microelectronics Research & Development In Canada, (This demonstration won the Micralyne award.) June, 2002.
7. S. Chowdhury, M. Ahmadi, G.A. Jullien, and W.C. Miller, "MEMS Based Connectivity for System Integration and Testing," Micronet Workshop, April, 2002.
8. R. Muscedere, J. Li, V.S Dimitrov, G.A. Jullien, M. Ahmadi, and W.C. Miller, "Multi-Dimensional Logarithmic Number Systems and Applications to Hearing Instrument Processors," Micronet Workshop, April, 2002.
9. M. Fu, V.S. Dimitrov, G.A. Jullien, M. Ahmadi, and W.C. Miller, "Implementation of an Error-Free DCT using Algebraic Integers," Micronet Workshop, April, 2002.

Contribution to Standards (2002-2003)

1. M. Alam, W. Badawy and G.A. Jullien. "Implementation & Hardware Reference Code for AMBA Bus Interface - Decoder (MPEG-4) IP Cores," ISO/IEC JTC1/SC29/WG11 MPEG2002/M8564
2. M. Alam, W. Badawy and G.A. Jullien. "MPEG-4 Video Hardware Reference Code for DCT & its Specifications for MPEG-4 Decoder," ISO/IEC JTC1/SC29/WG11 MPEG2002/M8565
3. M. Alam, W. Badawy and G.A. Jullien. "Integer DWT Reference Code and Specifications for MPEG-4," ISO/IEC JTC1/SC29/WG11 MPEG2002/M8582
4. ISO/IEC JTC1/SC29/WG11 N4965, Wael Badawy, Marco Mattavelli, and Robert Turney, Current development status of the MPEG4: Part 9 Reference Hardware Description.
5. ISO/IEC JTC1/SC29/WG11 MPEG2002/ M8562, Wael Badawy and Mohammed Sayed, "Embedded Memory Architecture For Motion Compensation in MPEG-4 Simple Profile"
6. ISO/IEC JTC1/SC29/WG11 MPEG2002/ M8563, Wael Badawy and Mohammed Sayed, "Motion Estimation Architecture for MPEG-4 Simple Profile"

Tutorials

1. W. Badawy, Y. Savaria, and G.A. Jullien, "System-On-Chip (SoC) Technology: The Future of VLSI Design," to be presented at the IEEE International Symposium on Circuits and Systems, Bangkok, May 2003.

Advanced Technology Information Processing Systems

Adapted and reprinted courtesy ATIPS

Fresh *THINKING*

ATIPS is an acronym for **A**dvanced **T**echnology **I**nformation **P**rocessing **S**ystems. It's a name intended to convey the fact that our research spans a diverse field of interests, not limited only to analog or digital VLSI design. While the old VLSI group is now an integral part of the ATIPS group, our research continues to branch out in new directions - not the least of which are the pursuits of the Biomedical Microsystems Group (BMMG).

Our mission is to build a world-class research laboratory in the application of advanced fabrication technologies to problems in information processing systems. We provide the link between these emerging technologies and their various application areas, thus facilitating their rapid exploitation. More than simply building with what is available, we look for exciting new ways to integrate existing technology into

Jim Haslett

Dr Haslett's research group specializes in RF Integrated Circuit Design in a variety of fabrication technologies, and is part of the University of Calgary VLSI ATIPS (Advanced Technology Information Processing Systems) Laboratory, directed by iCORE Research Chair Dr. Graham Jullien. Dr Haslett is the RF Wireless group leader in the ATIPS lab.

Dr Haslett was elected as a Fellow of the Engineering Institute of Canada in 2001 "in recognition of excellence in engineering and for service to the profession and to society," and a Fellow of the IEEE in 2001 "for contributions to high temperature instrumentation and noise in solid-state electronics." His recent research projects have focused on next-generation wireless products.

RFIC DESIGN GROUP

We are entering a new age of ubiquitous wireless connectivity. Cellphone usage is targeted to hit hundreds of millions of users by 2002. New wireless networks like Bluetooth and WiFi - 802.11 seek to connect not only our cellphones, but also our laptops, PDA's, and even our home appliances. Inside each of these devices will be a wireless transceiver in integrated circuit form, a Radio Frequency Integrated Circuit (RFIC).

There are many challenges involved in creating RFIC's. At the transistor level, various competing technologies (GaAs, Si, SiGe, and CMOS) each provide different benefits and drawbacks. Aside from the transistors, the creation of passive devices such as inductors, capacitors, and resistors also pose unique challenges to the IC designer. To create the amplifiers, mixers, and oscillators required in all wireless transceivers, RFIC designers must use clever circuit techniques to boost performance. These wireless "building blocks" can then be connected in different system architectures to achieve the required performance. The goal is to have a single radio-on-a-chip that need only to be connected to an antenna, output device, and a battery.

The ATIPS - RFIC research group is investigating solutions to many of the challenges presented above. Our research group is lead by IEEE Fellow Dr J.W. Haslett. The team currently consists of one PhD candidate, nine MSc candidates, one M.Eng. candidate and two undergraduate research assistants. We also work with Dr J. McRory who is both an Adjunct Professor with the University of Calgary and the Chief RF Scientist at TRLabs. Some of our past and present work includes:

- Developing solutions in state-of-the-art GaAs, CMOS, and SiGe technologies.
- Creating innovative new structures for integrated capacitors and inductors.
- A Tuneable, Active Inductor in both GaAs and CMOS implementations.
- Analog signal processing circuits for smart antenna systems.
- Circuit techniques for improved passive device performance.
- A 4GHz logarithmic amplifier for fiber-optic applications.
- High performance variable gain amplifiers for DSL wireline communications.
- SiGe RFIC circuits for 4th generation wireless networks.
- Novel Voltage Controlled Oscillators with improved phase noise.

The ATIPS - RFIC research group has access to design and test equipment within the department, and at TRLabs in the research park adjacent to campus.

DR JAMES HASLETT

TRLABS/iCORE/NSERC INDUSTRIAL RESEARCH CHAIR

iCORE Chair
Electrical and Computer Engineering
University of Calgary

Dr Jim Haslett leads a research program called the Wireless Science and Technology Initiative. To develop the research team, Dr Haslett has received an iCORE Industrial Chair Establishment (ICE) grant of $200,000 per year for five years for a total of $1 million dollars.

EXECUTIVE SUMMARY

This five-year Industrial Research Chair program, funded by TRLabs, iCORE and NSERC, is focused on developing, in conjunction with the TRLabs Wireless Research Center in Calgary, a sophisticated wireless RF Integrated circuit design and test capability, with Dr Jim Haslett as the group leader. The main intention of the research program is to develop the expertise required to design novel new devices, circuits and systems for 3rd and 4th generation wireless products of interest to the industrial sponsors of TRLabs, and to the wireless community in general.

The research program began in May of 2002, and in the ensuing 11 months, a team of 12 graduate students and two postdoctoral fellows has been assembled by Dr Haslett to carry out the chair mandate. Close collaboration with staff scientists at TRLabs, and extensive collaboration with other researchers and industrial sponsors has resulted in an excellent list of accomplishments for the first year of the chair program.

The student team currently consists of four PhD students, three holding NSERC/iCORE scholarships; and eight MSc students, three holding NSERC/iCORE scholarships, and a fourth holding an NSERC Industrial Scholarship. Two of the students have direct industrial RF design experience, and all have become proficient in RF Integrated Circuit design in a variety of fabrication technologies, including CMOS and Silicon Germanium BiCMOS.

The RF IC Design laboratory uses state-of-the-art design, simulation and layout software tools, and a sophisticated test laboratory is in use at TRLabs. Excellent infrastructure resources provided by the Canadian Microelectronics Corporation are complemented by an expanded VLSI laboratory, a new RF laboratory, a new secure System on Chip laboratory and a Clean Room Facility, house in the new ICT and CCIT buildings on the University of Calgary campus.

Dr Haslett and the research team have been successful in bringing in significant external funds to complement the $600,000 annual chair budget. In the past 11 months, an additional $244,368 has been obtained by Dr Haslett as principal applicant, to support the research program, excluding the student scholarships which amount to an additional $209,000 per year. Other funding has been obtained with Dr Graham Jullien, as outlined in the report.

During the year, 23 new RF ICs designed by the research group were fabricated through the CMC, and the results published in a variety of conferences and journals. Two new patent applications were filed through TRLabs. A national award and a local award were received by the students for some of the work. A number of new collaborative research projects were initiated, and a team of 10 principal researchers, including Dr Haslett, is currently preparing a CFI grant application to provide additional infrastructure to support the research programs.

RESEARCH GOALS AND OBJECTIVES

This Industrial Chair Program in Wireless Science and Technology (WISTI) was initiated on May 1st, 2002, for a 5-year period. The main research goals and objectives outlined in the chair proposal focused on developing, in conjunction with the TRLabs Wireless Research Center in Calgary, a state-of-the-art wireless RF devices, circuits and systems design and test capability, with Dr Jim Haslett as the group leader. The main thrust of the new research program was to develop new and novel techniques for providing operational flexibility, low noise, and low power devices for the next generations of wireless products, of interest to the Industrial sponsors of TRLabs, and to the wireless community in general.

WISTI Strategy:
The WISTI initiative was targeted to contribute to the development of a critical mass of RF researchers in Alberta with a primary focus on the device and circuit aspects, in cooperation with researchers working on overall system aspects at the University of Calgary, in the TRLabs Wireless Research Centre in the Discovery Place Research Park adjacent to campus, and at the University of Alberta. It was envisaged that the enhanced wireless RF research activity would provide a focal point for the training of highly qualified personnel that the industry needs as it moves into the next generation of wireless systems.

WISTI was intended to provide a capability to address the problems faced by Alberta and Canadian industry in generating new products using new technologies for the wireless marketplace. The TRLabs industrial sponsor consortium includes many of the major players in the wireless communications industry, providing an excellent opportunity to transfer the technology directly to the industry in a timely fashion. The critical mass was also expected to attract excellent graduate students, visitors and postdoctoral fellows from around the world.

THE TRLABS INDUSTRIAL SPONSOR CONSORTIUM INCLUDES MANY OF THE MAJOR PLAYERS IN THE WIRELESS COMMUNICATIONS INDUSTRY, PROVIDING AN EXCELLENT OPPORTUNITY TO TRANSFER THE TECHNOLOGY DIRECTLY TO THE INDUSTRY IN A TIMELY FASHION.

To enhance the chair research program, an additional academic staff member was to be hired into Electrical Engineering from supporting fields such as integrated optics, nanoscale fabrication technology, quantum electronics, multimedia, or low power systems.

Accomplishments to Date: The program has had a very good start, and after the first 12 months, a research team of 12 graduate students and two Postdoctoral Fellows is in place. Several of the students have won local, national and international awards and scholarships. A large number of RF integrated circuits have been designed, with a number of these fabricated and tested. The results have been disseminated to the industrial sponsor, and several journal and conference papers have been published. Two patents have been filed, and other papers are under preparation, under review or accepted for presentation at conferences in 2003.

Dr Haslett has also been successful in attracting additional funds from external agencies to support the research. This includes, with Dr Haslett as principal applicant, $67,700 from the Canadian Microelectronics Corporation (CMC) for integrated circuit design workstations and server, over $100,000 in chip fabrication grants from the CMC to support the RFIC design group in 2002-3, $39,383 from NSERC in the form of an equipment grant in March of 2003, and a $55,000 portion of Micronet funding with Graham Jullien as principal investigator in 2002-3. An additional software donation was received by Dr Haslett from Applied Wave Research in the US, to provide Microwave Office software to 20 students, valued at a commercial value of $28,800 US per copy, to support the graduate teaching and research.

In addition, $300,000 was allocated to Drs Haslett and Jullien from the Calgary Centre for Innovative Technology

(CCIT) Intelligent Technologies Research Group budget (Gerard Lachapelle, Group Director) to establish new RF Lab and Clean Room Facilities, in July of 2002. Dr Haslett is currently in the process of supervising the construction of a new RF design and test lab in the CCIT facility. A new RF Shielded enclosure was constructed in March and April of 2003, and has just been certified. Drs Haslett and Jullien have also been working toward a major expansion of the VLSI design facilities in the new Information and Communications Technology (ICT) building, and in CCIT. A second VLSI lab has been constructed in ICT, and a secure System-on-Chip (SOC) facility and Integrated Circuit Design Lab have been constructed in CCIT and are now operational. A Canada Foundation for Innovation (CFI) grant application is currently being prepared to provide additional equipment for these labs, with Dr Jullien as principal applicant, and with 15 other researchers involved. Dr Haslett is one of 10 principal researchers on that application.

At TRLabs, a new wide ranging collaborative research program in home technologies has been initiated, with financial support from new industrial sponsors, and from Western Diversification. Dr John McRory is leading a CFI grant application to support the research, and Dr Haslett is a principal researcher on that application as well.

In summary, the chair program is off to an excellent start, the team is largely in place, and infrastructure is being established to support the research program.

RESEARCH PROJECTS

Quite a number of research projects are currently under way, most targeted at developing building blocks for wireless transceiver systems, with applications in wireless local area networks, optical communications, biomedical monitoring, home technologies, and wireless location as examples.

Development of General RF Integrated Circuit Design Expertise

During the past year, Dr Haslett's research group has been developing expertise in the design, fabrication and testing of RF wireless circuit building blocks, in a variety of state-of-the-art fabrication technologies, for RF transceiver applications in the 1 to 20 GHz frequency range. Since many of the team members are new, and since the successful design, fabrication and testing of state-of-the-art RF integrated circuits is very challenging, the first year has involved a steep learning curve for many of the team members. The group is becoming proficient in the design of low noise amplifiers, mixers, voltage controlled oscillators, phase locked loop frequency synthesizers, filters, and other transceiver building blocks in Silicon-Germanium (SiGe) BiCMOS and deep submicron CMOS technologies, and this expertise can now be applied to several research projects as outlined below.

Realizing Fully Monolithic Transceivers in CMOS Fabrication Technology

The major challenge facing the wireless industry at present is to economically realize all required transceiver circuit functions on one silicon substrate (a monolithic realization), and to provide programmability to accommodate the various transmission standards encountered. This will reduce the cost of production very significantly, as well as miniaturizing the circuitry. Miniature low power circuits will open up the possibility of many new applications in the biomedical and other areas.

In order to achieve fully monolithic BiCMOS and CMOS circuits in the 5 to 20 GHz range, and to achieve maximum functional flexibility, the research group is working in several areas, as follows:

High Frequency Modeling of RF CMOS and Bipolar Transistors

Dr Haslett has published a number of papers in the area of the high frequency modeling of MOS devices, using tractable models suitable for hand analysis of small circuits such as those encountered in the RF building block research. With the widespread use of silicon-germanium bipolar high frequency transistors, similar RF characterization needs to be carried out. A great deal of activity is currently ongoing in the industry to provide

sophisticated computer-aided design models for these devices. Dr Haslett's group has developed approximate analytic models for hand analysis of analog RF circuits, along with the development of a detailed understanding of current state-of-the-art computer-aided models such as the Berkley BSIM4 Model, and the RF Bipolar transistor model high frequency scattering parameters. Dr Haslett's research group has ported CMOS 0.18 micron technology models from the Cadence Spectre RF modeling program to Cadence's new PSPICE modeling program that runs on PC platforms. This enables graduate students and others to use PC's for modeling the sophisticated processes rather than requiring a high level Unix Workstation and several millions of dollars (1 complete seat of Cadence software costs 3.5 million dollars U.S.) to perform basic circuit simulations.

Quality Factor Enhancement of Passive on-chip Spiral Inductors

One of the major impediments to achieving fully monolithic low cost transceivers in the industry today relates to the poor quality of on chip passive components, and the worst of these is the spiral inductor. Researchers throughout the world have tried a myriad of solutions, but no real success has been achieved without expensive additional fabrication steps in the manufacturing process. Initial work by our group involved the development of a detailed understanding of the modeling and design issues involved, and more recently a technique to optimize the design of these inductors using the accepted approach to fabrication was developed and published. However, only marginal improvements are achievable with this approach, and a more dramatic solution is needed.

A possible solution for certain applications is being explored by the team, involving the use of a flux compensating second inductor mutually coupled to the main component, and driven in such a way as to enhance the quality factor electronically. A simple CMOS solution has been demonstrated experimentally, and a patent application has been filed through TRLabs. Detailed noise, distortion and stability analyses are under way. The circuit has interesting applications in filtering, and preliminary designs look promising in simulation.

The Gigabit Radio RFIC Project

The experience gained in the fundamental research is being applied to a new large integrated circuit design project that we have initiated at TRLabs. The hostility of the wideband radio channel imposes severe multipath and intersymbol interference (ISI) that must be overcome in order to send data successfully. A novel new architecture for a very high-speed wireless local area network (LAN) system has been designed by Dr Grant McGibney, a TRLabs Staff Scientist, over the past three years. Mitigation of these effects is accomplished by using digital signal processing (DSP) techniques to predistort/equalize transmitted data before/after passing through the wireless channel. To minimize the power consumption and complexity of the terminals, the DSP functionality is placed solely in the basestations of the network. The remote terminals are left as relatively simple devices consisting of a direct conversion receiver and simple comparators for analog/digital conversion.

The goal of this project is to produce a Radio Frequency Integrated Circuit (RFIC) which implements the functionality of a Gigabit Radio simple terminal. Initial research has concentrated on designing the RF low noise amplifier LNA), direct down conversion mixer, and voltage controlled oscillator (VCO) that will form part of the receiver frequency synthesizer. These projects push the technology right to the limits, and so far we have had partial success.

Integrated Optics and Optical Fiber Communication Systems

This project uses an RF logarithmic compression amplifier, along with a Hilbert Transformer and several other components, to reduce chromatic dispersion in optical fiber networks by generating a single-sideband modulated optical carrier. A first generation compression amplifier with a 4 GHz bandwidth has been successfully designed, fabricated and tested in collaboration with Nortel Ottawa using the NT 25 bipolar fabrication process, and the next generation logarithmic amplifiers have been designed and fabricated in Silicon-Germanium, through a new process made available to us by the Canadian Microelectronics

Corporation, MOSIS and IBM Corporation. We are currently waiting for these chips to be returned for testing. The initial design has won a National Award in June of 2002, and the details have been published in the IEEE Journal of Solid State Circuits and elsewhere. A patent application has also been filed.

The next major challenge is to produce a monolithic Hilbert Transformer, and this project is currently under way.

Self-Configuring RF Antennas and Millimeter Wave Systems
The lab has initiated a collaborative project with Dr Michal Okoniewski and Dr Ron Johnston, relating to the use of RF switches to electronically reconfigure antennas and other microstripline elements. Initial results are promising, and this research is ongoing, with applications in wireless navigation and location as well as in spatially selective communications.

These collaborative projects involve the application of RF wireless systems and nanotechnologies to biomedical and other applications, where we, along with a number of other University of Calgary researchers in Electrical Engineering, Geomatics, Mechanical Engineering and Medicine, are uniquely poised in Canada to make significant breakthroughs. Areas include a new generation of lab-on-a-chip diagnostic systems for a variety of detection applications.

System-on-Chip (SoC) Research
These projects involve the integration of wireless RF cores for use in the newly established SOC (System-on-a-Chip) laboratory, to allow the rapid design of sophisticated systems in monolithic form for a variety of applications. Our VLSI group is one of three Canadian lead clients for CMC on the Bluetooth SoC platform that will eventually be distributed to 21 Canadian Universities. Our role is to take the Bluetooth digital IP core through the design cycle. Our RF group is also investigating a variety of products for the RF transceiver portion that would provide a complete and reconfigurable Bluetooth wireless transceiver system.

RF MicroElectroMechanical Systems (MEMS)
We are collaborating with Dr Graham Jullien, Dr Michal Okoniewski and TRLabs to combine RF MEMS devices designed by their research groups with RF integrated circuits designed by my group, to build unique new devices for several new applications ranging from wireless navigation and location to health related devices.

RESEARCH TEAM

TEAM LEADER	AWARDS
Jim Haslett	President's Circle Award, Teaching Excellence

* One vacant academic staff position to be filled as soon as possible

COLLABORATORS

COLLABORATORS	TITLE
Graham Jullien	iCORE Chair in Advanced Technology Information Processing Systems
Michal Okoniewski	CRC Chair in Electromagnetics

OTHER RESEARCH TEAM MEMBERS

OTHER TEAM MEMBERS	RESEARCH TOPICS
John McRory	TR*Labs*
Bob Davies	TR*Labs*

POSTDOCTORAL FELLOWS

PDF	TOPIC	AWARDS
Hua Yan	RF Board Level Systems, Self-Configuring Antennas	
Vijay Devabaktuni	RF CAD Systems and Modeling	NSERC Postdoctoral Fellowship

PHD STUDENTS

PHD	TOPIC	AWARDS
Chris Holdenried	Optical Data Transmission Circuits and Systems	NSERC PGS-B, iCORE, JB Hyne Research Innovation
Holly Pekau	SubSampling Mixers for Next Generation Wireless Transceivers	
Bogdan Georgescu	Transformer Based On Chip Spiral Inductor Q Enhancement	NSERC PGS-B, iCORE
Rob Randall	CMOS Monolithic Power Amplifier Linearization Schemes	NSERC PGS-B, iCORE
Ahmed Youssef	Analog RF Front End Circuits for Wireless LAN	

MSC/MENG STUDENTS

MSC/MENG	TOPIC	AWARDS
Josh Nakaska	Wireless LAN Frequency Synthesizers	NSERC Industrial Scholarship
Jim Kulyk	Monolithic Q-Enhanced Filters	
Damon Holmes	RF Power Amplifiers	NSERC PGS-A, iCORE
Ken Townsend	Wireless LAN Vector Modulator	NSERC PGS-A, iCORE
Cavell Li (part time)	Active Inductors	
James Quan (part time)	High Linearity Programmable Gain Amplifiers for Baseband Applications	
Jonathan Yeboah	Cellular Neural Networks	
Stephen Tseng	Coursework MEng.	

COLLABORATIONS

RESEARCH COLLABORATIONS:

Research Collaborations are currently being carried out with the following individuals:

• **Dr Graham Jullien**
Electrical and Computer Engineering, University of Calgary
Dr Jullien and Dr Haslett are collaborating on several projects, including a high data rate wireless LAN with TRLabs, and on biomedical lab-on-chip type devices, plus RF MEMS devices with Dalsa Semiconductor.

Dr Michal Okoniewski
Electrical and Computer Engineering, University of Calgary
Dr Okoniewski and Dr Haslett are collaborating on several projects, including self-configuring antenna and other micostripline devices, plus RF MEMS devices for those applications.

Dr Wael Badawy
Electrical and Computer Engineering, University of Calgary
Dr Badawy and Dr Haslett are collaborating on the Bluetooth RF SoC platform from the Canadian Microelectronics Corporation

Dr John McRory
TRLabs
Dr McRory and Dr Haslett are collaborating on several projects, including RF Power Amplifier Design, Spiral Inductor Q-Enhancement Techniques, and Home Technologies

Dr Bob Davies
TRLabs
Dr Davies and Dr Haslett are collaborating on several projects, including Optical Data transmission systems, and home technologies.

Collaboration Discussions have been initiated with the following individuals:

Dr Christian Schlegel
University of Alberta
Dr Schlegel and Dr Haslett are are planning on initiating research into analog circuit interfaces for signal processing systems.

COLLABORATIONS WITH INDUSTRY

TRLabs and its Industrial Sponsors (Samsung, Nortel)

TRLabs is the industrial sponsor of the research chair, and, as such, most of the research projects that we are pursuing will be of interest to their industrial sponsors. Our research projects are vetted and reviewed each year by a committee made up of sponsor representatives and TRLabs staff. We also have direct collaboration with some of the sponsors, as indicated below.

A. J. Bergsma, and R.D. Beards
Nortel Ottawa
Chris Holdenried, a PhD candidate under Dr Haslett's supervision, has been working with researchers at Nortel to design a wideband true logarithmic compression amplifier for optical fiber communications applications. The designs are successful, and the next project involves the design of an accompanying Hilbert Transformer.

SiWorks
Calgary
Dr Ivars Finvers, a former PhD student of Dr Haslett's, is now one of the members of this semicustom integrated circuit design house located adjacent to the University in the Research Park. He currently co-supervises one of Dr Haslett's PhD students. Another SiWorks employee, James Quan, is an MEng Thesis route student under Dr Haslett's supervision.

Dalsa Semiconductor
Ontario
Drs Jullien, Okoniewski and Dr Haslett are collaborating on the development of an RF MEMS process that is of interest to Dalsa, a chip manufacturing company in Ontario.

Multidiscipline or Multi-Institutional Partnerships: Canadian Light Source
University of Saskatchewan
Dr Haslett is a potential user of the Canadian Light Source CFI Initiative.

Dr Gérard Lachapelle, and Dr Elizabeth Cannon
Geomatics, University of Calgary
Drs Cannon and Lachapelle are collaborators on the CFI grant application currently being led by Dr Jullien. We plan to work on self-configuring antennas, with applications to wireless location. At a later time, it is anticipated that custom integrated circuits will be designed by our group for these applications.

Dr Arief Budimann
Mechanical Engineering, University of Calgary
Dr Budimann is another member of the multidisciplinary team that is putting together the CFI grant application. His specialty is thin films, and nanotechnology. He has just received funding for a sputtering system, which will allow us to try out some of our new ideas with antennas and stripline devices.

FUNDING

The iCORE funding of $200,000 per year is leveraged by $120,000 per year from the TRLabs chair program and $120,000 per year from NSERC. The University of Calgary contributes $164,000 to the chair program.

New Funds Acquired as Prime Investigator
Funding secured this year includes $39,348 from an NSERC Equipment Grant for a Laser Cutting Facility for the RF Wafer Prober, an NSERC Discovery Grant for $37,320, $67,700 from the Canadian Microelectronics Corporation (CMC) for the IC design Server and Workstations, $100,00 for Integrated Circuit Fabrication Grants from CMC, and $40,000 in Microwave Office Software donation from Applied Wave Research in the US.

New Funds Acquired as Co-Investigator
These funds include $55,000 from Micronet (Graham Jullien, PI, $225,000 total), and $300,000 from the CCIT Intelligent Technologies budget to construct an RF Shielded room and a Clean Room Facility (Graham Jullien and Dr Haslett).

INTELLECTUAL PROPERTY

Activity this year:
Patents
1. M. L.Holbert, J.W. Haslett, R.E. Smallwood and F.N. Trofimenkoff, Subsurface Signal Transmitting Apparatus, US Patent # 6,405,795, Issued June 18th, 2002.

2. J.W. Haslett, B. A. Georgescu, H. Pekau and J. McRory, Monolithic Transformer Compensated Circuit, full US and Canadian patents filed January 2003.

3. C. D. Holdenried, J.W. Haslett, J.G. McRory, and R.J. Davies, Branch Logarithmic Amplifier and Logarithmic Amplifier Delay Circuitry, US and Canadian Patents Filed, US file # 10/156,731, April 2002.

PUBLICATIONS

Refereed Journal Publications

1. A. Garg, G.A Jullien, G. McGibney, and J.W. Haslett, "A Modulus Replication Adaptive Filter IP Core," Canadian Journal of Electrical and Computer Engineering, vol.27, no. 4, October 2002, pp. 177-181.
2. C.D. Holdenried, J.W. Haslett, J.G. McRory, R.D. Beards, and A.J. Bergsma, "A DC-4 GHz True Logarithmic Amplifier: Theory and Implementation," IEEE Journal of Solid-State Circuits, vol. 37, no. 10, October 2002, pp.1290-1299.

Conference Papers

1. C. D. Holdenried and J.W. Haslett, "Two Baseband Logarithmic Amplifiers Using Parallel Feedback Amplifier Cells," Proc. of Wireless 2002, Calgary, Alberta, July 2002, pp. 181-189.
2. B. A. Georgescu, J.W. Haslett, and J. McRory, " Practical Synthesis of Optimized Inductor Circuits," Proc. of Wireless 2002, Calgary, Alberta, July 2002, pp. 206-209.
3. M. Lynch and J.W. Haslett, "The Design of a 17.35 GHz LNA and Mixer," Proc. of Wireless 2002, Calgary, Alberta, July 2002, pp. 505-514.
4. M. Lynch, J.W. Haslett, G. McGibney, and A. Garg, "A Novel Gigabit Radio Transceiver for System-on-Chip Wireless LAN," Paper and Poster Presentation, International Workshop on System-on-Chip, Banff, Alberta, July 2002, pp. 420-429.
5. A. Garg, G.A.Jullien, G. McGibney, and J.W. Haslett, "A Modulus Replication Complex Adaptive Filter IP Core," Paper and Poster Presentation, International Workshop on System-on-Chip, Banff, Alberta, July 2002, pp. 430-437.
6. C. D. Holdenried and J.W. Haslett, "Two Baseband Logarithmic Amplifiers Using Parallel Feedback Amplifier Cells," Poster Presentation, Canadian Microelectronics Corporation Texpo 2002, Ottawa, Ontario, June 18, 2002. This poster won the CMC Componentware/CAD Award, one of three national awards presented at the workshop.
7. M.W. Lynch, C. Holdenried, and J.W. Haslett, "A 17-GHz Direct Down-Conversion Mixer in a 47-GHz SiGe BiCMOS Process," accepted for presentation at the Radio Frequency Integrated Circuits Symposium, Philadelphia PA, June 2003, pp. 461-464.
8. A. Garg, I. Steiner, G.A. Jullien, J.W. Haslett, and G.H. McGibney, "A High Speed Complex Adaptive Filter for an Asymmetric Wireless LAN Using a New Quantized Polynomial Representation," accepted for presentation at the IEEE International Circuits and Systems Conference, (ISCAS), Bangkok, Thailand, May 2003.

The Wireless Cowboys at Home on the Frequency Range

They are self-professed analog 'range riders' - as designers of the physical, transistor layer of the wireless system of the future. Seemingly at odds to the uninitiated versed in the belief that 'digital is better', analog wireless design is a cost and power efficient contribution to novel circuit designs evolving to a point in the future where entire wireless systems will be present on single 'chips'.

"To do wireless economically, many types of 'radios on a chip' are needed," says TRLabs Adjunct Scientist Dr. Jim Haslett. "In a world where switches, filters, amplifiers and the like tend to be off-chip and therefore more expensive and less reliable, getting high performance [> 10 GHz, low power, programmable] wireless building blocks onto a single chip and speaking the same language [i.e. analog/digital conversion] is a sizeable technological challenge - but is a key to low cost systems."

Haslett notes that the integrated circuit designs (RFIC) of the future will remove the technological barriers that have constrained wireless ubiquity. "If we can unite systems and functions onto single chips at higher frequencies that achieve higher bandwidth, we open the door to an era of cheap, small and fast products of virtually any form or function. Taken to its extreme, we may even see a day where we drop 'smart dust' to locate someone lost in the wilderness - hundreds of thousands of tiny wireless system sensor communicators that send messages back to trackers."

An NSERC, iCORE, University of Calgary, and TRLabs $3.42 million investment partnership has created an Industrial Chair for Dr. Haslett, and the establishment of the Wireless Science and Technology Initiative to explore RFIC design. System on Chip design is a strategic goal; incremental innovation will involve the design of novel circuits that provide efficiency and better performance, RF System on Chip design, and ultimately integrated System on Chip design incorporating computer, digital, and RF systems on a single chip. Along the way innovation will take place in the form of design of leading edge components, from low noise amplifiers to frequency synthesizers.

THE Network-

Stepping

Centre for Information Security and Cryptography

Welcome to the University of Calgary's Centre for Information Security and Cryptography (CISaC), an academic research centre housed within the Department of Mathematics & Statistics, and supported and administered by the Faculty of Science.

We are a multidisciplinary centre that focuses on research in cryptography and information security. Together, our team of researchers and students in mathematics, computer science and electrical and computer engineering is collaborating on projects to improve computer security and protect information in every facet of daily life.

Partners and Sponsors

CISAC MEMBERS

CISaC Management Board

- Dr Hugh Williams

CISaC Management Board

- Dr Vassil Dimitrov
- Dr Michael J. Jacobson, Jr.
- Dr Renate Scheidler

Affiliated Faculty

- Dr Richard Cleve
- Dr Clifton Cunningham
- Dr Behrouz Homayoun Far
- Dr Graham Jullien
- Dr Thomas Keenan
- Dr Richard Mollin
- Dr John Watrous
- Dr Clifton Cunningham
- Dr Behrouz Homayoun Far

Post-Doctoral Fellows in Mathematics

- Dr Filip Saidak
- Dr Safuat Hamdy
- Dr Siguna Mueller

Graduate Students in Mathematics

- Richard Cannings
- Kell Cheng
- Chris Foster
- Brendan Oseen
- Reg Sawilla
- Kjell Wooding

Graduate Students in Comuter Science

- Richard Cannings
- Andreas Hirt

Support Staff

- Susan Schuck
- Betty Teare
- Marc Wrubleski

DR HUGH WILLIAMS

ALGORITHMIC NUMBER THEORY AND CRYPTOGRAPHY

iCORE Chair
Mathematics and Statistics
University of Calgary

Dr Hugh Williams was awarded $600,000 dollars per year for five years to establish the iCORE Chair in Algorithmic Number Theory and Cryptography at the University of Calgary. Total iCORE funding of $3 million dollars represents roughly 50 percent of the total budget of the research group developed around this Chair.

EXECUTIVE SUMMARY

The iCORE Chair in Algorithmic Number Theory and Cryptography (ICANTC) has the goal of creating a recognized centre of excellence for education, research and industrial cooperation on computer security at the University of Calgary. As the ICANTC team completes its second year of operation, they are well on track to reaching that goal. At the end of March 2003, a number of key milestones have been achieved.

One significant milestone was the establishment of the Centre for Information Security and Cryptography (CISaC), which was inaugurated July 17th, 2002. In the past year, ICANTC has seen CISaC begin to move from a concept to reality. The development and launch of a Web site and a mission statement helped establish an infrastructure for CISaC, two critical elements to building a membership base and attracting private industry participation. An official launch for CISaC is planned in fall 2003.

Other highlights of ICANTC's activities include further progress toward getting the cryptography laboratory up and running, and successfully applying for a Mathematics for Information Technology and Complex Systems (MITACS) grant. ICANTC team members have continued their research, submitting numerous papers and presentations to various journals and publications. They are also actively recruiting graduate and post-doctoral students and faculty. As a result, two new masters' students and one PhD student began in September 2002. They are expecting a new masters' student in September 2003, Paul Sheridan. They also hope to have three more PhD students. Peter Anderson and Kjell Wooding are confirmed, while the third could be confirmed by the end of April.

As a new fiscal year begins, the team will continue to build on achievements in 2002-2003, making steady progress to reaching goals for 2003-2004. Plans include an official launch of CISaC, cultivation of industrial partnerships, the realization of the cryptographic laboratory, and recruiting an additional assistant professor to the team. In addition, the team continues to work with other institutions in Canada, the United States and abroad. The movement and exchange of students with other universities should become even easier as research progresses. As partnerships are forged with business and industry, it is hoped that student internships in the province will follow.

The group is focused on building the program and cultivating partnerships with other universities as well as industry and government. The strength and commitment to these goals demonstrated by the team, along with the support and enthusiasm of iCORE, should make these objectives a reality in 2003-2004.

RESEARCH GOALS AND OBJECTIVES

In the past year, ICANTC has continued to build upon achievements from 2001-2002. Each accomplishment brings the group closer to our goal of making the University of Calgary a recognized centre of excellence for education, research and industrial cooperation on computer security issues in Canada.

The most significant accomplishment is the progress toward establishing a Centre for Information Security and Cryptography (CISaC) at the University of Calgary. CISaC is a multidisciplinary centre that focuses on research in cryptography and information security. Together, CISaC's team of researchers and students in mathematics, computer science and electrical and computer engineering is collaborating on projects to improve computer security and protect information in every facet of daily life.

By employing a broad depth of skills and knowledge, the team members are testing and establishing protocols to ensure secure communications, with a particular focus on mathematically based cryptosystems. This includes all aspects of work from abstract theory to the fabrication of special-purpose cryptographic and computing devices.

The security of almost all commercially available cryptosystems is based on the presumed difficulty of certain mathematical problems. It is important to emphasize that no rigorous mathematical proof of security has ever been given for any of these systems. The difficulty of these problems is usually established anecdotally through frequent and unsuccessful attempts by specialists to solve them.

One particular part of mathematics, the study of quadratic fields, has not been used very much to produce cryptosystems. One major research project is to conduct a full investigation into the development and testing of efficient encryption techniques based on the difficulty of performing certain operations in quadratic fields.

ONE SIGNIFICANT MILESTONE WAS THE ESTABLISHMENT OF THE CENTRE FOR INFORMATION SECURITY AND CRYPTOGRAPHY (CISAC), WHICH WAS INAUGURATED JULY 17th, 2002.

CISaC is creating a foundation that will allow further development of the research. Activities to expand the research team include:

- Maintaining an active Distinguished Visitors' Program to bring top researchers to the University of Calgary.
- Recruiting top students at all levels - undergraduate, masters, PhD and post-doctorate - to be part of the program.
- Offering new undergraduate courses as part of an area of concentration in cryptography.
- Working on a sequence of graduate courses in cryptography that could be accessed by students in mathematics, computer science mand engineering.
- Cultivating partnerships with other universities as well as industry and government.

The goal is to broaden CISaC's membership beyond the university, and evolve it into an established centre with links to local businesses and national industry partners.

Other milestones related to CISaC this past year include:

- Building an infrastructure. Business cards have been printed and the group is currently developing brochures to promote both academic and business contacts.
- Crafting of a mission statement, which captures the centre's goals and objectives.
- Developing a Web site. The Web site provides an information source for students, faculty and other interested parties. See http://cisac.math.ucalgary.ca.
- A management board was appointed to oversee and provide guidance and

input on running CISaC's activities. Currently a director and three members make up the board, but this will expand as the centre grows. The term of office for board members is three years. The management board includes: Renate Scheidler from Mathematics and Computer Science; Michael Jacobson from Computer Science; and, Vassil Dimitrov from Electrical and Computer Engineering.

- CISaC is also considering setting up a Technical Advisory Panel to provide expertise on specific projects as needed. The initial panel would be comprised of management board members, three researchers from the University of Calgary and three from the industrial sector. The make up of the panel will be relative to the need that it is required to fulfill.

Other ICANTC accomplishments include:

- Continuing to develop undergraduate and graduate courses in cryptography. Renate Scheidler developed and taught a new fourth year special topics course in cryptography, which was offered in winter 2003. Hugh Williams also developed and taught a graduate course PMAT 603.40: Topics in Computational Number Theory.
- A concentration in cryptography will come on line in September 2003. Renate Scheidler will teach PMAT 329. Richard Mollin will teach PMAT 429 in winter 2003. These courses will run yearly. PMAT 529 will come online in fall 2004 and is the third course in our PMAT 329/429/529 sequence. Teaching assignments have not yet been made for this course.
- Coordinating our graduate and undergraduate courses with Michael Jacobson in Computer Science. Hugh Williams will teach PMAT 603.38. Michael Jacobson has already taught it under the course descriptor CPSC 699. Michael Jacobson is also developing a follow-up course to PMAT 329 for computer science students that he will offer in winter 2003, at the same time as the math follow-up course PMAT 429 is being offered. This course does not yet have a number, and will focus on computer security. The idea is that math students will take PMAT 329/429/529, while computer science students will take PMAT 329 and Michael Jacobson's new course.
- The Distinguished Visitors' Program, piloted last year by Renate Scheidler, began again in September 2002. The program continues to bring internationally regarded experts to the University of Calgary. Jerzy Urbanowicz from the Polish Academy of Sciences was here August 18th to September 12th; Jonathan Borwein of Simon Fraser University was here on October 18th; and, Stéphane Louboutin, from Institut de Mathématiques de Luminy in Marseilles, France, was here November 15th to December 15th. The team welcomed Roger Patterson in September to October 2002, and Catherine Webster from the University of British Columbia in March 2003.
- ICANTC continued the campaign to recruit graduate students, post-doctoral students and faculty. Three new students began in fall 2002. They are Christopher Foster (MSc), Reginald Sawilla (MSc), and Kell Cheng (PhD). One new masters' student is confirmed for September 2003. Two more PhD students have also been confirmed, with the potential for a third to be confirmed by the end of April. The group is currently developing a new recruiting brochure targeted at students, and they have completed a display board for the Faculty of Science that will sit in the case in the corridor outside the Dean's office.
- Alfred Menezes at the University of Waterloo and Hugh Williams have been jointly awarded $120,000 from MITACS.

Dr Williams' half of the funds is already committed to: developing a Web site for the MITACS project, holding a major conference on privacy in Alberta, and funding a post-doctoral fellow who will conduct research in the development of very low power consuming cryptographic protocols for use in wireless medical monitoring systems. These funds should be available toward the end of April 2003. This grant is for one year with the possibility of a second year extension if the year-end report is acceptable.

- ICANTC has received permission to hire an associate professor with a cryptography background. The closing date for applications was March 15th, and the proposed starting date is July 1st, 2003. The interviewing process for this position is complete, and an offer has been made.

The Advanced Cryptography Laboratory is now up and running. Work on the lab began in February 2003. In a short time, a space agreement was drafted, appropriate renovations were done and the necessary equipment was ordered. Preliminary tests began in mid-March, and were completed at the end of the month. This laboratory was made possible through the merging of Hugh Williams' Alberta Ingenuity Fund grant with Michael Jacobson's CFI grant. The Advanced Cryptography Laboratory consists of an extensive, powerful and dedicated system of high-speed computing devices used to test and benchmark cryptographic systems. The hardware in the laboratory is configured on the Beowulf cluster design, where many commodity grade processors are interconnected using commodity hardware. The Head Node monitors these many processors and controls what jobs are running on the system. This cluster consists of 129 computers interconnected using Ethernet (100Mb/s). Each computer has Dual 2.4 Ghz Pentium 4 processors, 2 GB memory, and a 40 GB Hard Disk. The head node has a 2.4 Ghz processor, 1.5 GB memory, and 40 GB of usable disk space. This system has a theoretical maximal processing power of 1.2 T flops. IBM supplied the innovative Blade Center solution to enable the system to fit in less than half the space of conventional systems. This solution was easier to build, and is easier to maintain than conventional systems. The system is configured to allow us to build and run computer programs utilizing the Message Passing Interface (MPI). MPI is an add-on to programming languages that enable programs to run on many systems at a time and to take advantage of the processing power of the entire system.

- Together with Lynn Batten of Deakin University in Melbourne, Australia, the group applied to the ANU Centre for Mathematics and its Application National Research Symposia Committee to hold a workshop on Polynomial Aspects of Cryptography. The application was successful with the award of AUD$7,500 to help defray some of the costs in holding this meeting, likely in July 2004. The conference will bring together 30 experts across the fields of algebra, cryptography and algorithm implementation in an Oberwolfach-style meeting. Half of the people will be from Australia and the other half from North America and Europe. The results of this workshop will have a major impact on the direction of this area of cryptography for the next five to 10 years.

- The team continues to move forward in building a partnership with the Illinois Center for Cryptography and Information Protection at the University of Illinois at Urbana-Champaign.

As indicated earlier, one of the principle foci of our research is investigating the use of quadratic fields in cryptography. Results from many different areas of mathematics have been applied to the development of cryptographic systems. One reason for this is that it is always sound cryptographic practice to have access to as many different systems as possible. This ensures that the sender has a choice of possible schemes, a very useful feature if one or more of them is compromised.

One area of mathematics that has not received much attention from cryptographers is algebraic number theory. The simplest number fields are the quadratic fields. Performing arithmetic in these structures is relatively efficient and simple compared to doing this in other algebraic number fields. Nevertheless, they still possess many of the complicating features that make them resistant to methods that have proved to be successful in other structures such as finite fields. The group has developed methods of performing certain fundamental cryptographic protocols, but as yet, these are too slow for commercial use.

There are two main long-term objectives for this project. One is to develop a set of efficient, easily applicable and mathematically rigorous techniques for performing arithmetic in quadratic number fields and function fields. The second (and primary) objective is to use these ideas to develop and test cryptosystems whose security is based upon the presumed difficulty of solving certain problems in these structures. The mathematical results of the research are expected to be useful in developing methods for performing arithmetic efficiently in the structures under investigation. Furthermore, the results are expected to add to the growing number of techniques for ensuring secure communication.

Improved Implementation

In the case of our protocol involving real quadratic fields, we developed a new representation for the objects (called ideals) on which we must perform our operations. This has allowed us to lower considerably the numerical precision needed at the expense of increasing the complexity of a second communication round. It turns out that in practice this second round proved to be no real problem as it is rarely needed and executes rapidly in those cases where it is required. We have also succeeded in integrating a particular technique, called NUCOMP, into our protocol. This is significant because we must make frequent use of a particular operation, involving multiplication and reduction of ideals, which takes over 97 per cent of the time required to execute the protocol. Implementing NUCOMP has allowed us to cut the amount of time required by the protocol by a factor of more than half. Renate Scheidler recently received a University of Calgary URGC research grant for further work on NUCOMP and related questions, including its extension to hyper elliptic function fields.

Determination of Optimal Discriminants

One advantage to using number fields for cryptographic purposes is we have some freedom in selecting a certain parameter, the discriminant. However, this parameter needs to be chosen optimally with respect to both security and efficiency of implementation. We have developed a low cost, high-speed special computing device (CASSIE), called a number sieve, to help determine optimal selections. In the case of real quadratic fields, attempts by adversaries to break the corresponding cryptographic scheme can be thwarted by selecting discriminants that are quadratic nonresidues for many of the smallest primes. Previously, we were able to use the fastest number sieve then in existence, constructed in 1995 at the University of Manitoba, to show that finding such discriminants can be done very quickly. We have used more modern Field Programmable Gate Array (FPGA) technology to build a faster and more flexible number sieve that can be tailored to a specific sieve problem instance. The project was a collaborative effort involving Hugh Williams, masters' student Kjell Wooding and Dr C. Patterson of Xilinx (Boulder, Colorado). Our new device can sieve at an effective rate of $2 \cdot 1015$ numbers per second. This is 1000 times faster than the 1995 sieve speed.

Benchmarking

There is no rigorous mathematical proof of the security of our (or

almost any other) cryptosystem. The only way to certify security and effectiveness is to test it extensively. We need to conduct very large-scale numerical experiments to acquire the data needed to accurately determine the security of our cryptographic schemes. We have assembled a Beowulf cluster built of IBM components as the hardware configuration for the testing. A Beowulf cluster is a collection of individual stand-alone processors connected together so they can communicate. The cluster, which is scalable, currently consists of 129 2.4GHz Pentium 4 dual processors, each with 2 GB of RAM and 40 GB of hard disk space. The servers are interconnected with standard fast Ethernet connections and provide the required computer power. All software required for the cluster, including the operating system Linux, is free of charge when used for research purposes. The cluster is sufficiently flexible that it can be used to test the effectiveness of many other cryptosystems and can be used well beyond the lifetime of this project. This facility became operable on March 21st, 2003.

Unconditional Determination of the Regulator

One way to test the effectiveness of techniques is to compute a particular object associated with our quadratic field, called the regulator. Unfortunately, the fastest algorithm currently available to determine the regulator is conditional on an unproved hypothesis. It is of great interest to find the regulator unconditionally. The conditional algorithm can at least be used to compute what should be an integral multiple of the regulator, and this is something that can be checked very quickly. Having made this determination, the next problem is to establish that the integral multiplier of the regulator in the conditional regulator is 1. There are two phases of doing this. The first is to establish the regulator must exceed some predetermined bound. The next is to prove that for no integer less than a certain amount can we have the regulator being the conditional one divided by that integer. It is interesting that both of these phases can be parallelized. Furthermore, the technique can, with an appropriate representation of the ideals involved, be completely integral. That is, we do not at any point have to work with any numbers but integers. This means that we do not have to deal with approximations to irrational numbers and the concomitant loss of rigour that often occurs as a result. Michael Jacobson and Hugh Williams are collaborating on this problem and already have some preliminary results. Recently they were able to compute unconditionally a regulator for a quadratic field with a fifty-five-digit discriminant. This was done with only eight processors; thus, when fully parallelized and running on the new Beowulf cluster the new algorithm should allow us to compute regulators for fields of perhaps 60 or 65 digit discriminants.

Verifying the Cohen-Lenstra Heuristics

The security of these schemes depends upon the number of reduced principal ideals in the quadratic number field (or function field) and the difficulty of solving the DLP in the field. The first of these problems is easily handled using Cohen-Lenstra heuristics on the distribution of the odd part of the class number. However, as the Cohen-Lenstra heuristics are not rigorously established, it is essential that they be thoroughly tested numerically. Recently, in collaborative work between Dr H. te Riele of CWI, Amsterdam, and Hugh Williams, it was possible for the first time to compute all the class numbers for all real quadratic fields of prime discriminant less than 200,000,000,000. The results obtained agreed with what the Cohen-Lenstra heuristics predicted, and a paper describing this work was recently accepted for publication by Experimental Mathematics.

Invariants in Function Fields

Renate Scheidler's research focuses primarily on developing and implementing algorithms for computing invariants of cubic function fields as well as exploring these fields for cryptographic applications. Jointly with Dr Yoonjin Lee of the University of Delaware (USA), she has developed an algorithm for computing the fundamental units and the regulator of a purely cubic function field of unit rank two. This research is to appear in the journal Experimental Mathematics. It is expected that this summer, one or two research students will continue work on the implementation of this and other algorithms, a project that undergraduate student Eric Nosal began last summer. Work on developing fast arithmetic in arbitrary cubic function fields and on fast algorithms for computing the Jacobian of a purely cubic function field (jointly with Professor A. Stein of the University of Illinois at Urbana-Champaign) is ongoing.

RESEARCH TEAM

Dr Hugh Williams

Professor, Department of Mathematics & Statistics, iCORE Chair in Algorithmic Number Theory and Cryptography and CISaC Director

Hugh Williams holds the iCORE Chair in Algorithmic Number Theory and Cryptography (ICANTC) at the University of Calgary. His main research interests are in computational number theory, cryptography, and the design and development of special-purpose hardware devices. Most recently, he has been investigating secure key exchange systems that make use of the properties of quadratic fields or function fields.

TEAM MEMBERS

Dr Michael J. Jacobson, Jr.

Assistant Professor, Department of Computer Science and CISaC Management Board Member

Michael Jacobson's main areas of expertise are computational number theory and public-key cryptography. His most important contribution to date is his extensive work on invariant computation in quadratic fields. He recently developed parallel implementations of his novel index-calculus algorithms.

Dr Richard Mollin

Professor, Department of Mathematics & Statistics

Richard Mollin has over 150 publications in numerous aspects of number theory, algebra and computation, including applications to cryptography. His current research on continued fraction expansions, Diophantine analysis and cryptographic applications is widely viewed as important and groundbreaking. He is considered a world expert on the theory of quadratics.

Dr Renate Scheidler

iCORE Research Associate and Associate Professor jointly appointed to the Department of Mathematics & Statistics and the Department of Computer Science; CISaC Management Board Member

Renate Scheidler is an expert in algorithmic number theory and its applications to cryptology. She is interested in the design and analysis of secure communication schemes whose underlying mathematical structure is associated with an algebraic number field or function field.

AFFILIATED FACULTY

Dr Richard Cleve

Professor, Department of Computer Science

Richard Cleve received his PhD from the University of Toronto in 1989, specializing in computational complexity theory and cryptography. He is particularly interested in quantum information processing, and has made several contributions to quantum algorithms and quantum information theory.

Dr Clifton Cunningham

Assistant Professor, Department of Mathematics & Statistics

Clifton Cunningham's research concerns certain aspects of the Langlands Programme as it relates to the interplay between number theory, analysis and algebraic geometry; progress in this area often finds applications in cryptography. Clifton received his PhD under James Arthur in 1997 and worked at the University of Massachusetts (Amherst) and the Ecole Normale Supérieure (Paris) before coming to the University of Calgary in 2000.

Dr Vassil Dimitrov

Associate Professor, Department of Electrical & Computer Engineering and CISaC Management Board Member

Vassil Dimitrov's main research interests include efficient algorithms and architectures for digital signal processing, information security and image compression applications. He is particularly interested in applying methods from number theory and algebraic geometry aimed at speeding up the performance of very complex real-time digital signal processing and information security systems.

Dr Behrouz Homayoun Far

Associate Professor, Department of Electrical & Computer Engineering

Behrouz Homayoun Far received his PhD from Chiba University in Japan in 1990. His research specializes in the engineering of intelligent, distributed and heterogeneous networked systems, specifically in designing and implementing agent-oriented software systems and support tools and techniques for groupware systems.

Dr Graham Jullien

Professor, Department of Electrical & Computer Engineering

Graham Jullien holds an iCORE Research Chair in Advanced Technology Information Processing Systems. His interests are in the fields of integrated circuit design (from architectures to transistors), digital signal processing for real-time (data stream) applications, and microsystem integration of the disparate technologies of ICs, MEMS and microfluidics for bio-medical applications.

Dr Thomas Keenan

Director, e-Security Innovation Centre and Dean, Faculty of Continuing Education

Tom Keenan has taught courses and seminars on computer security at The University of Calgary, The Asian Institute of Technology (Bangkok, Thailand) and at the former World Trade Center in New York. He chairs the International Summit on Cybercrime held annually in a major U.S. city, and is one of the few civilian members of the Society for Policing in Cyberspace.

Dr John Watrous

Assistant Professor, Department of Computer Science and Canada Research Chair

John Watrous's research focuses on quantum computational complexity theory and quantum algorithms. His current interests include quantum variants of interactive proof systems and quantum algorithms for group-theoretic problems.

POST-DOCTORAL FELLOWS IN MATHEMATICS

PDF	TOPIC
Filip Saidak	Analytic and Probabilistic Number Theory
Safuat Hamdy	Numberfield Cryptography
Siguna Müller	Public-key Cryptography and Primality Testing

GRADUATE STUDENTS IN MATHEMATICS

PHD	TOPIC	
Kell Cheng	Simple Continued Fraction Expansions of Quadratics	
MCS	**TOPIC**	**AWARDS**
Richard Cannings	Quantum Computation and Cryptography	
Chris Foster	Researching Topic Space	
Brendan Oseen	Isogenies of Elliptic Curves	
Reginald Sawilla	Algorithms in Quadratic Fields	
Ahmed Youssef	Analog RF Front End Circuits for Wireless LAN	NSERC PGS-A, iCORE
Kjell Wooding	Development of a High-speed Numerical Sieving Device	Alberta Ingenuity Scholarship

GRADUATE STUDENTS IN COMPUTER SCIENCE

Andreas Hirt	Collaborative Caching in Ad hoc Networks

NEW STUDENT VISITORS IN MATHEMATICS

STUDENT	INSTITUTION/PERIOD OF VISIT
Daniel Weimer	Technical University of Darmstadt, June 2nd, 2003 to May 31st, 2004
Robbert de Haan	University of Amsterdam, April 29th to October 31st, 2003
Roger Patterson	Macquarie University, May 13th to July 10th, 2003

COLLABORATIONS

ICANTC's goal is to position Alberta as a centre of excellence in cryptography that attracts established research leaders, young academics beginning their careers and graduate students seeking the best education opportunities. As well as attracting top talent, we are committed to seeing results emerging from our research. We cannot achieve these results alone, so we are focused on building strong partnerships with other academic institutions, government and industry.

Now that the Centre for Information Security and Cryptography (CISaC) is a reality, our plan is to develop partnerships with other such centres around the world. We are currently completing a formal partnership agreement with the Illinois Center for Cryptography and Information Protection (ICCIP) at the University of Illinois at Urbana-Champaign.

We are also beginning to negotiate with Professor Hans Dobbertin of Ruhr-Universität Bochum for a partnership with his cryptographic group. We also hope to initiate a program of acquiring further partnerships with groups at the University of Waterloo, the Technical University of Darmstadt, Simon Fraser University and several others.

Alfred Menezes of the University of Waterloo and Hugh Williams have been informed that, as co-investigators, they have been jointly awarded $120,000 from MITACS. Hugh Williams' half of the funds is already committed to the development of a Web site for the MITACS project, hosting a major Alberta conference on privacy, and funding a post-doctoral fellow who will be conducting research in the development of very low power consuming cryptographic protocols for use in wireless medical monitoring systems. These funds should be available toward the end of April 2003. This grant is for one year, with the possibility to extend it a second year.

We had an exchange agreement with Macquarie University in Australia that provided funding for students and faculty exchanges. This agreement ended December 31st, 2002.

We are collaborating with Graham Jullien's group in the University of Calgary's Department of Electrical and Computer Engineering to develop a small, wireless device that can be implanted in patients and used to transmit data over very short distances. Such devices will undoubtedly become important over the next few years for the low-cost, widespread monitoring of patients for a variety of medical conditions. The misuse of such data could have disastrous consequences to the individual; therefore, such devices must be equipped with appropriate safeguards capable of encrypting sensitive medical data to protect it from unauthorized access. Such encryption must be performed quickly and reliably, and at the same time consume very low power.

We are currently working with Graham Jullien on putting together an NSERC Strategic Project Grant to help support our work in this regard. In doing this, it will also be necessary to involve some local industries. We have already contacted SiWorks Inc. and found them to be very interested in participating, and will soon be talking to Non-Elephant Encryption Systems, Inc. (NE2) about their participation.

We have also begun consulting work with another local industry: IQ Soft Professionals, Inc. (IQSP).

These collaborations are forming the base from which we will continue to build. Our future plans are to broaden our partnerships to include more government and industry.

A hiring freeze at the University of Calgary has prevented filling an additional academic position that was proposed in the original budget.

AS WELL AS ATTRACTING TOP TALENT, WE ARE COMMITTED TO SEEING RESULTS EMERGING FROM OUR RESEARCH. WE CANNOT ACHIEVE THESE RESULTS ALONE, SO WE ARE FOCUSED ON BUILDING STRONG PARTNERSHIPS WITH OTHER ACADEMIC INSTITUTIONS, GOVERNMENT AND INDUSTRY.

FUNDING

The Alberta Government has invested $131,000 in the current year in addition to the iCORE funding of $600,000 per year over 5 years. University investment totals over the next year are $33,900 cash and $136,300 in-kind. CFI funding for the current year is $58,000; NSERC funding is $95,000. Other government income for the current year is $48,500. Contracts with the US National Security Agency and the US. National Science Foundation are for $17,000 and $3,600 respectively.

INTELLECTUAL PROPERTY

In the two years since iCORE created ICANTC, the team has focused on establishing the program and reaching some early goals. One of the most significant accomplishments has been the establishment of CISaC as an interdisciplinary centre dedicated to research in cryptography and information security.

The goal of the centre is to conduct research into the testing and establishment of protocols to ensure secure communications, with a particular emphasis on studying, improving and implementing mathematically based cryptosystems. This includes everything from abstract theory to fabricating special cryptographic and computing devices.

Now that the centre is established, the team is confident more partnerships will develop between academia and the private sector. There is potential for joint projects with Professors Jullien, Dimitrov, and Far of the University of Calgary's Electrical and Computer Engineering Department. As these partnerships mature, there will be advancement in terms of intellectual property and commercial results.

PUBLICATIONS

Refereed Journal Contributions

1. F. Saidak, "An Elementary Proof of a Theorem of Delange Comptes Rendus (Canada)," vol. 6, to appear in December 2002 (or March 2003).
2. F. Lemmermeyer and R. Mollin, "On the Tate-Shafarevich groups of y2=x(x2-k2)," to appear Acta Math. Universitatis Comenianae.
3. H. te Riele and H.C. Williams, 'New Computations Concerning the Cohen-Lenstra Heuristics," to appear in Experimental Mathematics.
4. J.D. Hühnlein, M.J. Jacobson, Jr., and D. Weber, "Towards Practical Non-interactive Public-key Cryptosystems Using Non-maximal Imaginary Quadratic Orders," to appear in Designs, Codes, and Cryptography, 2003.
5. M.J. Jacobson, Jr., Á. Pintér, and P.G. Walsh, "A Computational Approach for Solving y2 = 1k + 2k +...+ xk," to appear in Math. Comp., 2003.
6. M.J. Jacobson, Jr. and H.C. Williams, "New Quadratic Polynomials with High Densities of Prime Values," Math. Comp., vol. 72, 2002, pp. 499-519.
7. M.J. Jacobson, Jr. and H.C. Williams, "Modular Arithmetic on Elements of Small Norm in Quadratic Orders," Designs, Codes and Cryptography, vol. 27, 2002, pp. 93-110.

8. R.A. Mollin, "Criteria for Simultaneous Solutions of X2-DY2=c and x2-Dy2=-c," Canadian Math. Bulletin, vol. 43, 2002, pp. 428-435.
9. R.A. Mollin, "Ideal Criteria for Both X2-DY2 = m1 and X2-DY2=m2 to have Primitive Solutions for any Integers m1, m2 prime to D>0," Serdica Math. J., Bulgarian Academy of Sciences, vol. 28, 2002, pp. 175-188.
10. R.A. Mollin, "A Brief History of Factoring and Primality Testing B.C. (Before Computers)," Math. Magazine, February 2002.
11. R.A. Mollin, "The Diophantine Equation AX2-BY2=C and Simple Continued Fractions," Int. Math. J., vol. 2, 2002, pp. 1-6.
12. R.A. Mollin, K. Cheng, and B. Goddard, "Pellian Polynomials and Period Lengths of Continued Fractions," JP Journal Alg., Number Theory and Applications, vol. 2, 2002, pp. 47-60.
13. R.A. Mollin and K. Cheng, "Continued Fraction Beepers and Fibonacci Numbers," Math. Rep. Acad. Sci. Canada, vol. 24, 2002, pp. 102-108.
14. R.A. Mollin, "Period Lengths of Continued Fractions Involving Fibonacci Numbers," to appear in Fibonacci Quarterly.
15. R.A. Mollin, "Sums of Squares Revisited," to appear Inter. Math Journal.
16. R.A. Mollin, "Infinite Families of Pellian Polynomials and Their Continued Fraction Expansions," to appear in Results in Mathematics.
17. R.A. Mollin and K. Cheng, "Beepers, Creepers, and Sleepers," Intern. Math. Journal, vol. 2, 2002, pp. 951-956.
18. R.A. Mollin, "New Prime-producing Polynomials Related to Class Number One or Two," New York J. Math, vol. 8, 2002, pp. 161-168.
19. R.A. Mollin, B. Goddard, and K. Cheng, "The Diophantine Equation AX2-BY2=C Solved Via Continued Fractions," to appear in Acta Mathematica Universitatis Comenianae.
20. R.A. Mollin and K. Cheng, "Matrices and Continued Fractions," Intern. Math. Journal, vol. 3, 2003, pp. 41-58.
21. R.A. Mollin, "Cryptography - A Brief History," to appear in CUBO, Journal of Universidad de la Frontera, Temuco, Chile.
22. S. Müller, "On the Computation of Square Roots in Finite Fields," to appear in Designs, Codes, and Cryptography (DESI1165-01).
23. S. Müller, "A Probable Prime Test with Very High Confidence for n=3 mod 4," J. Cryptology, vol. 16, no. 2, 2003, pp. 117-139.
24. S. Müller, "On the Computation of Cube Roots Modulo p," to appear in Fields Institute Communications Series.
25. Y. Lee, R. Scheidler and C. Yarrish, "Computation of the Fundamental Units and the Regulator of a Cyclic Cubic Function Field," to appear in Experimental Mathematics.

Books and Book Chapters

1. R.A. Mollin, RSA and Public-Key Cryptography, Chapman and Hall/CRC Press, Boca Raton, New York, London, Tokyo, 2003. ISBN # 1-58438-338-3

Please join us

for the launch of the
Centre for Information
Security and Cryptography

Are your secrets safe?

- **90% OF COMPANIES HAVE HAD SOME SORT OF INFORMATION PRIVACY INVASION.**
- **MOST PERSONAL COMPUTERS ARE NOT PROTECTED AGAINST INVASION OF PRIVACY.**

The Centre for Information Security and Cryptography is an academic research centre housed within the Department of Mathematics and Statistics, and supported and administered by the Faculty of Science at the University of Calgary. It works on the mathematical building blocks of encryption systems that keep private information private.

The launch of the Centre includes the opening of Canada's premiere **Advanced Cryptography Laboratory**, located at the University of Calgary.

Friday October 10
10:30 am – 12:30 pm
Rozsa Centre Great Hall
University of Calgary

10:30 - 11:00 am	Launch
11:00 - 11:30 am	**Book signing**
11:30 - 12:30 pm	Public lecture

Calgary kick-off event
Science & Technology Week 2003
October 10-19

NANOTECHNOLGY

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CHAIRHOLDER PROFILES

Mark R. Freeman
Canada Research Chair in Condensed Matter Physics
The University of Alberta
Tier 1 - July 1, 2001
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Achievements:	E.W.R. Steacie Memorial Fellowship; Invention Achievement Award (Five Fortune 500 companies). Patent-holder.
Involves:	Nanoscience and nanotechnology - the study and application of minuscule structures, with linear dimensions of tens of atoms.
Research Relevance:	Magnetic science; read-write devices for information storage and retrieval; applications for the computer and recording industry.

MANIPULATION THE ATOM

Miniaturization has already revolutionized technology in our world. What if science could develop ways to manipulate material at the next level - the level of a single atom?

In fact, nanoscience - the ability to study and manipulate tiny molecules that measure one-billionth of a metre - is already the topic of cutting edge discoveries and applications in physics. Mark Freeman is at the forefront of that science, where physicists are trying to understand and manipulate complex materials at the atomic level.

Nanotechnology has sweeping applications in the information technology field involving, among other things, the interaction between magnets and superconductors. Already, Freeman has worked with IBM on some of their advanced disk drive products.

Awarding Freeman this chair will enable him to continue to set the agenda in applying nanoscience and nanotechnology to applications that will be fundamental to the computer and communications industries of the future. Nanotechnology will fuel the continuing trend of smaller, faster, more capable devices and products, becoming the engine of the information and computer technology economy at the hardware level.

Freeman is already attracting top-calibre graduate students and colleagues to work with him. These researchers will be sought-after by the information technology, materials science, and engineering sectors in Canada. Already a global force in telecommunications, Canada can only benefit from developing greater expertise in nanoscience. Mark Freeman's Web site address is http://laser.phys.ualberta.ca/~freeman/

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CHAIRHOLDER PROFILES

Michael J. Brett
Canada Research Chair in Nanoengineered Films
The University of Alberta
Tier 1 - October 1, 2002
(780) 492-4438
brett@ee.ualberta.ca

Achievements:	Published over 130 refereed papers and gave numerous talks at major international conferences; awarded the Arthur G. McCalla Research Professorship and the Killam Annual Professorship; three patents issued and three patents pending on a process developed by his group.
Research:	Further development of a new materials
Involves:	process, and study of the application of the material in various devices
Research Relevance:	Potential applications in nanobiotechnology and nanoelectromechanical systems.

THIN FILMS BY GLAD

An innovative process was recently invented for fabricating porous, nanostructured thin films with a geometry and porosity that can be engineered to specific needs. The new process, called Glancing Angle Deposition (GLAD), does not require complex lithographic processing; rather, it utilizes computer-controlled substrate motion in conjunction with glancing incidence flux from physical vapour deposition to precisely tailor the columnar structure in thin films. This exciting process was discovered by Dr. Michael Brett and his team.

These porous nanostructured thin films form a new base materials technology that has potentially broad use across many application areas, such as optics, nanobiotechnology, sensing, and nanoelectromechanical or microelectromechanical systems.

In this one-step deposition process, arrays of isolated sub-micrometre helices, posts or chevrons can be fabricated with control over the geometry of the nanostructure, in a type of inorganic self-assembly of structures. Three U.S. patents have been issued for this technology, and others are pending.

As Canada Research Chair in Nanoengineered Films, Dr. Brett will further develop this new materials process, dividing the work into various projects. These include periodic nanostrucutures and photonic crystals; nanostructured electrochemical devices; nanoengineered inorganic/liquid crystal devices; nanoelectromechanical systems; nanobiotechnology applications; modelling; sensor devices; and speculative and other research.

To cover such broad application areas, Dr Brett has already established effective collaborations with leading researchers and organizations, including an industry sponsor (Micralyne). He has also formed a company, ChiralTF Devices Inc., which is the primary vehicle for commercializing of GLAD. The ultimate goal of the research is not simply to license the technology, but also to establish a manufacturing facility in Alberta. This technology could have applications in optical devices for photonic and communications firms, the fuel cell industry, materials for nanosystems devices and for improved sensor devices, and optical systems such as flat panel displays.

NANOSCALE ENGINEERING PHYSICS INITIATIVE ("NANOCORE")

Dr Michael Brett
Electrical and Computer Engineering
University of Alberta

Dr Mark Freeman
Physics
University of Alberta

Dr Mark Freeman and Dr Michael Brett are both iCORE Professors of the iCORE Nanoscale Engineering Physics Initiative, jointly leading a project at the University of Alberta. iCORE has committed $500,000 per year for five years for a total of $2.5 million dollars to develop this research group.

EXECUTIVE SUMMARY

The iCORE Nanoscale Engineering Physics Initiative has concluded its second year of operation. Major research accomplishments this year included experimental demonstrations of spatial and temporal control of magnetization dynamics in mesoscopic structures (and better understanding developed through numerical simulations); and highly controlled growth of large-scale square spiral GLAD structures for photonic crystals.

Nanocore has also continued to play an instrumental role in the growth of nanoscience and engineering research in Alberta. Our efforts to attract Dr Bob Wolkow to Alberta came to fruition, and he is now installed as the senior chair targeted in our original application, and also cross-appointed as a Principal Research Officer at National Institute of Nanotechnology (NINT), a significant bonus we would not have dared predict at the time of the proposal. The "uptake" of Nanocore trainees to Alberta initiatives has begun, with Marek Malac hired by NINT, and Mirwais Aktary in negotiation with Raith Gmbh about setting up a North American office for their nanofabrication product line in Edmonton.

In granting, major funding for nanofabrication tools was secured (CFI + ASRIP $8.3M, Brett). The commercialization process of GLAD is progressing with ChiralTF Devices Inc., the first Nanocore spin-off, now formulating business plans.

Within the scientific community, Brett and Freeman each made several prestigious appearances at international conferences. In professional service, a number of new appointments to national and international committees were accepted. Brett was recognized with a Canada Research Chair and Freeman received the University of Alberta Alumni Honour Award. Participation in the Canadian Institute for Advanced Research effort in nanotechnology increased, with Brett, Freeman and Wolkow now all associates of the nanoelectronics program. Brett and Freeman have each been announced as cross-appointments to the National Institute of Nanotechnology, an affiliation that should provide for future research collaboration opportunities.

RESEARCH GOALS AND OBJECTIVES

The principle mission of Nanocore is to build upon existing strengths in nanoscale engineering physics to develop world-class expertise in selected areas of nanotechnology. Specifically, the areas can be summarized as nanofabrication methods related to thin film technology, and advanced characterization of nonequilibrium physical properties of nanosystems relevant to future ICT. The goals are accomplished in parallel with the training of a large number of personnel developing at the forefront of nanoscience and engineering, some of who continue upon graduation to expand the presence of this field in Alberta.

During this second year, the research groups of Nanocore principals Brett and Freeman reached steady-state size, with turnover into Alberta and other nano-initiatives already occurring. After helping to attract the National Institute for Nanotechnology in our first year, we took advantage of the confluence of iCORE, NINT, and the priority on nanotechnology within the University of Alberta to nucleate the recruitment of an iCORE Chair in nano-ICT.

As Nanocore unfolds, it is proving (as expected) instrumental in continuing the evolution of U of A capabilities in nanotechnology. Nearly one-third of Nanocore funds support personnel developing advanced nanofabrication methods in support of the other researchers. As a result, our Nanofabrication Facility is the best in Canada and competes in its specialties with any the world. The remainder of Nanocore funding largely supports postdoctoral fellows, graduate students, and undergraduate research associates working on applications in nanoscience and engineering enabled by the foundational methods of nanofabrication. Continuous upgrading of infrastructure is also essential, a spectacular example of which is the showpiece $2M Raith electron beam writing tool arriving later in the year to complement the existing modified scanning electron microscope.

RESEARCH PROJECTS

The team continues to explore the potential of nanomagnetic systems. The almost unbelievable success of conventional magnetic data storage systems shows that magnetic devices miniaturize beautifully to smaller and faster scales, in many respects even better than the semiconductor devices more commonly associated with the ICT revolution of the second half of the twentieth century. The nanomagnetic universe is remarkably rich, however, and many possibilities for future devices remain to be explored. Our favourite stems from the fact that ferromagnetic materials support wave-like excitations (called spin waves or "magnons") of very short wavelengths, down to range of single-digit nanometers. The emerging area of "magnonics" aims to control the generation and propagation of these waves by means analogous to the control of light in photonic crystals. The challenge is very great owing to the exceedingly small scales, but the potential is intriguing. There is significant exploratory work to be done because the intrinsic nonlinear coupling of magnetic excitations adds an additional richness not present in the photonic system.

NANOCORE HAS ALSO CONTINUED TO PLAY AN INSTRUMENTAL ROLE IN THE GROWTH OF NANOSCIENCE AND ENGINEERING RESEARCH IN ALBERTA.

Miro Belov has begun studies of spatial control of magnetic oscillations by examining the influence of individual nanoscale pinholes patterned within a mesostructure. He is able to control the spatial pattern of oscillation and understand the nature of its damping. Sasha Krichevsky is exploring the temporal control of magnetic switching by applying two orthogonal and independently timed switching pulses in a crossed-wire magnetic random access memory geometry. His measurements add temporal and spatial dimensions to the famous Stoner-Wohlforth magnetic "switching astroid". Kristen Buchanan has discovered a very exciting giant Faraday rotation with ultrafast response in nanocrystalline magnetic composites. The mechanism is not yet understood, but appears to also be magnetic field tunable.

Advanced nanofabrication is

being pursued on a variety of fronts. Marek Malac has developed electron beam patterning on the sub-10 nm length scale in the transmission electron microscope. This is particularly promising because the TEM also allows registration to the crystallinity of the starting material in the case of a subtractive pattern transfer process. Mirwais Aktary has made great progress in sub-50 nm patterning with novel electron beam resists in the Nabity-SEM system at the Nanofab. Allan MacDairmid and Rhyan Arthur have succeeded in synthesizing protein/inorganic nanocrystal composite nanowires driven by the self-assembly of tubulin drivers into microtubules. The wires have been characterized by transmission electron and fluorescence microscopy, but electrical measurements have yet to be performed. Allan, Dave Fortin, and Jason Blackstock have constructed a conductive AFM add-on for a microscope of Professor Green, Chemistry.

Jason Blackstock has succeeded in developing very flat platinum nanoelectrodes for molecular electronics by template stripping of films deposited through porous membranes. In the area of advanced characterization, Marke Malac and colleagues at Brookhaven have accomplished qualitative mapping of magnetic fields from small magnetic elements, and demonstrated correspondence with simulation by Zhigang Liu.

The Marsiglio group has made advances in the study of effects of low dimensionality and surface/impurities/geometries relevant to nanoscale superconductive Hegmann's group, with Slepkov, Barker and Tykwinski continued their work on the nonlinear optical properties of organic materials, and began the examination of transient photoconductivity of functionalized molecular crystals. The measurements are helping to elucidate the nature of photoscitations and photoconductivity in organic materials. Meldrum's group is make rapid progress in the synthesis and characterization of light-emitting silicon nanocrystal, intended for integrated silicon optoelectronics. Michael Brett's team continues to explore the fabrication and applications of nanoengineered structures in thin films. The patented Glancing Angle Deposition (GLAD) process is used to fabricate nanostructures with a porous chiral, post, or chevron morphology. These novel coatings are providing opportunities for team researchers to explore device applications where the structure and surface area provide advantages over conventional materials. Some of the projects are listed below.

In photonics applications, Scott Kennedy and Martin Jensen are fabricating and studying a new geometry of 3D photonic crystal, the square spiral array, which was recently proposed by collaborator Dr Sajeev John. This architecture of photonic crystal may be more readily manufactured and more amenable to intentional defect incorporation than other competing photonic crystal technologies. In related work, graduate student Andy Van Popta, with co-supervisor Dr Jeremy Sit and collaborator Dr Dick Broer of Philips Research Labs, is studying the infiltration of arrays of helical structures with optically active liquid crystals. This combination provides for an electrically switchable chiral optic medium, which has potential applications to power-efficient flat panel displays. Peter Hurdey is developing luminescent chiral materials, which are also a potential component for flat panel displays.

In a project that applies ICT technology to the energy field, Jim Broughton is utilizing the GLAD fabrication processes to develop porous electrode structures for application in supercapacitors. Such supercapacitors have been proposed as devices to provide energy load-levelling in technologies such electric cars. Graduate student Barb Djurfors, co-supervised with Dr Doug Ivey, is studying microstructural properties of the GLAD coatings in an effort to understand and optimize the charge storage mechanism.

Ken Harris and Anastasia Elias are developing new forms of nanostructured materials, specifically helically perforated membranes and films. These are fabricated by a template and casting process in a variety of materials, and Harris and Elias have demonstrated that chiral perforated thin films (or PTF's) may have superior optical properties when compared to the original chiral structures.

Research affiliates with NanoCore have been working in other exciting areas. These include: integrating tunnel diodes and other devices to fabricated remotely and radio frequency detectable tags for monitoring purposes (Jay Sulima and Dr Chris Backhouse), studying ultrafast femtosecond dynamics in semiconductors (Michael Cummings and Dr Abdul Elezzabi), and simulating and studying ion beam nanostructuring of surfaces (Maria Stepanova and Dr Steven Dew).

RESEARCH TEAM

FACULTY TEAM MEMBERS

TEAM LEADER	AWARDS
Michael Brett	Canada Research Chair in Nanoengineered Thin Films, NSERC/Micralyne, Senior NSERC Industrial Research Chair
Mark Freeman	Canada Research Chair in Condensed Matter Physics, Alumni Honour Award

TEAM	TITLE
Chris Backhouse	Affiliated Researcher
Steven Dew	Affiliated Researcher
Ray Egerton	Affiliated Researcher
Abdul Elezzabi	Affiliated Researcher
Frank Hegmann	Affiliated Researcher
Frank Marsiglio	Affiliated Researcher
Al Meldrum	Affiliated Researcher
Jeremy Sit	Affiliated Researcher

OTHER RESEARCH TEAM MEMBERS

OTHER TEAM MEMBERS	RESEARCH TOPIC
Marek Malac	Patterning of Permalloy Structures in Transmission Electron Microscope
Mirwais Aktary	Nanolithographic Process Development
Jim Broughton	Porous Electrodes for Supercapacitors
Gregory Kiema	Microfluidic Devices, Carbon Electrodes
Dr. Maria Stepanova	Ion Beam Nanostructuring
Dr. Doug Vick	Nanostructure Growth and Modeling

POST DOCTORAL FELLOWS

PDF	TOPIC	AWARDS
Won Kee Kim	Theory of Nanoscale Superconductivity and Magnetism	
Mark Roseman	Dynamics in Low Temperature Mesostructures	NSERC Postdoctoral Fellowship
Xiaobin Zhu	Current-driven Dynamics and Relaxation in Multilayers	

PHD CANDIDATES

PHD	TOPIC	AWARDS
Greg Ballentine	Numerical Simulation of Magnetic Dynamics	
Miroslav Belov	Spatial Control of Modal Oscillations	JDS Uniphase Scholar
Jason Blackstock	Molecular Electronics	Julie Payette Award
Kristen Buchanan	Nanocrystalline Magnetic Composites	Steinhauer, Killam Memorial Scholar and Graduate Awards
Brian Dick	Fabrication of Periodic Nanostructures	
Barb Djurfors	Nanostructure Characterization	
James Gospodyn	Spectroscopic Ellipsometry of Chiral Materials	
Ken Harris	Perforated Thin Films	
Martin Jensen	Photonic Crystal Devices	Alberta Ingenuity
Scott Kennedy	Photonic Crystal Fabrication	AIXTRON Young Scientist Award
Sacha Krichevsky	Dynamic Switching "Astroids	NSERC PGS-B

Allan MacDairmid	Bio-inspired Macromolecular Nanowires	
Mary Seto	Mechanical Properties of Microsprings	

MSC CANDIDATES

MSC	TOPIC	AWARDS
Grey Arnup	Single-shot Ultrafast Microimaging	
Zhigang Liu	Numerical Simulation of Equilibrium Magnetization	
Mike Colgan	Graetzel Solar Cells	
Michael Cummings	Ultrafast Carrier Dynamics in Semiconductors	
Anastasia Elias	Perforated Thin Films	Alberta Ingenuity
Peter Hrudey	Chiral Luminescent Coatings	NSERC PGS-A
Jay Sulima	Tunnel Diodes for Wireless Applications	
Andy Van Popta	Liquid Crystal Hybrid Devices	NSERC PGS-A

UNDERGRADUATES

UNDERGRADS	TOPIC
Rhyan Arthur	(Physics Industrial Internship) Biochemical Synthesis and Confocal Microscopy
Timmy Le	(Engineering Co-op student) Anodic Aluminum Oxide Membrane Fabrication
Lindsay Leblanc	Digital In-line Holography
Graham Nelson	Magnetic Switching from Nonequilibrium Initial State
Daniel Salamon	Glass Microfabrication

NANOCORE SUPPORTED STUDENTS OF AFFILIATED RESEARCHERS

AFFILIATED STUDENTS SUPPORTED BY NANOCORE	TOPIC	AWARDS
Lloyd Barker	Time-resolved Photoconductivity of Pentacene	
Lucian Covaci	Numerical Simulations of Surfaces, Nanoscale Superconducting Devices	Steinhauer Award
Aaron Hryciw	Light-emitting Nanocrystalline Silicon	
Peng Li	Radiation Damage to Organic Compounds	
Colm Ryan	Whispering Gallery Modes in Spherical Cavities	
Aaron Slepkov	Nonlinear Optical Properties of Organics	
Simona Verga	Researching Nanoscale Superconductivity Issues	

COLLABORATIONS

Research Collaboration

Strong collaborations exist within the Nanocore program. Brett and Freeman co-supervise postdoc Mirwais Aktary in his work on sub-50 nm resolution electron beam lithography and pattern transfer. Freeman and Meldrum co-supervise PhD student Kristen Buchanan in her work on nanocrystalline composite magnetic materials exhibiting giant and ultrafast magneto-optical response. Freeman and Hegmann co-supervise MSc student Grey Arnup at work on single-shot imaging of ultrafast phenomena. Freeman is co-supporting postdoc Won Kim with Marsiglio, working on theory of nanoscale superconductivity and magnetism. Brett and Sit co-supervise Andy Van Popta who is studying chiral photonic materials.

Collaboration with Industry

Brett ended his first 5-year term working with Micralyne under the Micralyne/NSERC Industrial Research Chair, and has applied (with Micralyne's support) for a further 5 years of funding. This research concerns device development of GLAD nanostructured materials.

Freeman and Krichevsky continued to work with Maxtor and Read-Rite on high data rate magnetic recording head characterization.

Jason Blackstock took an internship in molecular electronics at Hewlett Packard Laboratories, with the group of Stan Williams that has become famous for its work on prototype molecular random access memories in the crossbar configuration.

Multidiscipline or Multi-Institutional Partnerships

Important multidisciplinary and multi-institutional collaborations have arisen as a result of the CIAR program. One of the most compelling discoveries in magnetism in recent years has been the "spin-transfer torque" phenomenon, in which a spin-polarized electrical current at high current density carries with it a capability to re-orient magnetization via relaxation of the spin polarization that competes with or even exceeds the influence of the conventional "Oersted field" associated with the current itself. A corollary of this effect is a novel mechanism of damping (or amplification) of magnetic excitations via the passage of currents through "multilayer" geometries (in which ferromagnetic layers are separated by thin non-magnetic spacers). We are working with Simon Fraser University on magnetodynamics in multilayers. Bret Heinrich and colleagues have the ability to grow the most nearly perfect films in the world, and our time-resolved microscopy methods are suited to the study of current-driven and nonlinear response of the multilayers and of mesoscopic devices patterned from them. Within the CIAR, we also collaborate with leading theoretician Dr Sajeev John, who has highly innovative proposals for photonic crystal materials and devices.

A strong collaboration has been established with organic chemists Dr Dick Broer of Philips Research Laboratories (The Netherlands) and Dr Kees Bastiaansen of the Technical University of Eindhoven in the field of making hybrid materials composed of organic liquids or polymers and inorganic GLAD nanostructured coatings. This research is studying methods to better tailor the orientation and performance of liquid crystals in displays, and of methods to make uniquely structured polymers.

The Brett group continues to work closely with Dr Tom Smy of Carleton University, who is able to perform full 3dimensional simulations of the intricate structures engineered by Glancing AngleDeposition. This simu-lation insight is essential to optimizing the GLAD structures in various applications, particularly photonics. The GLAD films also provide a good experimental verification for the 3D simulator, which may ultimately be released as a commercial product similar to the SIMBAD simulator developed by Smy, Brett and Dr Steven Dew.

We have begun work on biomaterials, inspired by the theoretical work of physics professor Jack Tuszynski on microtubules, and experimental results of (and assistance from) his colleagues Silke Behrens and Eberhard Unger of Forschungszentrum Karlsruhe. The work is further motivated by the view that wet nanotechnology is quite important, for instance it's perhaps the only way that the "wiring problem" will be conquered in a cost-effective manner. Graduate student Allan MacDairmid and internship student Rhyan Arthur are working on polymerization and depolymerization of tubulin, decoration with inorganic nanocrystals, and electrical characterization interfacing with microfluidics techniques. Valuable assistance has been received from U of A chemist Jed Harrison (microfluidics) and John-Bruce Green (atomic force microscopy). Frank Hegmann and Rik Tykwinski (Chemistry) maintain a strong collaboration on optical properties of organic materials.

IMPORTANT MULTIDISCIPLINARY AND MULTI-INSTITUTIONAL COLLABORATIONS HAVE ARISEN AS A RESULT OF THE CIAR PROGRAM.

Brett and Research Associate and chemist Dr Gregory Kiema, are studying the incorporation of GLAD nanostructures into microfluidic devices. These highly tailorable structures may have advantages over current packed bead systems used for microchromatography and other on-chip processes.

FUNDING

In addition to the iCORE funding of $500,000, the NanoCore project received $966,000 from Western Diversification, $8,247,533 (includes ASRIP and matching funds) from the CFI Innovation fund, and successful leveraging of iCORE funds with CIPI. As part of the Canada Research Chair appointment, Michael Brett was awarded $312,500 for an advanced Physical Vapour Deposition System. Canada Research Chair funding was $358,000, and $279,500 was received from NSERC.

Industry funding included $112,000 in cash from Micralyne, Read-Rite and Maxtor, and $232,000 in-kind from Micralyne and JDS Uniphase.

INTELLECTUAL PROPERTY

Received or created over lifetime

1. M.R. Freeman, Method for measuring current distribution in an integrated circuit by detecting magneto-optic polarization rotation in an adjacent magneto-optic film, US Patent #5,663,652 (1997).
2. M.R. Freeman, Fiber optic probe with a magneto-optic film on an end surface for detecting a current in an integrated circuit, US Patent #5,451,863 (1995).
3. Spin-off company, Picomagnetics Inc., 1996 - 2003 (phasing out in favour of simple direct invoicing by the Department of Physics).
4. K.J. Robbie, D.J. Broer, M.J. Brett, J.C. Sit, "Optical Device," US Patent #6,549,253 (2003).
5. K.J. Robbie and M.J. Brett, "Shadow sculpted thin films," US Patent #6,248,422 (2001).
6. K.J. Robbie and M.J. Brett, "Glancing angle deposition of thin films," U.S. Patent #6,206,065, (2001).
7. K.J. Robbie and M.J. Brett, "Method of Depositing Shadow sculpted thin films," U.S. Patent #5,866,204 (1999).
8. R.R. Parsons and M.J. Brett, "Transparent, Heat Reflective, Metal Oxide Films," Canadian Patent #1,216,821 (1987).

Potential for future commercial activity

The University of Alberta Industry Liaison Office, in a partnership with Micralyne, led the creation of a new spin-off company, ChiralTF Devices Inc., which was established to commercialize the Glancing Angle Deposition (GLAD) Technology invented in Brett's lab. The company is in a business development and concept planning stage.

PUBLICATIONS

Refereed Journal Publications

1. W.K. Hiebert, G.E. Ballentine, and M.R. Freeman, "Correspondence of Experimental and Numerical Micromagnetic Dynamics in Coherent Precessional Switching and Modal Oscillations," Physical Review B (Rapid Communications), vol. 65, 2002, pp. 140404-140408.
2. G.M. Steeves and M.R. Freeman, "Ultrafast Scanning Tunneling Microscopy," Advances in Imaging and Electron Physics, vol. 125, 2002, p. 195-229.
3. S. Zelakiewicz, et al., "Time-Resolved Kerr Measurements of Magnetization Switching in Crossed-Wire Ferromagnetic Memory," J. Applied Physics, vol. 91, 2002, pp. 7331-7333.
4. W.K. Hiebert et al., "Ultrafast Imaging of Incoherent Rotation Magnetic Switching with Experimental and Numerical Micromagnetic Dynamics," Journal Applied Physics, vol. 92, 2002, p. 392.
5. J.N. Broughton and M.J. Brett, "Electrochemical Capacitance in Manganese Thin Films with Chevron Microstructure," Electrochemical and Solid State Letters, vol. 5, 2002, pp. A279-282.
6. K.D. Harris, A. Huizinga, and M.J. Brett, "High Speed Porous Thin Film Humidity Sensors," Electrochem. Solid State Letters, vol. 5, no. 11, 2002, H27-H29.
7. M. Seto, K. Westra, and M.J. Brett, "Arrays of Self-Sealed Micro-Chambers and Channels," J. Materials Chemistry, vol. 12, 2002, pp. 2348-2351.
8. K.D. Harris, A. Huizinga, and M.J. Brett, "A Simple and Inexpensive Humidity Control Chamber," Measurement Science and Technology, vol. 13, 2002, pp. N10-N11.
9. D. Vick, M.J. Brett, and K. Westra, "Porous Thin Films for the Characterization of AFM Tip Morphology," Thin Solid Films, vol. 408, 2002, pp. 79-86.
10. S.R. Kennedy et al., "Fabrication of Tetragonal Square Spiral Photonic Crystals," Nano Letters, vol. 2, 2002, pp. 59-62.
11. M.D. Cummings, J.F. Holzman, and A.Y. Elezzabi, "Carrier Transport Dynamics in an Edge-Illuminated Photoconductive Switch," J. Vacuum Science Technology A, vol. 20, 2002, p. 1057.
12. M.D. Cummings and A.Y. Elezzabi, "Photo-Excitation of Coherent Acoustic Phonons in InSb," Ultrafast Phenomena XIII, ed. R.D. Miller, M.M. Murnane, N.F. Scherer, and A.M. Weiner, Springer Series in Chemical Physics, 2002, p. 383.
13. M. Stepanova and S.K. Dew, "Discrete-Path Theory of Physical Sputtering," J. Applied Physics, vol. 92, 2002, pp. 1699-1708.
14. M. Stepanova, S.K.Dew, and I.P. Soshnikov, "Sputtering from Ion-Beam Roughened Cu Surfaces," Physical Review B, vol. 66, 2002, p. 125407.
15. R. Egerton and M. Malac, "Improved Background-fitting Algorithms for Ionization Edges in Electron Energy-Loss Spectroscopy," Ultramicroscopy, vol. 92, no. 2, July 2002, pp. 47-56.
16. R.F. Egerton, "The Future of EELS," Microscopic Microanalysis, vol. 8 (Suppl. 2), 2002, pp. 464-465.
17. R.F. Egerton, "Application of Electron Energy-loss Spectroscopy to the Study of Solid Catalysts," Topics in Catalysts, vol. 21, 2002, pp. 185-190.
18. M. Malac et al., "Exposure Characteristics of Cobalt Fluoride (CoF2) Self-Developing Electron-Beam Resist on a Sub-100nm Scale," J. Applied Physics, vol. 92, 2002, pp. 1112-1122.
19. Y. S. Yang et al., "Spin Wave Response in the Dilute Quasi-one Dimensional Ising-Like Antiferromagnet CsCo{0.83} Mg{0.17} Br3," Physical Review B, vol. 65, pp. 212408-1-4.ss.
20. L. Deakin et al., "Superconductivity in Ba2 Sn3 Sb6 and SrSn 3Sb4," J. of Alloys and Compounds, vol. 388, 2002, pp. 69-72.
21. K. Tanaka and F. Marsiglio, "Microscopic Study of Inhomogeneous Superconductors," J. Phys. Chem. of Solids, vol. 63, 2002, pp. 2287-2293.
22. K. Tanaka and F. Marsiglio, "S-wave Superconductivity Near a Surface," Physica C, vol. 384, 2003, pp. 356-368.
23. F. Marsiglio and J.P. Carbotte, "Electron-Phonon Superconductivity," in The Physics of Conventional and Unconventional Superconductors, (Springer-Verlag), pp. 233-345, (also cond-mat/0106143).

24. S. Verga, A. Knigavko, and F. Marsiglio, "Inversion of ARPES Measurements in High Tc Cuprates," Physical Review B, vol. 67, 2003, pp. 054503-1-5.
25. F.A. Hegmann et al., "Picosecond Transient Photoconductivity in Functionalized Pentacene Molecular Crystals Probed by Terahertz Pulse Spectroscopy," Physical Review Letters, vol. 89, 2002, p. 227403.
26. A.D. Slepkov et al., "Optical Properties of Cross-Conjugated Iso-Polydiacetylene Oligomers as Measured by UV-vis Spectroscopy and the Optical Kerr Effect," J. Optics. A: Pure Applied Optics, vol. 4, 2002, pp. S207-S211.
27. R.R. Tykwinski et al., "Nonlinear Optical Properties of Thienyl and Bithienyl Iodonium Salts as Measured by the Z-Scan Technique," J. Optics. A: Pure Applied Optics, vol. 4, 2002, pp. S202-S206.
28. A.D. Slepkov et al., "Ultrafast Optical Kerr Effect Measurements of Third-Order Nonlinearities in Cross-Conjugated Iso-Polydiacetylene Oligomers," J. Chem. Phys., vol. 116, 2002, pp. 3834-3840.

Accepted publications by refereed journals

1. B. Dick, M.J. Brett, and T. Smy, "Controlled growth of periodic pillars by glancing angle deposition," to be published in J. Vacuum Science and Technology B, Jan/Feb 2003.
2. K.D. Harris, J.C. Sit, and M.J. Brett, "Fabrication and Optical Characterization of Template-Constructed Thin Films with Chiral Nanostructure" to be published in IEEE Trans. Nanotechnology.
3. K.D. Harris, et al., "Column Angle Variations in Porous Chevron Thin Films" to be published in J. Vacuum Science Technology A.
4. D. Vick, T.J. Smy, and M.J. Brett, "Growth Behavior of Evaporated Porous Thin Films," to be published in Journal Materials Research.
5. S.R. Kennedy and M.J. Brett "Porous Broadband Antireflection Coating by Glancing Angle Deposition," to be published in Applied Optics.
6. B.C. Choi, A. Krichevsky, and M.R. Freeman, Ultrafast Magnetization Imaging, to be published in Proceedings of the IEEE, June 2003.
7. A. Hryciw et al., "Luminescence of Silicon Nanocrystals in SiO2: Effects of Excitation Spectrum," to be published in Mater. Res. Soc Symp. Proc. vol. 777.
8. M.O. Jensen, S.R. Kennedy, and M.J. Brett, "Fabrication of periodic arrays of nanoscale square helices" Materials Research Society Symposium, April 2002, San Francisco. Accepted (July 30, 2002) for publication in the proceedings.
9. S. R. Kennedy et al., "Fabrication of Square Spiral Photonic Crystals by Glancing Angle Deposition," SPIE Proc. of the 10th International symposium on Nanostructures: Physics and Technology, St. Petersburg, Russia, in press (2002).
10. A.L. Elias, K.D. Harris, and M.J. Brett, "Fabrication of perforated film nanostructures," Materials Research Society Fall Meeting, December 2002, Boston, MA., Accepted for publication (January/03) in Mat. Res. Soc. Symp. Proc.
11. B. Djurfors, M.J. Brett, and D.G. Ivey, "Microstructural Characterization of Porous Films," Materials Research Society Fall Meeting, December 2002, Boston, MA., Accepted for publication (February/03) in Mat. Res. Soc. Symp. Proc.

Conferences

1. Mark Freeman, Intermag Europe opening conference talk, Amsterdam, May 2002.
2. Mark Freeman, American Physical Society Northwest Section meeting plenary talk, Banff May 2002.
3. B.C. Choi, "Dynamic Domain Configurations in Mesoscopic Thin Film Elements with Various Aspect Ratios," Magnetism and Magnetic Materials Conference, Tampa.
4. A. Krichevsky, "The Effect of Pole-tip Geometry on the Flux Rise Time of Write Heads," Magnetism and Magnetic Materials Conference, Tampa.
5. M. Belov, "Magnetization Dynamics of Internally Patterned Thin Film Microstructures: a Spatiotemporal Study," Magnetism and Magnetic Materials Conference, Tampa.

6. M.J. Brett, "Fabrication and Optical Behaviour of Chiral Thin Film Materials," Invited talk at the Society of Vacuum Coaters Annual Convention, Orlando, April 16, 2002. With invited paper in: SVC 45th Ann. Technical Conf. Proc., 2002, pp. 238-244.
7. J.C. Sit, D.J. Broer and M.J. Brett, "Control of Liquid Crystal Orientation in Optical Devices Using Porous Engineered Thin Films Grown by Glancing Angle Deposition," 19th International Liquid Crystals Conference, Glasgow, July 2002.
8. M. Malac, "Electron Beam Patterning with Carboneous Contamination Resists Below 10 nm Linewidth," 49th International Symposium of American Vacuum Society in Denver (CO).
9. M.J. Colgan, G.K. Kiema, and M.J. Brett, "Application of Nanocrystalline Structures to Photovoltaic Cells," Materials Research Society Fall Meeting, December 2002, Boston, MA.
10. B. Dick, M.J. Brett, and T.J. Smy, "Growth Studies of Periodic and Aperiodic Arrays of Posts and Helices," Materials Research Society Fall Meeting, December 2002, Boston, MA.
11. S.R. Kennedy, M.O. Jensen, M.J. Brett, O. Toader, and S. John, "Three-Dimensional Square Spiral Photonic Crystals," Photonic Nanostructures 2002, San Diego, October 25, 2002.
12. M.O. Jensen, S.R. Kennedy, and M.J. Brett, "Thin Film Chiral Nanostructures for Photonic Applications," Photonic Nanostructures 2002, San Diego, October 25, 2002.
13. B. Dick, M.J. Brett, and T.J. Smy, "Sculptured Thin Films Grown by Glancing Angle Deposition," NRC Frontiers of Integration Meeting, Edmonton, October 28, 2002.
14. M.O. Jensen, S.R. Kennedy, and M.J. Brett, "Thin Film Chiral Nanostructures for Photonic Applications," NRC Frontiers of Integration Meeting, Edmonton, October 28, 2002.
15. J.N. Broughton and M.J. Brett, "Performance of Nanostructured Thin Films in Electrochemical Capacitors," NRC Frontiers of Integration Meeting, Edmonton, October 28, 2002.
16. M.D. Cummings and A. Y. Elezzabi, "Photo-Excitation of Coherent Acoustic Phonons in InSb," 13th International Conference on Ultrafast Phenomena, Vancouver, B.C., May 2002.

Books and Chapters

1. B. Dick and M.J. Brett, Nanofabrication by Glancing Angle Deposition, Accepted (December 17, 2002) by the Encyclopedia of Nanoscience and Nanotechnology (ed. H.S. Nalwa, American Scientific Publishers).
2. D. Vick, J.C. Sit, and M.J. Brett, "Glancing Angle Deposition of Thin Films," Book chapter accepted (August 20, 2002) for publication in Research Signpost.
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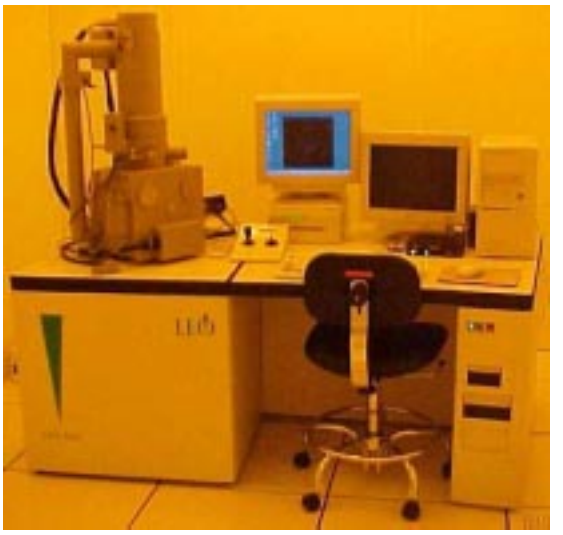
Atomic Force Microscope



Electron Beam Lithography

Oxidation Furnace

Wentworth Prober Station

Ion Mill

Aisle 3 Fume Hood

NANOTECHNOLOGY: MOLECULAR MOVERS AND SHAKERS

Adapted and reprinted courtesy Nature

When nanotechnology became a buzzword about a decade ago, no one was quite sure what it was. Just how the field will develop is still unclear, but the past year has seen a transformation in its ability to attract public investment. The US federal government will almost double its spending on nanotech next year, to more than $400 million. Japan is planning a budget hike of more than 40%, and several European countries have made nanoscale research a priority. Nanotechnology looks poised to shed its science-fiction image and don the mantle of respectability.

But what opportunities should we expect to see the new funds create? The highlights of the past 12 months give some pointers. One of these is nanotechnology's potential to reinvent and revitalize chemistry. For example, chemists should have fun with nanotech's party piece, the manipulation of individual atoms using the scanning tunnelling microscope (STM).

In September, a team at the Free University of Berlin synthesized a biphenyl molecule from two benzene radicals using the STM1. Such piece-by-piece molecule-building, although impressive, is unlikely to replace standard chemical synthesis. But the combination of nanoscale manipulation and spontaneous chemical processes has huge potential.

This was shown in July by researchers at the Steacie Institute for Molecular Sciences in Ottawa, Canada2. Robert Wolkow and his colleagues used the STM to remove individual hydrogen atoms from a hydrogen-covered silicon surface. This allowed a styrene molecule to bind to the silicon, setting off a chain reaction in which a neighbouring hydrogen was displaced, another styrene bound to the silicon, and so on - resulting in rows of molecules up to 13 nanometres long.

In a similar vein, Stanley Williams and colleagues at the Hewlett-Packard Research Laboratories in Palo Alto, California, reported in June that they had made grid-like arrays of self-assembling erbium disilicide nanowires on a silicon substrate3. They anticipate using such grids in a memory-rich architecture for a nanoscale computer. And Williams's collaborator James Heath and his team at the University of California at Los Angeles have developed another of the building blocks for such a device: molecular switches that work at room temperature4.

The connections in nanoscale circuits could well be made of conducting carbon nanotubes. And the discovery of a simple method for fashioning them into 'Y' shapes broadens their scope for use in electronic circuitry5. Conducting organic materials might open the way to a genuine molecular electronics - as was acknowledged by this year's chemistry Nobel.

The cell, meanwhile, is a ready-made toolbox of molecular machines, and biomolecular science is sure to be a big part of nanotechnology. By coupling the ability of specific biomolecules to recognize one another with manipulation using laser beams as optical tweezers, chemist George Whitesides and his colleagues at Harvard University this year explored the frontier with biology, making sculptures from red blood cells tagged with polymer microspheres6.

In June, a paper from Angela Belcher and colleagues at the University of Texas at Austin united protein chemistry with semiconductor technology. They created peptides that can recognize and bind to the surfaces of different semiconductors7. This points to the possibility of devices based on biological molecules, such as the motor proteins that power cell movement, that can assemble electronic or other inorganic structures. The exciting beginnings of such a hybrid technology were heralded in November, with the report of a nanoscale metal rotor powered by the enzyme ATP synthase8.

Practical applications remain years away. "Nanotechnology doesn't yet exist," says Don Eigler

of IBM's Almaden Research Center in San Jose. But there is one concrete sign that nanoscale research will eventually deliver working technologies: the spin-off companies launched by some of the field's academic pioneers. In the past year, Richard Smalley of Rice University in Houston formed Carbon Nanotechnologies, which aims to commercialize the use of carbon nanotubes; and Chad Mirkin and co-workers at Northwestern University in Illinois have launched Nanosphere. This company seeks to use a system based on tiny gold particles to develop diagnostic tests that recognize particular sequences of DNA.

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DR ROBERT WOLKOW

NANOSCALE INFORMATION AND COMMUNICATIONS TECHNOLOGY

iCORE Chair
Physics
University of Alberta

Dr Robert Wolkow is leading a $10 million research program called Nanoscale Information and Communication Technologies, through his appointment as an iCORE Chair, affiliated with the Department of Physics at the University of Alberta and the National Research Council's National Institute for Nanotechnology.

EXECUTIVE SUMMARY

The Nanoscale Information and Communications Technology group is in an initial start up phase at the University of Alberta, and will be associated with the new National Institute of Nanotechnology (NINT) in Edmonton. Initial projects will include investigations into nanoscale structure and manipulation, instrument development, connections to nanostructures, directed growth, and theory.

RESEARCH GOALS AND OBJECTIVES

The research team will continue to create and analyze complex hybrid silicon-organic structures in the near future in order to create a robust base on which to build hybrid silicon-organic devices. Some key projects:

Nanoscale structure

- Determining Structure. With spectroscopy, scanning tunneling microscopy and theory we will resolve the electronic structure of surface-molecule complexes. One goal is to control local band bending (in the substrate) via subtle but controlled adsorption processes. We see connections to switching, hybrid transistors, memory elements, and sensors.
- Self-directed growth. A substantial advance has been made in automatically growing well-defined molecular structures on a surface. We showed for the first time that arduous atom-by-atom crafting techniques are not the only way to build on the tiniest scale. Many extensions are soon to be published and underway including new mechanisms, new functionality and theory advances. Further elements of control are being sought. We aim for a parallel (simultaneous) molecular fabrication tool that provides atom-level control by merely turning valves. A patent is pending.
- Understanding dynamics of adsorption is as important as structural determinations in searching for phenomena inherent to the nanoscale that might underpin new technologies. Several years ago we capped 60 years of study, showing definitively

that molecules hover and search over a surface before settling in to form a chemical bond. That phenomenon is of general importance - it daily affects our thinking about building molecular structures.

Nanoscale manipulation

- Spatially defined attachment points. Further methods to alter substrate structure in order to create spatially defined attachment points for molecules will be pursued.
- All in-vacuum nano-lithography is being developed, at this point for one-off structures, to allow connection and testing of nanostructures.

Instrument development

- Technique development is always ongoing. We wish to be thought of as the premiere centre in the world for innovation in scanned probe and related nanoscience techniques. Today, scanned probe experiments are notoriously difficult. A machine will be built that is substantially more productive. Tips (the actual scanned probe) are intolerably unreliable. We are undertaking a program to create superior tips and instruments. We have credentials in this area, having created the world's first tunable temperature cryogenic STM, a machine that greatly expanded the scope of accessible nano-scale phenomena.

Connections to nanostructures

In order to use nanostructures we must find means to address them. The focus is on self-forming and well-defined connections. Connections must be defined in absolute position and in terms of internal structure. Most work to date has created structurally ill-defined connections. Our molecule-silicon studies have solved the most complex silicon interface problems approached to date and as a result we are ideally positioned to lead in this area.

"Connected STM"

At this stage, we need a machine that facilitates connection to single nanoscale entities - thereby avoiding the need for extensive (or, at this point, impossible) lithographic steps.

Growing contacts to silicon

We will extend our work on well-defined $TiSi_2$ contacts. These are attractive as they withstand harsh thermal and chemical conditions and present a very small Schottky barrier. Methods for defining very closely spaced contacts on silicon are being developed. These will allow ultra-small, functionalized silicon surface regions to be probed. Early applications will include measurements of chemi-electric-field control of near-surface conductive channel structures.

Local doping control

Local doped regions will provide another attractive method for creating silicon surface contacts. In addition to conventional dopants (defined lithographically and with focused ion beam) we aim to create a new class of surface bound (as opposed to substitutional/bulk) dopants which can act without high temperature annealing/activation and which will be restricted to a plane. This technique could find near term application (to be patented if warranted).

Directed growth

A variety of schemes for efficient, controlled growth of nano-structures will be explored. This is a centrally important issue. Self-assembly will be key to nano/molecular technologies.

- Field directed growth. Field controlled approaches may provide one way to efficiently control nano-structure growth. A patent application has been prepared.
- Chemically directed growth. We will attempt to have molecules find their intended docking points by employing chemical "lock and key" methods.
- Assisting Assembly. Many of the components we wish to manipulate are too large to migrate freely, hampering assembly. We are devising novel methods for assisting motion.

Theory

Theory has and will continue to be an essential part of our work. Theory doesn't stand apart as perhaps suggested by this section; it is integrated with all of the above.

- Structure of molecular-substrate complexes
  1. as determined by strong chemical bonds.
  2. and as determined by relatively weak physical interactions.
- Dynamics of structures
  1. barriers which control growth processes

2. fluctuations in existing structures that can embody the function of the nanostructure (for example a field-induced structural change that allows a charge (electron or hole) to be stored).

- Tunneling Transmission through well-defined structures will likely prove useful in molecular devices.
- Electrostatic calculations like those used for present semiconductor devices, will be used to predict and understand the control of channel conduction as a function of the configuration of surface mounted nanostructures.

Exploratory Devices
These will be fabricated to test and develop ideas. These projects will be broadly collaborative and interdisciplinary.

- Molecular Computation devices will be made as soon as possible. Knowing how to achieve connection/addressing will likely be best explored with sensing devices first.
- Molecular Sensing
  1. Earliest designs will make a kind of pressure sensor-the adsorption of molecules will be detected. This will serve to test the viability of our scheme and then as a vehicle for assessing and extending sensitivity. Engineers must be engaged as partners.
  2. Biological molecules provide an endlessly varied and lucrative target for detection technology. The challenge is an order of magnitude greater than the pressure sensor above. Tight collaboration with (bio)chemical/medical experts will be engaged.

RESEARCH PROJECTS

The team for Nanoscale Information and Communications Technology is still in transition, as the project has just recently started. Arrangements are underway for moving staff and equipment to the University of Alberta and NINT.

RESEARCH TEAM

TEAM MEMBERS

TEAM LEADER	TITLE
Bob Wolkow	iCORE Chair in Nanoscale Information and Communications Technology
OTHER TEAM MEMBERS	**TITLE/TOPIC**
Jason Pitters	Ultra High Vacuum Scanned Probe Microscopes
Gino DiLabio	Quantum Chemistry Theorist

POST GRADUATE FELLOWSHIPS

PDF	TOPIC
Mohamed Rezeq	Field Ion Microscopy
Paul Piva	Hybrid Molecular-silicon Structures
Zailong Bian	Metal and Low-K Dielectric Thin Films

COLLABORATIONS

Dr Werner Hofer, who collaborates with Paul Piva, is a new lecturer at Liverpool and an expert in solid-state density functional calculations. Professor Alain Rochefort, Département de génie physique, École Poly-technique de Montréal and Centre de Recherche en Calcul Appliqué (CERCA), is a theorist with expertise molecular interactions related to electrical transport, also working on the Piva project.

Dr Yuh-Lin Wang of Academia Sinica in Taiwan (Chemical Physics) is an expert in focused ion beam instruments, nanostructures and scanned probe microscopy. He has worked with Dr Wolkow for two years on a project that aims to connect small numbers of molecules to macroscopic electrodes, allowing direct electrical characterization of hybrid silicon-molecular structures. In conjunction with Dr Wang, the team is fabricating (in Taiwan) and making ultra high vacuum measurements (in Canada) of the small structures described above.

Dr ChiiDong Chen of Academia Sinica in Taiwan (Physics) is an expert in low temperature characterization of solid-state semiconductor structures and in lithography, including ebeam. In conjunction with Dr Wang, the team fabricating (in Taiwan) and studying (in Canada) the small structures described above.

Professor Andrew Fisher of University College London has worked with Dr Wolkow for several years on joint experimental-theoretical studies of molecules on silicon. The team plans a unique, exciting joint effort that will address ways to gain a new level of control over semiconductor electronic properties via surface chemical control.

SOFTWARE SYSTEMS

Reprinted courtesy of the Government of Canada, Canada Research Chairs Program

CHAIRHOLDER PROFILES

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Achievements: Inventor of Chinook, the world checkers champion. Chinook is the first computer program to win a human world championship, a feat recognized by the Guinness Book of World Records. Author of four books and more than one hundred articles and papers on artificial intelligence, parallel computing, and bioinformatics; holder of Informatics Circle of Research Excellence (iCORE) Chair; American Institute of Artificial Intelligence Fellow; recipient of E.W.R. Steacie Award from NSERC; co-founder of BioTools Inc.; consultant to Electronic Arts Canada and BioWare.

Research Involves: Development of high-performance, real-time artificial intelligence applications.

Research Relevance: Development of high-performance, real-time artificial intelligence applications.

GAMES THAT IMITATE LIFE

Dr Jonathan Schaeffer is one adult who knows that computer games represent much more than just a way of killing time. One of the world's leading authorities on artificial intelligence, Dr Schaeffer believes that games are ideal domains for exploring the capabilities of computational intelligence. Because, unlike life, the rules are fixed, the scope of the problem is constrained and the interactions of the players are well defined; games can act as perfect "control" situations. Games can also be a microcosm of the real world, and successfully achieving high computer performance in a non-trivial game can be a stepping stone toward solving more challenging real-world problems.

Dr Shaeffer's program as Canada Research Chair in Artificial Intelligence will use games as experimental test beds for artificial intelligence research. His intent is to achieve a better understanding of what it takes to build high-performance systems that operate in real time, where high-performance is defined as achieving a performance level comparable to, or better than, that of the best humans. Rather than seeking small incremental advances that are in isolation of the domain in which the ideas could be applied, Dr Schaeffer plans to take an application and solve all the problems necessary to achieve high performance. His research is driven by the requirements of the application, with the intent that, if interesting applications are selected, the research results will have wide applicability. His past research is a prime

example, having led to the formation of a bioinformatics company whose software is being used by research laboratories around the world.

Specifically, his research project will tackle three priorities: single-agent search games (puzzles), with emphasis on path finding algorithms, DNA sequence alignment algorithms, and development of a generic planning system; algorithms for computer-based poker, with attendant problems of dealing with imperfect information and opponent modelling; and development of "realistic" characters for sports and role-playing games.

DR JONATHAN SCHAEFFER

HIGH-PERFORMANCE ARTIFICIAL INTELLIGENCE SYSTEMS

iCORE Chair
Computing and Science
University of Alberta

Dr Jonathan Schaeffer is iCORE Chair of the High Performance Artificial Intelligence Systems Laboratory at the University of Alberta. iCORE has committed $500,000 per year for five years for a total of $2.5 million dollars to develop this research group.

EXECUTIVE SUMMARY

This report represents a summary of the second year of the iCORE Chair in High-Performance Artificial Intelligence Systems. The group now consists of three professors, four affiliated professors, one post-doctoral fellow, 9 PhD students, and 16 Masters students supervised or co-supervised by the Chair. In addition, there are four programmer/analysts (two part-time), and a half-time secretary.

The High-Performance Artificial Intelligence Systems research group specializes in artificial intelligence research, investigating new technologies for creating "intelligent" behaviour in a computer. Although the research spans many areas of artificial intelligence, including search, machine learning, and heuristic knowledge, historically the group has used games to demonstrate the ideas. Fundamental problems in artificial intelligence are being investigated in the context of computer programs that play chess, checkers, Go, and poker. Many of the game-playing programs have achieved a high level of performance and have challenged the best human players in the world.

Although the group's reputation was initially made by applying research work to classic board and card games, since 1999 the team has been moving more towards addressing the challenges of the commercial games industry. Commercial games (or, more precisely, interactive entertainment) is a maturing industry that had $15 billion in sales in North America last year, with an impressive 15% growth in the market. In the past year the team strengthened ties with Electronic Arts of Vancouver (the largest games company in the world) and BioWare of Edmonton (the world leader in role-playing games). The new technology has been well received by both companies, with good prospects for integration into commercial products.

Another thrust of this project is the development of parallel programming environments. For over 15 years, the team has been building tools to simplify the task of parallel programming. The third generation tool, CO2P3S, is now available on the web and actively promoted at major parallel computing conferences.

RESEARCH GOALS AND OBJECTIVES

The project is progressing extremely well along the lines outlined in the original iCORE proposal. The group has built an international reputation based on artificial intelligence (AI) research, using games as an experimental test-bed for this work. However, the research challenges from the classic board and card games are limited (the games of poker and Go being notable exceptions). Since 1999, we have been slowly moving our research efforts towards addressing the challenges of the commercial games industry. This represents a golden opportunity for us, since artificial intelligence research in this industry is still in its infancy. At this point in time, over 40% of our graduate students are working in this area, and this number will only increase. More details can be found at www.cs.ualberta.ca/~games.

RESEARCH PROJECTS

In the past year we have made major strides forward in engaging the commercial games industry and making significant progress in doing industry-based research. We have become one of the largest research groups in this area. However, as we are learning, there is a large gap between academic research and industry expectations. The commercial games industry in particular is heavily performance oriented. They need real-time solutions that use little CPU and memory. Few AI efforts address real-time constraints-an area which is one of our research group's strengths. We are not developing industrial strength solutions for our partners, but we are building proof-of-concept demonstrations that show that our technology can meet the stringent industry demands.

Our group continues to build on its past success in artificial intelligence. Most notable is the poker project, which is addressing the hard AI problems of reasoning with imperfect and incomplete information. Our progress in the past year has been excellent, developing new technology that has resulted in a quantum improvement in the state of the art, Our poker-playing program became the first such program to be competitive with a top human player (January 2003). In the upcoming year, we hope to challenge the best players in the world.

THE HIGH-PERFORMANCE ARTIFICIAL INTELLIGENCE SYSTEMS RESEARCH GROUP SPECIALIZES IN ARTIFICIAL INTELLIGENCE RESEARCH, INVESTIGATING NEW TECHNOLOGIES FOR CREATING "INTELLIGENT" BEHAVIOUR IN A COMPUTER.

The long-term objective of our work is to enhance our understanding of search, knowledge and their interactions. We have one of the strongest groups in the world working on developing high-performance search algorithms. Unlike most research groups, we build complete AI systems, addressing all the issues needed to achieve high performance. It always starts with search (well defined and understood), integrating application-dependent knowledge (not yet well understood) only on an as-needed basis. Discovering new ways to lessen dependence on knowledge is critical to AI success; human knowledge is fraught with error and difficult to obtain. The goal is to automate this process as much as possible.

Part of the project funding supports research into parallel computing, which was not discussed in the original iCORE proposal. For over 15 years we have been developing new parallel algorithms and tools to simplify the difficult task of writing a correct parallel application. These activities have always hovered around 30% of my research time. While this research area is not artificial intelligence, it is considered "high performance".

Of interest is that the technology we built to develop parallel applications (our CO2P3S parallel programming environment) is directly applicable to our artificial

intelligence scripting project. CO2P3S builds on the (sequential) software idea of design patterns-exploiting commonly occurring software designs. CO2P3S uses parallel design patterns. We have copied this technology for AI scripting. Character behaviour also follows patterns. If one describes a character as a "guard" then that conveys a lot of information about that character's behaviour. The guard notion becomes a behavioural pattern that can be customized to give the specific behaviour that is desired. It is interesting that the technology we developed for parallel computing is relevant in artificial intelligence.

Commercial Games Research

In the past, computer graphics were the major technological differentiators between competing games products. The realism of the graphics has increased consumer demand for realism in the game characters. The commercial games industry now recognizes that artificial intelligence has become a major consumer consideration in assessing the quality of a product. Unfortunately, the games industry has few AI experts researching new technologies, giving universities an opportunity to have a major impact in new technology development. In academia, the University of Alberta has the world's largest research group working in this area.

The first major thrust is in AI scripting. Character behaviours in games are usually defined using scripts. However, the result is complex software that is hard to maintain. Further, the resulting performance of the characters is disappointing because the characters will only do precisely what has been scripted, and typically this is a very small (usually one) set of behaviours. We have been developing a tool that allows for the rapid construction of complex character behaviours. The tool, called ScriptEase, is based on having a rich set of pre-defined behaviours (for characters, speech, situations, and plot) that the user can select and then customize to their needs. This work is novel and, because our extensive experience with patterns (see the CO2P3S section below) gives us a competitive edge for developing the next generation of scripting technology. Our prototype tool has been used to build complex stories in a very short time. The work has been demonstrated to BioWare and been very well received. Creating realistic characters has many industrial applications, including training programs, web interfaces, and other forms of interactive entertainment.

The second major thrust is pathfinding. For many computer games, the "simple" task of having a character find a path from their current position to a goal is a time-critical, CPU-intensive function. This is an instance of a problem domain called single-agent search, but in this case is restricted to a two-dimensional grid (with the intent of moving to three dimensions). We developed new algorithms for grid-based pathfinding, yielding some surprising results that run counter to conventional wisdom. BioWare has implemented some of our ideas in their next product and report that they resulted in improved performance. The same technology is applicable to a wider domain of applications, including robot planning.

The third major thrust is applying machine learning to games. Game companies are reluctant to ship games that learn in response to the user's interactions. The reason for this is that it is difficult to control the learning, and a player can contrive to have a program learn poor behaviour. Also, conventional learning algorithms are either too slow, or learn too slowly. For example, in Electronic Arts successful FIFA soccer game, the computerized soccer players are incapable of adjusting their play to match that of their human opponents. We have developed new technology that allows computer soccer players to dynamically modify their behaviour in a controlled way, allowing the program to recognize when it has made a mistake and adjust its play so that the mistake is not repeated. This technology has been enthusiastically endorsed by Electronic Arts.

A major highlight of this year was Jack van Rijswijck's paper on the machine learning algorithms that he developed for FIFA soccer. This work was accepted for presentation at the annual Game Developer's Conference. This is the premier conference in the industry, with a heavy emphasis on new developments that can impact game-program development. Very few academic papers have ever been accepted for this conference.

Another commercial games-

related research initiative is Michael Buro's work on real-time strategy games. He has developed a test-bed for exploring issues in real-time strategy games including client-server architectures, managing limited CPU resources, and complex group behaviours. Michael is working with Relic, a Vancouver-based games company.

Classic Games

Traditional games research has concentrated on two-player games of perfect information (the opponents are not hiding anything). Poker is very challenging because of hidden information (you do not know the opponent's cards), multiple players (typically 10 in a game), and deception (bluffing is critical to successful play). These dimensions significantly complicate the problem domain, making it an application domain that better represents the complexities of intelligence in real life. For example, poker is a model for economic game theory as well as business negotiations and Internet auctions.

For almost a decade we have been developing new technologies for dealing with imperfect information. We have applied the notion of Nash equilibriums to build a pseudo-optimal two-player poker program (an optimal program is too computationally expensive to build right now). This program achieved international success by narrowly losing a match to a world-class player in January 2003. Plans are in place for a real-money match against one of the best players in the world in 2003.

Other efforts in classic games include:

1. Martin Müller has built up a team of six people working on computer Go. Unless games like chess, search is ineffective here. Success in the game depends on using complex interacting knowledge.
2. For almost a decade we have been working on solving the game of checkers. It has a search space of O(1020) -a daunting number. We believe it likely that we can solve the game in the next year. That is we will have a program that will never lose (assuming checkers is a draw with perfect play, as seems likely). Although the final result-solving checkers-is not particularly exciting from the scientific point of view, the technology and tools developed to solve such a large computational problem are relevant to a wide audience.

We continue to improve our world-championship programs for the games of Lines of Action and shogi (Japanese chess). In addition, we were the first team to build a perfect program for the game of 10 x 10 domineering.

Other Artificial Intelligence Initiatives

Planning: Many of our search-based research contributions are applicable to the field of artificial intelligence planning systems. For the past year we have been building a hierarchical planning system. It takes a planning problem domain (e.g. a robot having to plan how to restock inventory) and decomposes it into a global problem (what has to be done) and a series of local problems (stocking individual items). The result is a system that can come up with workable plans considerably faster than conventional approaches. We are working on generalizing the technology to handle a wider set of application domains.

Optimal multiple sequence alignment: A cornerstone for understanding the human genome is the computational problem of sequence alignment-determining the (dis)similarity of DNA protein strands. We have developed new technology for performing an optimal alignment of multiple (long) DNA/protein strands that is roughly four times faster than existing approaches. In the past year we have worked with biologists to assess and improve the quality of our alignment results.

CO2P3S

The CO2P3S project attempts to use modern software technology to simplify the complexities of developing parallel applications. CO2P3S stands for Correct Object-Oriented Pattern-based Parallel Programming System. As the name suggests, the package uses objected-oriented technologies, design patterns and frameworks to facilitate code development. A user selects a parallel design pattern that best matches their application needs, selects some options to customize it to their application, and then fills in CO2P3S-generated sequential code stubs with application-dependent code. The result is a complete, functional parallel application. The software is available for download

(www.cs.ualberta.ca/-systems/cops).

The state of the art in parallel programming tools remains primitive, and we face a difficult task to demonstrate the value of our tool set. Despite being well received in academia (for example, reflected by a best paper prize), we have not yet been able to build up a strong user community.

CISS

We initiated CISS, the Canadian Internetworked Scientific Supercomputer (www.cs.ualberta.ca/-ciss). We have worked on developing grid-like software that can be installed at the user level, without need for system administrator support. The software allows an otherwise idle computer to "pull" in computational tasks to be executed from a remote site. In effect, one can create a virtual supercomputer. The scalability and portability of the software was demonstrated on a national scale on November 4, 2002. On that date, we were able to harness 1,376 computers spanning 20 administrative domains at 18 different sites. In a single day, we were able to do 3.5 years of computing to help solve an interesting computational chemistry property.

The purpose of CISS was three-fold. First, it demonstrated the functionality of the software used. Second, it furthered chemistry research. Third, it helped build the social infrastructure for sharing high-performance computing resources in Canada.

WestGrid

Although this is not a direct research contribution, in many ways the WestGrid project may have the most long-term impact. WestGrid is a partnership of eight Alberta and British Columbia institutions to bring world-class high-performance computing resources to Western Canada. The partners are the University of Alberta, University of British Columbia, University of Calgary, University of Lethbridge, Simon Fraser University, TRIUMF, Banff Centre, and NewMIC. This project was successful at achieving roughly $50 million of funding from the Canada Foundation for Innovation, the province of Alberta, the province of British Columbia, computer vendors, and the member institutions. The five co-principal investigators for the project are Jonathan Borwein (Simon Fraser University), Gren Patey (University of British Columbia), Jonathan Schaeffer (University of Alberta), Brian Unger (University of Calgary), and Mike Vetterli (TRIUMF). Although my research will benefit in only small ways from this infrastructure, the impact on the research productivity of Alberta and British Columbia researchers will be immense. There will be major benefits to researchers in areas diverse as biology, chemistry, physics, engineering, medicine, and the social sciences.

RESEARCH TEAM

TEAM MEMBERS

TEAM LEADER	AWARDS
Jonathan Schaeffer	Canada Research Chair in Artificial Intelligence Fellow, AAAI NSERC E.W.R. Steacie Fellowship
TEAM	**TITLE**
Michael Buro	Associate Professor
Martin Müller	Associate Professor

OTHER TEAM MEMBERS	TITLE
Russ Greiner	Professor
Rob Holte	Professor
Paul Lu	Assistant Professor
Duane Szafron	Professor

POSTDOCTORAL FELLOWS

PDF	TOPIC	AWARDS
Yngvi Bjornsson	Learning Search Control	Gold medal-Computer Olympiad

PHD CANDIDATES

PHD	TOPIC	AWARDS
Darse Billings*	Computer Poker	+
Adi Botea*	Planning Systems	+
Markian Hlynka*	Learning Search Control	+
Akihiro Kishimoto	Computer Go	World Computer Shogi Champion
David O'Connell*	Single-agent Search	PGS-B
Ehud Sharlin*	Tangible User Interfaces	+
Brian Sheppard	Computer Scrabble	
Jack van Rijswijck*	AI Architectures for Sports Games	+
Peter Yap*	Pathfinding on a Grid	
Ling Zhao	High-level Planning	Alberta Ingenuity

MSC CANDIDATES

MSC	TOPIC	AWARDS
Michael Chung*	Real-time Strategy Games	Alberta Ingenuity
Patrick Earl*	Meta Parallel Programming	
Mark Goldenberg*	Parallel Job Scheduling	PGS-A
Dave Gomboc	Tuning Evaluation Functions	
Zhuang Guo*	Web-server Patterns	
Thomas Hauk*	Probabilistic Two-player Search	
Alex Kovarksy	Machine Learning in RTS	+
Jonathan Newton	Learning Mistakes	
Xiaochen Niu	Heuristic Knowledge and Search	
Dominique Parker*	Pattern-based AI Scripting	
James Redford*	Pattern-based AI Scripting	
Terry Schauenberg*	Opponent Modelling	PGS-A
Xiaomeng Wu	Bayesian Learning	
Jonathan Yip	Scripting in RTS	PGS-A
Haizhi Zhang*	Search Algorithms	
Jianjun Zhou	Incremental Search Algorithms	

Students that are supervised or co-supervised by Jonathan Schaeffer are indicated by a *. Faculty involved in (co-)supervising these students include Michael Buro, Rob Holte, Paul Lu, Martin Müller, Duane Szafron, Jaap van den Herik (University of Maastricht) and Ben Watson (Northwestern University). Students who are current or past holders of a major scholarship are indicated by a +.

SUPPORT	POSITION
Neil Burch	Programmer/Analyst
Aaron Davidson	Programmer/Analyst
Marcus Enzenberger	Programmer/Analyst
Amanda Hansen	Administration
Matthew McNaughton	Programmer/Analyst
Kai Tan	Programmer/Analyst

COLLABORATIONS

The group is actively working with several partners:

1. Electronic Arts (commercial games research) has historically provided cash and graduate student internships. In the past year, they made a (small) software donation to the group.
2. BioWare (commercial games research) sponsors the research with $10,000 per year.
3. Relic (commercial games research) is negotiating a project.
4. Joerg Denzinger, University of Calgary works on a joint research project, supported by Intelligent Robotics and Intelligent Systems (IRIS) NCE funding.
5. Strong research ties with IKAT at the University of Maastricht (The Netherlands) and the Computer Games Laboratory at Shizouka University (Japan) include annual visits and graduate student exchanges.
6. WestGrid is a multi-institutional initiative (University of Alberta, University of British Columbia, University of Calgary, University of Lethbridge, Simon Fraser University, TRIUMF, Banff Centre, and NewMIC) and multi-disciplinary initiative. The industrial partners include Hewlett Packard, IBM, and Silicon Graphics.
7. Alberta Ingenuity Center for Machine Learning (AICML). This research center was formed in the past year, with Jonathan Schaeffer one of the co-principal investigators. AICML is starting to work with a number of industrial partners.

FUNDING

In addition to the iCORE grant of $500,000 per year, Russ Greiner, Rob Holte, Randy Goebel, and Jonathan Schaeffer attracted $7 million over five years from Alberta Ingenuity's Centre of Excellence program. NSERC provides yearly operating grants of $20,000 and $46,200 to Drs Müller and Schaeffer, and part of the $600,000 NSERC MFA grant (Pollard et al. with Schaeffer as a coapplicant) provides infrastructure. Dr Schaeffer's Tier 1 CRC provides $200,000 per year for salaries and overhead. The National Centres of Excellence funding provides $155,000 (IRIS-Schaeffer) and $125,000 (PENCE-Szafron et al.) per year.

The $11,990,000 Canada Foundation for Innovation WestGrid grant is to build high-performance computing facilities in Western Canada. The PIs are Jonathan Borwein (Simon Fraser University), Gren Patey (University of British Columbia), Jonathan Schaeffer (University of Alberta), Brian Unger (University of Calgary), and Mike Vetterli (TRIUMF). Schaeffer and Unger leveraged the CFI funds to get $6 million in provincial matching funds. Combined with vendor contributions and operating funds from CFI, the total project budget is roughly $50 million.

INTELLECTUAL PROPERTY

Schaeffer is the co-founder of BioTools Inc. (www.biotools.com), a bioinformatics company. BioTools has three successful commercial products: PEPTOOL (protein analysis), GENETOOL (DNA analysis), and CHROMATOOL (DNA/protein assembly). These products are used in over 1,000 research laboratories around the world. Our success with these products led to the opportunity to do contract work with some of the biggest players in the human genome efforts. Currently most of BioTool's work is on a contractual basis.

Chenomx is a spinoff from BioTools (www.chenomx.com). Chenomx has developed revolutionary software technology to do fluid analysis. From a spectrogram produced by a NMR machine, our programs can analyze the data to a level of detail not easily possible in a laboratory. Our first application is to analyze urine. Conventional urine analysis (as prescribed by a doctor) returns the analysis of six (of over 250) compounds in the urine. Our software accurately returns an analysis of over 100 compounds, faster and at less cost. We have partnered with Varian and Breuker, the two largest NMR manufacturers in the world. Our product, ECLIPSE, is currently under evaluation by a major pharmaceutical company.

BioTools and Chenomx are successes, but both have been hampered by a lack of venture capital. Together they employ over 20 people and have combined revenues of roughly $1 million.

Additional Activities

Our group has had several other notable events happen:

1. Hosted the third biennial Computers and Games conference in Edmonton (July 2002). Over 110 people attended from around the world.
2. Martin Müller organized the 21st Century Cup Computer Go championship in Edmonton (July 2002). Twelve programs from around the world competed. The two University of Alberta entries finished in the middle of the pack.
3. Schaeffer is the co-author of the official FIDE rules for man-machine chess matches (FIDE is the body that governs international chess). Schaeffer was one of the match officials for the Garry Kasparov-DEEP JUNIOR chess match in New York (January/February, 2003).
4. Schaeffer is on the executive committee of C3.ca, the national voice for high-performance computing in Canada. C3.ca is producing a long-range strategy for funding high-performance computing in Canada. The team is headed by Kerry Rowe (Vice-President Research, Queen's University) and Schaeffer is one of the seven co-authors.
5. Competed in the 2002 World RoboCup Championships (small-sized league). Matt McNaughton and his team won two games and lost two games, placing third in their division.

PUBLICATIONS

Refereed journal papers

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2. J. Schaeffer, "Tangled up in blue," New Scientist, vol. 91, no. 3, May-June 2003, pp. 276-278.
3. A. Botea, M. Müller, and J. Schaeffer, "Using abstraction for planning in sokoban," in Computers and Games, ser. Lecture Notes in Artificial Intelligence. Springer Verlag, ????, to appear
4. S. MacDonald, J. Anvik, S. Bromling, D. Szafron, J. Schaeffer, and K. Tan, "From patterns to frameworks to parallel programs," Parallel Computing, vol. 8, no.12, 2002, pp. 1663-1683.
5. J. Zhou and M. Müller, "Depth-first discovery algorithm for incremental topological sorting of directed acyclic graphs," Information Processing Letters, 2003, to appear.
6. M. Müller, "Conditional combinatorial games and their application to analyzing capturing races in Go," Information Sciences, 2003, to appear.
7. M. Müller,"Proof-set search," in Computers and Games, ser. Lecture Notes in Artificial Intelligence. Springer Verlag, 2003, to appear.
8. M. Müller,"Counting the score: Position evaluation in computer Go," Journal of the International Computer Games Association, vol. 25, no.4, 2002, pp. 219-228.
9. M. Buro, "Report on the IWEC-2002 man-machine Othello match," Journal of the International Computer Games Association, vol. 25, no.2, 2002, pp. 113-114.
10. M. Buro,"The evolution of strong Othello programs," in Entertainment Computing-Technology and Applications, R. Nakatsu and J. Hoshino, Eds. Kluwer, 2003, pp. 81-88.

Refereed conference papers

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3. Y. Bjornsson, M. Enzenberger, R. Holte, J. Schaeffer, and P. Yap, "Comparison of different abstractions for pathfinding on maps," in International Joint Conference on Artificial Intelligence (IJCAI), 2003, pp. 1536-1538.
4. M. McNaughton, J. Redford, J. Schaeffer, and D. Szafron, "Pattern-based AI scripting using ScriptEase," in AI'2003: The Sixteenth Canadian Conference on Artificial Intelligence, 2003, pp. 35-49.
5. K. Tan, D. Szafron, J. Schaeffer, J. Anvik, and S. MacDonald, "Using generative design patterns to generate parallel code for a distributed memory environment," in ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming (PPoPP), 2003, pp. 203-215.
6. A. Botea, M. Müller, and J. Schaeffer, "Extending PDDL for hierarchical planning and topological abstraction," in iCAPS workshop on PDDL, 2003, pp. 25-32.
7. Pinchak, P. Lu, J. Schaeffer, and M. Goldenberg, "The Canadian internetworked scientific supercomputer," in High Performance Computing Systems and Applications, D. Senechal, Ed., 2003, pp. 193-199.
8. Y. Xu, A. Huckauf, W. Jager, P. Lu, J. Schaeffer, and C. Pinchak, "CISS-l experiment: Ab initio study of chiral interactions," in 39th International Union of Pure and Applied Chemistry (IUPAC) Congress and 86th Conference of the Canadian Society for Chemistry, 2003, poster abstract, to appear.
9. B. Li, S. Buckingham, J. Schaeffer, A. Spencer, and W. Gallin, "Computational analysis of voltage-gated potassium channels," in Intelligent Systems for Molecular Biology (ISMB), 2003, p. 131, poster abstract.

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15. J. Schaeffer, "Solving the games people play," in Seventh Computer Olympiad. Technical Report CS 02-03, Department of Computer Science, University of Maastricht, 2002, abstract for keynote talk at the Seventh Computer Olympiad.
16. M. Müller,"Multicriteria evaluation in computer game-playing and its relation to AI planning," in AIPS-2002 Workshop on Planning and Scheduling with Multiple Criteria, 2002, pp. 1-6.
17. M. Müller," A generalized framework for analyzing capturing races in Go," in Sixth Joint Conference on Information Sciences, 2002, pp. 469-472.
18. M. Buro,"ORTS: A hack-free RTS game environment," in Computers and Games, ser. Lecture Notes in Artificial Intelligence. Springer Verlag, 2003, to appear.
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23. Y. Bjornsson and T. A. Marsland, "Learning extension parameters in game-tree search," Information Sciences Journal, 2003, to appear.
24. A. Botea, "Using abstraction for heuristic search and planning," in 5th International Symposium on Abstraction, Reformulation, and Approximation, ser. Lecture Notes in Artificial Intelligence, S. Koenig and R. Holte, Eds., vol. 2371. Springer Verlag, 2002, pp. 326-327.
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27. R. Hayward and J. van Rijswijck, "Hex and mathematics," Discrete Mathematics, 2003, to appear.
28. J. van Rijswijck, "Learning goals in sports games," Game Developers Conference, 2003, to appear .

MACHINE LEARNING

Alberta is a leading centre for machine learning
iCORE Chairs: Jonathan Schaeffer, Rich Sutton (starting 2003), Ian Witten (Visiting Professor)
CRC chair: Schuurmans
Alberta Ingenuity Centre for Machine Learning: Rob Holte, Russ Greiner, Randy Goebel, Jonathan Schaeffer, Bowling, Rich Sutton, Schuurmans
UofA Computing Science:
Data mining - Saunder, Mario Nascimento, Osmar Zaiane, Davood Rafei
Pattern recognition - Terry Caelli, Walter Bischof, Vadim Bulitko
Natural language - Andrew Lin, Kondrak

DATA OVERLOAD PROBLEM

Business: Data volume doubles or triples every year, in decision making contexts (Globe & Mail, "How firms can cope with grip of data fear," 21 November 2002)

Biotechnology: "Automated sequencing technology accelerates the pace of input to database, from the current rate of doubling every 20 months. High throughput from cDNA sequencing is expected to double the size of databases in less than one year." National Library of Medicine Centre for Biotechnology Information (NCBI)

Online information:
2.1 billion publicly accessible pages, 7.3 million adder per day (Cyveillance, July 2000)

WHAT IS MACHINE LEARNING?

Developing efficient and robust algorithms for finding useful patterns in data.
Machine learning refines raw data into useful information.

- Patterns in medical data diagnose diseases from early symptoms predict effectiveness of alternative therapies
- Patterns in manufacturing process data improve process control
- Patterns in atomic probe microscope data improve understanding of molecular structure
- Patterns in human web use improve effectiveness of e-business, improve accuracy of navigation

Computers have learned:
to do accurate credit card approval
Humans analysts are 50% accurate; Machine learning was more than 70% accurate
to dispatch telephone technicians
BellAtlantic saved $10 million per year
to optimize parameter settings for separating oil from gas in an oil refinery
in 10 minutes (human experts require more than 1 day)
to catalogue celestial objects (Fayyad et al. 1993)
automatically discovered 22 new quasars with more than 92% accuracy
to identify genes (Delcher et al. 1995)
automatically identifies more than 97% of genes

CALL FOR INDUSTRY PARTICIPATION

INFORMATICS iCORE CIRCLE OF RESEARCH EXCELLENCE

Intelligent Support for Better Software

The Laboratory for Software Engineering Decision Support at the University of Calgary is seeking industry partners for collaboration on software engineering decision support.

Software is important

Software is increasingly complex and large scale, and is used pervasively in business. Whether applied directly or indirectly to develop products and services, the software affects the resulting quality and value.

However, there are many decisions that can affect software quality. Right or 'good' decisions are essential for achieving better software, especially under budget, time and quality constraints. These tend to be very complex decisions, beyond the capacity of any individual.

How can improved decisions be made in software engineering?

An integration of human and computational intelligence is needed. The combination of information, modeling and knowledge, with a sound methodology, can lead to better decisions.

Research team leader: Dr Guenther Ruhe
Team members: 15 researchers (professors, postdocs, PhDs, grad students)
Mandate: To provide research excellence and breakthrough solutions for individual software engineering decision support problems

Who qualifies?

We are seeking to partner with industry organizations.
We would like to hear from you if your organization:

- is developing or maintaining software
- has strong needs to improve maturity of their software projects
- understands software engineering decision-making capabilities as of crucial concern for business success
- is open to mutually beneficial collaboration between industry and academia

Current offerings

- focus on early stages of software development
- release planning tool for incremental development
- support tool for requirements negotiations
- support for requirements-centric selection of components-off-the-shelf (COTS) software products

FOR ADDITIONAL INFORMATION, CONTACT:

Dr Guenther Ruhe, iCORE professor, at ruhe@ucalgary.ca, with a one-page brief on the company and its software engineering challenge.

http://www.seng-decisionsupport.ucalgary.ca/

DR GUENTHER RUHE

SOFTWARE ENGINEERING DECISION SUPPORT

iCORE Chair
Computer Science and Electrical and Computer Engineering
University of Calgary

Dr Guenther Ruhe is an iCORE Professor of iCORE leading the Software Engineering Decision Support Laboratory, established in the department of computer science and department of electrical and computer engineering at the University of Calgary. ICORE has committed $350,000 per year for five years, for a total of $1.75 million dollars.

EXECUTIVE SUMMARY

Software is increasingly becoming the dominant factor for business success in a large number of products and services in the telecommunication, health care, automotive, banking, insurance, and manufacturing industries. In the same way, it is an integral part for emerging industries such as e-business, wireless technologies and mobile products and services. It is the dependence of Alberta industry on reliable software, conforming to original user requirements, that creates the need to increase their software engineering capabilities. The capability to react better and faster to changes in requirements, technologies and policies in all application domains will significantly improve the competitiveness of Alberta software dependent industries.

Decisions on software technologies, processes, resources and tools based on human and computational intelligence are the crystallization points to achieve quality of software-dependent products and services. More effective and more efficient decision support will improve the quality and cost-benefit ratio of decision-making. The impact of better decisions on the quality of software will be all the greater since the focus of the project is on the early stages of the software life cycle. Intelligent Decision Support Systems help decision makers in using communications technologies, data, documents, domain knowledge, and models to identify and solve problems. This is especially true for software development processes with a high degree of uncertainty and a high degree of change. The discipline of Software Engineering Decision Support integrates human and computational intelligence to facilitate better decisions during the software life cycle.

This is a highly interdisciplinary enterprise using concepts from other disciplines such as computational intelligence, cognitive science, and knowledge engineering where empirical evaluation is a fundamental principle.

The main achievements over the last year have been the development of novel approaches and tools supporting early life-cycle decisions. The most successful results were achieved in the area of software release planning under resource and budget constraints. Computational efficient evolutionary algorithms

have been designed and implemented, providing a set of most promising solutions. The final decision-maker can chose out of those solutions, taking into account further implicit and time-dependent constraints. First steps towards developing a commercial product out of these results have been conducted. In addition, a new approach called Soft Requirements Negotiator has been developed that initially uses qualitative, and later quantitative information to provide decision support.

The reported results are part of a broader effort to develop an integrated decision support system with intelligent components for knowledge retrieval, analysis and reasoning, multi-criteria decision aid, simulation and negotiation. Assuming a process-sensitive and web-based 'Intelligent Decision Guide', the system will proactively support process decisions in software development and evolution, to mitigate project risks and to generate the most promising solution alternatives taking into account different stakeholder interests, project parameters and business constraints.

During the reporting period, further progress has been achieved in creating a core team of researchers and in establishing or enhancing dynamic national and international collaborations. The team has started to prepare the 16th International Conference on Software Engineering and Knowledge Engineering, taking place in Banff in June 2004. This will be an excellent opportunity to present research excellence to both academia and industry.

RESEARCH GOALS AND OBJECTIVES

Background and Motivation

Software Engineering Decision Support is of critical interest to both research and industry. Decisions must be made during all iterations of the software life cycle. Currently, many of those crucial decisions are made in an ad hoc manner, based on simplistic rules of thumb, and without links to best knowledge, models, or experience. The impact of poor decisions on the quality of our software becomes more pronounced the earlier in the lifecycle those decisions are made. The main characteristics of decision-making during early lifecycle phases are that (i) the quantity and quality of information available at this stage is typically low, (ii) that the processes and available decision parameters are dynamically changing, and (iii) that a number of conflicting stakeholder interests with different objectives and constraints must be balanced and optimized.

Intelligent decision support is mainly required in situations characterized by the following factors: complexity, uncertainty, presence of multiple stakeholders, large quantities of (organization-specific) data, and/or rapid changes in problem parameters and related information. Support, here, means providing access to information that would otherwise be unavailable or difficult to obtain, facilitating generation and evaluation of solution alternatives and prioritizing alternatives by using explicit models that provide structure for particular decisions.

Only a few examples of software engineering decision support systems exist presently. None of them is specialized to characteristics mentioned above. Additionally, existing systems typically consider decision support as static, not as a continuous problem-solving activity. What is missing is an understanding of decision-making as a crucial part of the processes of evolutionary software development, the existence of active links to human and computational intelligence, and reusing prior decisions, knowledge, and experience.

Research at the Laboratory for Software Engineering Decision Support is oriented towards excellence related to two focus areas of the strategic iCORE research strategy: "Software Systems" and "Intelligent Information Systems". To achieve novel research results, we propose an interdisciplinary approach using concepts and results from other disciplines such as computational intelligence, cognitive science, knowledge engineering, management science, and optimization. In more detail, the following objectives are aimed:

(i) To develop a hybrid methodology "Intelligent Support for Evolutionary Software Development" integrating and enhancing

methods and techniques from related disciplines. Special emphasis is on:

- Uncertainty and incompleteness of information
- Involvement of different stakeholders;
- Conflicting objectives and constraints;
- Dynamically changing project, process and process parameters.

(ii) To instantiate and adapt the proposed methodology in the context of seven classes of problems of evolutionary software development:

- Release planning;
- Soft requirements negotiations;
- Trade-off analysis for requirements selection;
- Requirements-centric selection of COTS products;
- Design decisions for evolvable systems;
- Simulation-based decision support for software quality assurance;
- Scheduling and resource planning for software project management.

The long-term goal of the project is to provide a prototype intelligent decision support system. Assuming a process-sensitive and web-based 'Intelligent Decision Guide', the system will proactively support process decisions in evolutionary development, to mitigate project risks and to generate the most promising solution alternatives taking into account actual project parameters and constraints.

RESEARCH PROJECTS

Software release planning under budget and resource constraints
There is a growing recognition that an incremental approach to software development is often more suitable and less risky than the traditional waterfall approach. This preference is demonstrated by the current popularity of agile methods, all of which adopt an incremental approach to delivering software rapidly. In the incremental software process model, requirements are gathered in the initial stages and, taking technical dependencies and user priorities into account and the effort required for each requirement, the system is divided into increments. These increments are then successively delivered to customers. It is often true that any given requirement could be delivered in one, several or even all releases. Consequently, there is a need to decide which requirements should be delivered in any given release. Since there are likely to be many different users all with different viewpoints on what the user value of requirements is, this decision is potentially very complex. Exacerbating this is the fact that there is a range of constraints, one of which is the desired maximum effort for any given increment. In addition to this factor, risk is an important consideration. A given project may have a risk referent. This is a level of risk which should not be exceeded. In an incremental delivery model this means that a given release has also a risk referent.

In response to these issues we have developed an evolutionary and iterative approach called EVOLVE+ that offers quantitative analysis for decision support in software release planning. The model is extended from and takes into account:

- Priorities of the representative stakeholder groups with respect to requirements;
- Effort estimates for implementing each requirement and effort bounds for each release;
- Precedence constraints, where one requirement must occur in a release prior to the release for another requirement;
- Coupling constraints where a group of requirements must occur in the same release;
- Resource constraints where certain requirements may not be in the same release; and
- A risk factor estimate for each requirement and a maximum risk referent value, calculated from this for each release.

Soft requirements negotiations
Soft requirements negotiator SRN is a decision support method for requirements selection under incompleteness and uncertainty. Given a set of requirements, the decision maker needs support in the process of gradually reducing, evaluating and prioritizing the candidate sets of requirements. In our new approach SRN, the initial

data are used under consideration of their incompleteness and uncertainty. SRN explicitly considers the fact that the available information is always incomplete and uncertain, but gradually becomes better and better during the negotiation process. The approach is initially based on a simple three-point scale for all the involved attributes. Later on, quantitative information is used to determine trade-offs between the supposed value (or priorities) of selected requirements, and the estimated effort to realize them.

We do not compute the results from the given data but use these data as a guide to assist the decision maker in the exploration of the solution space and in the construction of the results. As a final result, we propose a set of the most appropriate solutions. Our approach is soft in the sense that it does not depend on a rigid model and does not make strong assumptions about the available information. It was inspired by the paradigm of multi-criteria decision aid, in particular the concordance/non-discordance principle.

Trade-off analysis for requirements negotiation

Evaluation, prioritization and selection of candidate requirements are of tremendous importance and impact for subsequent software development. Effort, time as well as quality constraints have to be taken into account. Typically, different stakeholders have conflicting priorities and the requirements of all these stakeholders have to be balanced in an appropriate way to ensure maximum value of the final set of requirements. Trade-off analysis is needed to proactively explore the impact of certain decisions in terms of all the criteria and constraints.

The proposed method called Quantitative WinWin uses an evolutionary approach to provide support for requirements negotiations. The novelty of the presented idea is four-fold. Firstly, it iteratively uses the Analytical Hierarchy Process (AHP) for a stepwise analysis to balance the stakeholders' preferences related to different classes of requirements. Secondly, requirements selection is based on predicting and rebalancing its impact on effort, time and quality. Both prediction and rebalancing is based on the simulation model prototype GENSIM. Thirdly, the alternative solution sets offered for decision-making are developed incrementally based on thresholds for the degree of importance of requirements and some heuristics to find a best fit to constraints. Finally, trade-off analysis is used to determine non-dominated extensions of the maximum value that is achievable under resource and quality constraints. As main result, quantitative WinWin proposes a small number of possible sets of requirements from which the actual decision-maker finally can select the most appropriate one.

TRADE-OFF ANALYSIS IS NEEDED TO PROACTIVELY EXPLORE THE IMPACT OF CERTAIN DECISIONS IN TERMS OF ALL THE CRITERIA AND CONSTRAINTS.

Requirements-centric selection of COTS products

As the use of COTS components becomes more and more prevalent in the creation of large systems, the need for assistance for the selection of suitable components in the early stage of the software life cycle grows. COTS-based Software Development (CBSD) focuses on building large software systems by integrating previously existing software components. CBSD's success depends on the successful evaluation and selection of COTS software components to meet customer requirements. However, this process is faced with several difficulties: Uncertainty, incompleteness and even inconsistency of the information available, instability of proposed system requirements, as well as a great variety of objectives and constraints for the actual development process and the final product. Objectives can be related to usability, correctness, compliance to requirements, stability, or performance. Constraints can be related to time, cost or fitness to architecture and dependencies between software components.

A number of methodological proposals have been formulated to improve effectiveness of the individual selection of COTS components based on the fitness to requirements. However, even more benefits can be expected if we look for multiple COTS components to be integrated from a global evaluation perspective.

The problem is to support the selection of a combination of components. As we are encountering typical trade-off relationships, support here means the generation of a set of most promising solution alternatives, from which the decision maker can finally select the best fit considering also implicit and subjective aspects.

In a large software system, components depend on each other and should not be evaluated individually. The domination procedure usually used in single and local COTS selection can easily lead to sub-optimal solutions from a global perspective. Since many interacting factors influence the global selection, these factors should be considered in final solution sets. The global perspective is also needed in order to avoid the interference of a new component selected for a subsystem with other components previously selected for other subsystems, and to avoid undesirable restrictions for further selections. We are then facing a problem that goes beyond a decision among several alternatives, but rather an optimization problem where an optimal combination of COTS products has to be found.

Simulation-based decision support for software quality assurance

Software development companies have real constraints for competitive market edge and delivery of a quality product. Decision processes are the driving forces to organize a corporation's success. To achieve quality processes and practices there are permanent trades-offs to the different aspects related to the final quality of the product. In today's markets, these trade-offs are forced by the pressures of constraint management (e.g. budget, schedule and resources).

The development of a simulation model based on information about current or past reality helps understand why system states that are of interest behave in the observed way given certain start conditions and exogenous influences are in place. The simulation models reproduce current or past behaviour of reality, systematic variation of model parameters (i.e., sensitivity analysis or inclusion and exclusion of model structures) and help in understanding system behaviour. In particular, the nature of trade-off relationships between system states can be investigated this way.

We consider software development from a system theoretic perspective and assume the existence of global (business) goals when studying systems. Starting from an initial understanding of the system under consideration, the most critical and worst understood parts of the overall system are most promising candidates for an in-depth investigation. This investigation can be done by designing and implementing a GQM-based measurement program with the goal derived from the subsystem under investigation. The results from this program are used to better understand system structure and system behaviour at this point. This process can be iterated several times, where not only one measurement program needs to be considered at each step. The application of this interactive (between SD and GQM) and evolutionary (models, results, and insights are evolving and relying on each other) process results in:

- a sequence of SD models with increasing accuracy and validity in describing reality;
- a sequence of GQM plans (including existing results) derived from the global improvement goal(s) and the perspective of the whole system;
- a means to incrementally improve the validity of both the SD models and the GQM models by checking their respective consistency;
- a method to combine the results of GQM with the power of SD to show how different individual/local goals fit together; and
- a method that combines experiments in a virtual world by conducting simulation runs with experiments in a real world by performing goal-oriented measurement.

Based on descriptive modeling of existing processes, products and quality related attributes, simulation will be used to better understand and predict the impact of the different verification and validation activities. The process models themselves will be initially based on the Unified Process and will be later tailored to customers' specific processes.

RESEARCH TEAM

FACULTY TEAM MEMBERS

The area of Software Engineering at University of Calgary is represented by about ten researchers with a broad range of expertise. Currently, most intensive collaborations are with:

- Dr Maurer (Associate Professor at Department of Computer Science),
- Dr Denzinger (Associate Professor at Department of Computer Science),
- Dr Walker (Assistant Professor at Department of Computer Science),
- Dr Eberlein (Associate Professor at Department of Electrical & Computer Engineering),
- Dr Far (Associate Professor at Department Electrical and Computer Engineering).

OTHER RESEARCH TEAM MEMBERS

OTHER TEAM MEMBERS	TITLE
Amandeep	Research Associate Department CS
Jinfang Sheng	Visiting Researcher, Department of ECE
Kornelia Streb	Adminstrative Assistant

POSTDOCTORAL FELLOWS

PDF	TOPIC
An Ngo The	Computational Intelligence, Department of Computer Science
Des Greer	Release Planning, University of Belfast
Dietmar Pfahl	Software Process Simulation, Fraunhofer Institute Experimental Software Engineering

PHD CANDIDATES

PHD	TOPIC
Abdallah Mohamed	Bayesian Belief Networks
Jingzhou Li	Decision Support Processes
Michael Ochs	COTS Selection
Liang Zheng	Evolutionary Modeling Intergating Measurement and System Dynamics

MSC CANDIDATES

MSC	TOPIC
Zhizhong Li	Requirements Management using Rough Set Analysis
Joseph Momoh	Decision Support for Software Project Management
Wei Shen	Trade-off Design Decisions
Yuhang Wang	Decision Support for Perspective-based Software Inspections
Qun Zhou	Effort Estimation for COTS-based Software Development

COLLABORATIONS

RESEARCH COLLABORATIONS

Fraunhoder IESE and Fraunhofer-Center Maryland
In accordance to the Academic Cooperation Research Exchange between the University of Calgary and the Fraunhofer Institute for Experimental Software Engineering ("Fh IESE"), the Laboratory for Software Engineering Decision Support and Fh IESE agreed to a collaborative research and personnel exchange. On this basis, Dr Dietmar Pfahl will visit the laboratory for three months. Collaboration with Fraunhofer-Center Maryland has just started after a visit in Fall 2002.

University of New South Wales
A similar agreement as signed with Fh IESE is in preparation to be signed with the research group of Dr Ross Jeffrey at University of New South Wales. It intends to conduct joint research and exchanging PhD students based on that.

INFORMAL COLLABORATIONS

Informal collaborations were launched especially with the groups of Dr Lionel Briand (Carleton University, Canada), Dr Khaled El-Emam (NRC, IIT), Dr Jens Jahnke (University of Victoria, Canada), Dr David Raffo (University of Portland, USA), and Dr Goivanne Cantone (University of Rome, Italy).

COLLABORATION WITH INDUSTRY

Brycol
An NSERC CRD proposal titled "Simulation-Based Decision Support Software Quality Assurance" was initially submitted to CSER, the (Canadian) Consortium for Software Engineering Research. Created in 1996, CSER is a multi-party, industry-led research program, geared toward solving selected industrial problems in software engineering. The project called SimQuali aims to benefit the collaborators, their students and the Canadian economy in various ways. As a small company, Brycol Consulting cannot afford to support a research department. This project provides the opportunity for Brycol to benefit from the collaborative research results embedded in an interaction/argumentation device when discussing trade-off in software quality improvements and outcomes. The intelligent decision support tool will provide the capability to evaluate the outcomes of feasibility alternatives based on standard variables for verification and validation techniques.

Motorola
A proposal for funding of one PhD student was submitted to the University partnership program of Motorola. The project is devoted to develop a new and innovative methodology to support analysis and decisions in software system development. In our new approach, the initial data are used under consideration of their incompleteness and uncertainty. Instead of computing the results from the given (uncertain) data, our new approach provides the decision-maker 'a guided tour' in the solution space and assists him/her in the construction of the final selection. The Support Tool will supplement the Motorola's use of

the Decision Driven(tm) design methodology and its existing Motorola DecisionLink tool for building and maintaining Decision Networks for the stage of software analysis and designs.

Corel

Collaboration with Corel is devoted to Release Planning. Their main interest is to provide plans that fit to resource and budget constraints. No commercial product for that purpose is available on the market. Corel has contacted me based on a self-running demo that is provided at http://pages.cpsc.ucalgary.ca/%7Etsangk/sengDecisionSupport.php. In accordance to discussions conducted with Inno-Center and University Technologies Inc. (UTI), the strategy is to have Corel as a reference customer for a later product development. For access to business relevant real-world data, a disclosure agreement as signed.

Nortel Networks and Alterna Technologies

Two non-academic organizations have joined the proposed NSERC Strategic Project Grant: Alterna Technologies Group Inc. (Calgary) and Nortel Networks (CDMA Base-station Development, Calgary). The CDMA wireless group of Nortel Networks is presently supporting three releases in the application field, plus three releases in development and one release in the planning phase. The base transceiver station is primarily driven by software. Each release, the software team adds more functionality to its application code. Release planning and requirements negotiation is of crucial importance for business success.

Alterna provides and integrates a full suite of internet-based global e-finance solutions allowing customers to maximize their visibility to liquidity, improve productivity, reduce costs, and increase shareholder value. Evolutionary development processes are an essential means to better react to changing markets and policies.

With both partners, we have extensively discussed the project goals and how these match with their priorities and current demands. In their letter of support, each expresses its strong commitment for in-kind contributions to achieve project goals.

ALBERTA SOFTWARE ENGINEERING RESEARCH CENTER ASERC
THE ALBERTA SOFTWARE ENGINEERING RESEARCH CONSORTIUM ASERC IS COMPOSED OF FACULTY AND GRADUATE STUDENTS FROM THE UNIVERSITY OF ALBERTA AND THE UNIVERSITY OF CALGARY THAT ARE ENGAGED IN APPLIED RESEARCH IN SOFTWARE ENGINEERING AND PARTNER COMPANIES THAT CURRENTLY PARTICIPATE OR INTEND TO PARTICIPATE IN COLLABORATIVE RESEARCH WITH THE ACADEMIC MEMBERS.

MULTIDISCIPLINE OR MULTI-INSTITUTIONAL PARTNERSHIPS

Alberta Software Engineering Research Center ASERC

The Alberta Software Engineering Research Consortium ASERC is composed of faculty and graduate students from the University of Alberta and the University of Calgary that are engaged in applied research in software engineering and partner companies that currently participate or intend to participate in collaborative research with the academic members.

International Software Engineering Research Network (ISERN)

The Software Engineering research group at the University of Calgary successfully applied to become a member of the International Software Engineering Research Network ISERN. This gives us excellent opportunities to further extend collaboration with leading researchers and research institutions all over the world. For a list of the 33 member organizations, see http://www.iese.fhg.de/network/ISERN/pub/isern.list_of_members.html.

FUNDING

Current funding is based on the iCORE research grant (350 K over a period of five years), and an existing NSERC grant 'Decision Support for COTS-Based Software Development' with an annual funding of $24,000 over a period of four years.

The proposal for an Alberta Research Center for Innovative Software Engineering Technologies (AISET) including 24 researchers from six departments located in three Alberta Universities was asking for funding of about $2 Million over a period of five years. The Alberta Ingenuity Science and Engineering Advisory Council finally evaluated the proposal in the category B (second best in a four pint scale). This means, the proposal did not receive funding but may advance to full proposal stage in future competitions, with help from Ingenuity and institution. SEAC especially recommended continued support from Alberta institutions and iCORE.

Three more proposals have been submitted:

(i) NSERC Strategic Project Grant asking for about $180.000 over a period of three years plus in-kind contributions from Nortel Networks and Alterna Technologies.

(ii) NSERC CRD Grant asking for about $100.000 including in-kind contributions from Brycol Consulting.

(iii) Funding of one for PhD student was submitted to the University partnership program of Motorola asking for about $25.000 over a period of three years.

INTELLECTUAL PROPERTY

Current commercialization is focused on a tool for software release planning. No commercial product for that purpose is available on the market. In accordance to discussions conducted with Inno-Center and University Technologies Inc. (UTI), the strategy is further conduct research in this context to incrementally develop a powerful support tool and to use Corel as a first reference customer for a later product development.

For access to business relevant real-world data, a disclosure agreement was signed. Currently, software release planning is widely done ad hoc and without tool support. A comprehensive analysis of existing software solutions and pending patents in this area was conducted by UTI Calgary. The results have shown that no competitive products or results are currently available for this dynamic and complex task.

PUBLICATIONS

Accepted publications by refereed journals

1. G. Ruhe, A. Eberlein, and D. Pfahl, "Trade-off analysis for requirements selection," International Journal on Software Engineering and Knowledge Engineering (In Press).
2. D. Pfahl, O. Laitenberger, G. Ruhe, J. Dorsch, and T. Krivobokova, "Evaluating the Learning Effectiveness of Using Simulations in Software Project Management Education: Results from a Two Times Replicated Experiment," Information and Software Technology (In Press).

3. D. Pfahl and G. Ruhe, "IMMoS: A New Framework for Integrated Measurement, Modelling, and Simulation," International Journal of Software Process: Improvement and Practice (In Press).
4. D. Pfahl, O. Laitenberger, G. Ruhe, and J. Dorsch, "An Externally Replicated Experiment for Evaluating the Learning Effectiveness of Using Simulations in Software Project Management Education," International Journal on Empirical Software Engineering (In Press).

Refereed Conference Papers

1. G. Ruhe and D. Greer, "Quantitative studies in release planning under risk and resource constraints," appears in: International Symposium on Empirical Software Engineering, 2003.
2. G. Ruhe, "Intelligent Support for Selection of COTS Products," Net.ObjectDays, Erfurt, Springer, 2003, pp. 34-45.
3. G. Ruhe, A. Eberlein, and D. Pfahl, "Quantitative WinWin - A New Method for Decision Support in Requirements Negotiation," 14th International Conference on Software Engineering and Knowledge Engineering, Ischia, Italy, July 2002, pp. 159-166.
4. I. Grützner, D. Pfahl, and G. Ruhe, "Systematic courseware development using an integrated engineering style method," World Congress Networked Learning: Challenges and Solutions for Virtual Education (NL 2002), Berlin, Germany, 2002.

Books

1. G. Ruhe, Software Engineering Decision Support - Methodology and Applications, Innovations in Decision Support Systems, (Ed. by Tonfoni and Jain), International Series on Advanced Intelligence Volume 3, 2003, pp. 143-174.

Workshop on Software Engineering Decision Support

The first International Workshop on Software Engineering Decision Support was held in conjunction with the 14th International Conference on Software Engineering and Knowledge Engineering SEKE'2002 in Ischia, Italy. The workshop was a great success, and I was asked to organize a successor event in 2003 again. Ten high quality papers were finally accepted after a peer review process. A special issue of the Journal on Software Engineering and Knowledge Engineering will be edited with advanced and improved versions of the four to five best papers of the workshop.