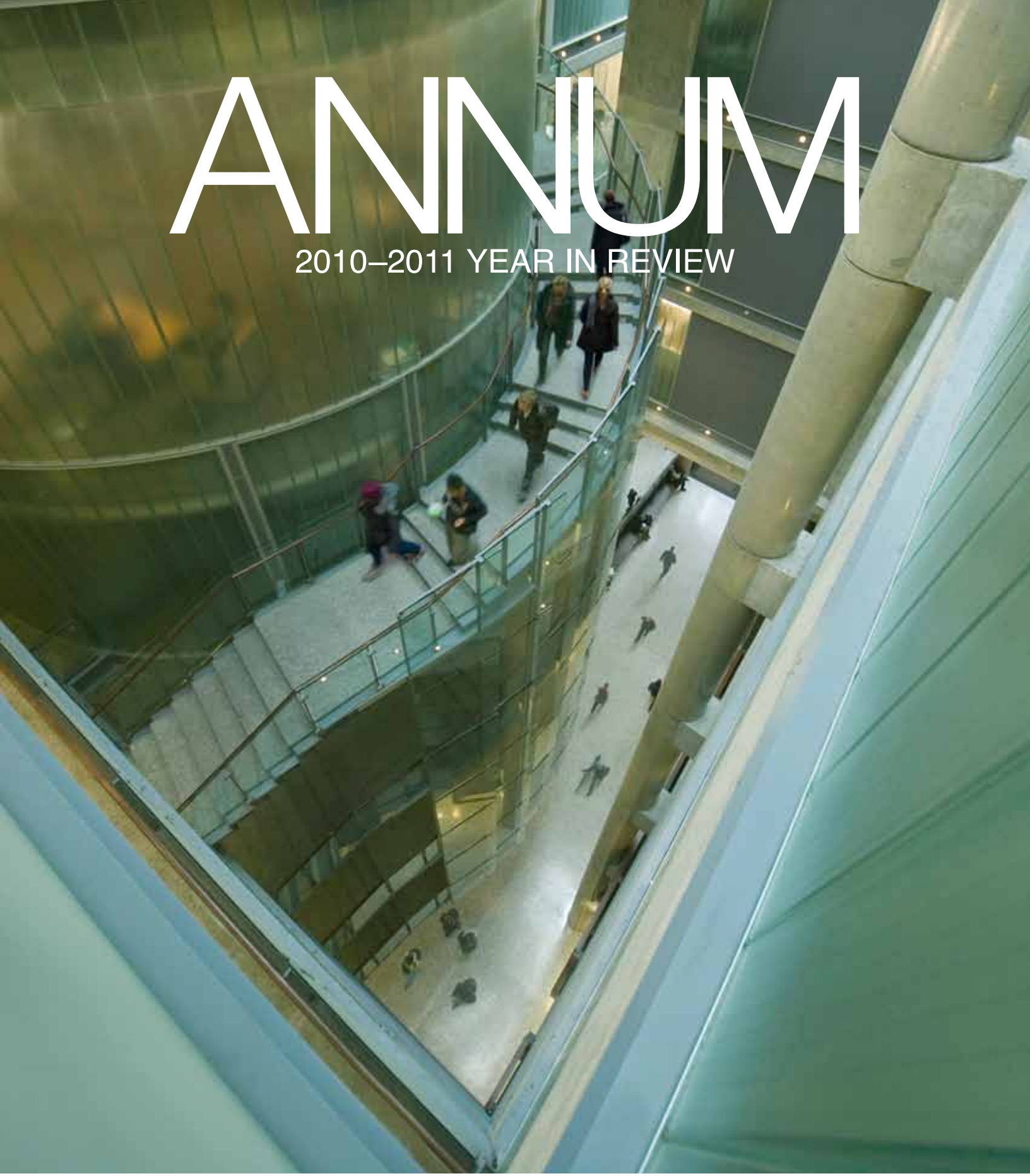

ANNUM

2010–2011 YEAR IN REVIEW

The Edward S. Rogers Sr. Department
of Electrical & Computer Engineering
UNIVERSITY OF TORONTO

Table of Contents

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Past Reflections

The roots of the Edward S. Rogers Sr. Department of Electrical & Computer Engineering at the University of Toronto reach as far back as 1909, when it was launched as an offshoot of the Department of Mechanical Engineering. At the time, and in fact until the early 1960s, only two such departments existed in Ontario, the other at Queen's University in Kingston, Ontario.

With the return of First World War veterans in the fall of 1919, the department saw enrolment swell from 241 to 819 students. A practical undergraduate curriculum was offered at this time, similar to that of the mechanical colleges in the United States. It was this North American model that the department was developed under, as engineering was not considered a discipline for academic study in Britain or Western Europe at the time.

By the mid 1920s, the applied science component of the department developed and the degree of Master of Applied Science had been instituted. Graduate study was pursued intermittently and the first PhD in Electrical Engineering was awarded in 1951.

Early research groups included those based in classical electromagnetic theory, followed by control engineering, dubbed systems disciplines, in the 1950s. Shortly thereafter came communications engineering, and electronic device and circuit engineering. In 1962 the department formed the Institute of Biomedical Electronics, now called the Institute of Biomaterials & Biomedical Engineering, and joined by Photonics. Computer engineering found its place in the department around 1965.

In June 2000, Ted Rogers Jr. made a substantial donation in honour of his father, who was a student of the department from 1919 to 1921. The department is now known as The Edward. S. Rogers Sr. Department of Electrical & Computer Engineering.

Department Chair's Welcome–

As Department Chair, I am delighted to share with you our first annual report for The Edward S. Rogers Sr. Department of Electrical & Computer Engineering at the University of Toronto. Founded in 1909, our department has a long and proud history of education, research, and service. Over the past century, it has evolved to meet the changing needs of society and the changing role of a large research university, with a mission that includes not only education and training but also research, innovation and knowledge creation. Today, this is the largest ECE department in the country, with an operating budget of about $25M, 75 faculty members (95, including our Professors Emeritus), more than 1,130 undergraduates, and approximately 500 graduate students.

Our undergraduate program draws some of the best students from around the country. Our curriculum is flexible, allowing our third- and fourth-year students to customize their experience.Our program also boasts a strong emphasis on hands-on and project-based learning, extensive modern laboratories, and various design-focused courses.

Research is also an integral part of our mission. We provide state-of-the-art training for our graduate students in our MEng, MASc, and PhD programs. With an annual research budget of about $16M, 21 named research chairs, and approximately 36 PhDs awarded annually, the department literally buzzes with innovative research ideas and projects. This creative energy, in turn, benefits our undergraduate program enormously, enriching the course content and providing valuable research experience.

As a result, ECE is engaged in the dissemination and creation of knowledge across a wide range of areas of engineering and applied science – from the fabrication of atomic level structures with special optical properties, through to the technologies that have revolutionized our world, such as microelectronics, computer systems, software, and networks.

This publication tells our story, highlighting the work of our undergraduate and graduate students, and our faculty. It covers both teaching and research and provides a useful and interesting snapshot of the state of the department. On the teaching side, much information is given about the various student activities and data is provided on the student body and student achievement. On the research side, you will find articles outlining some of the leading-edge research currently underway in our department, as well as a listing of all our professors and their research projects.

I hope you find this to be a useful report and I welcome your feedback and comments – you may reach me at chair@ece.utoronto.ca.

Farid N. Najm

Professor and Chair

Undergraduate Studies

Offering the broadest curriculum in Canada, including the Electrical Engineering and Computer Engineering program, the Edward S. Rogers Sr. Department of Electrical & Computer Engineering at the University of Toronto, is the school of choice for students who prefer flexibility in their course selection, and appreciate the value of having access to some of the world's most sought-after industry leaders, renowned experts in their fields. These experts not only lecture, but they also supervise vibrant on-campus research laboratories, facilitating a seamless transfer of knowledge from the lab to the classroom.

As an undergraduate degree, electrical and computer engineering offers the widest range of career opportunities. Seated at the heart of most technical advances made today, electrical and computer engineering is truly the engine that powers the technology of the 21st century.

At the University of Toronto, the first two years of study provide the essential background in basic science and mathematics and also introduce the student to the important concepts in electrical and computer engineering such as circuits, digital systems, electronics, and communication systems. These two years of study are identical for both the electrical engineering and computer engineering programs.

In third year, students are asked to choose an area of specialization. In fact, in both third and fourth year, students may choose from six areas of study, depending on their individual strengths and interests.The areas of study options include: Photonics and Semiconductor Physics; Electromagnetics; Analog and Digital Electronics; Communications, Systems Control and Biomedical Engineering; Computer Hardware; Computer Software.

To help guide students, curriculum streams have been developed, however students are free to create their own unique path of study if they so choose. The eight curriculum streams may be accessed at **http://uoft.me/ececurriculum.**

Example course packages can be found on Magellan —an online program to help facilitate the course selection process, located at **http://uoft.me/magellan.**

SHAUN **BENJAMIN** | third-year CompE undergraduate

Troubleshooting in a Dynamic Digital World

Purple

The legends say it was the glorious era of the mighty British Royal Navy. Her Majesty's Ships were being set out to explore, conquer and claim exotic lands at the far ends of the Earth. To identify themselves as engineers, each officer proudly wore a bright purple patch on his right arm, just below the shoulder. Alas, the sweat, grime and bilge water in the engineers' work environment resulted in a hefty portion of the bright purple dye from the badge transferring onto their skin. **engsoc.skule.ca**

Under the supervision of Professor Ashvin Goel, in the Edward S. Rogers Sr. Department of Electrical & Computer Engineering at the university of Toronto, undergraduate student Shaun Benjamin and his colleagues are working to develop innovative computer security and reliability systems that are exceedingly more efficient than what is currently available.

"Global reliance on computer software systems is growing exponentially, and of course the potential for problems and errors is naturally increasing," says Benjamin. "Our group is looking at checking tools that will detect and correct file system problems and errors."

One such checking tool developed by the group is Recon. The uniqueness of Recon is its ability to scan for problems and errors while the computer operating system is online. "Most of the popular operating systems have checking tools to discover and correct system errors, but they require the computer to be taken offline," says Benjamin. "So that's not really a great solution at the moment because of the downtime involved in doing so."

In addition to avoiding downtime, checking problems and errors while the operating system is online also means that the entire disc doesn't have to be read. Instead, Recon allows for the checking process to occur right after the new data has reached the disc, ensuring that the computer will remain in a consistent state.

"Right now our challenge with Recon is that sometimes not all of the data we're checking hits the cache, so it reverts to the disc," says Benjamin. "This means that we have to take the time to go to the disc and read the data there. So as it stands right now, we find that Recon will cause computers to run slightly slower – about ten per cent slower. We're working to solve this by removing as much of our dependency on the cache as possible by making more efficient programs."

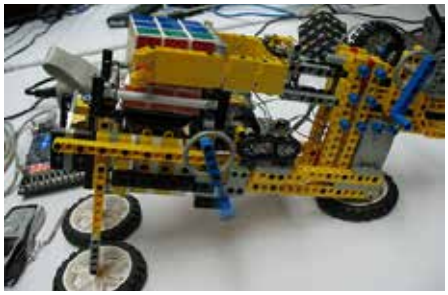
While Benjamin's main focus at the University of Toronto is working to further develop Recon, he also credits the camaraderie and enthusiasm of his supervisors and colleagues for his continued interest in the program. "I chose the engineering program at the University of Toronto because it is so highly regarded on an international scale," says Benjamin. "The bonus is that the people I'm working with are genuinely interested in our research and it's great to be with like minds who are so passionate about the same things as I am."

Undergraduate Summer Research Awards

A number of summer (May to August) research fellowships are available to second-, third- and fourth-year students in electrical and computer engineering. Selection criteria may include the applicant's academic background, financial need, and the duties and responsibilities of the applicant in the research project.

NSERC Undergraduate Summer Research Award (USRA) nominees are chosen based on academic standing, program of study and research supervisor. Applicants must meet the NSERC minimum standing requirement but the competitive average is often much higher. In addition, our goal is to ensure fair distribution amongst each of the programs for which we administer these awards—Electrical and Computer Engineering and Engineering Science, the year of study (second and third year) as well as amongst ECE Departmental supervisors.

Arian Omidzohour (ElecE 1T1), Gordon Cressy Student Leadership Award Winner, 2011



ANMOL **KAUR** | third-year ElecE undergraduate

Engineering Dynamics at U of T

Inspires Undergraduate Students

The Lady Godiva Memorial Band, or LGMB, is a student-run band consisting chiefly of University of Toronto engineering students. The LGMB is dedicated to the preservation and advancement of Skule™ spirit along with Ye Olde Mighty Skule™ Cannon and the Brute Force Committee (BFC). The LGMB is notable for its open membership policy and sometimes audacious appearances at events.

Enthusiasm radiates from undergraduate student Anmol Kaur as she describes her academic career in electrical engineering at the University of Toronto.

"Engineers change the world," says Kaur about her chosen field. "I'm inspired by the fact that just about everything we have around us was designed by some kind of engineer, and there's still so much room for growth. That's very exciting."

Considering several engineering programs, Kaur chose the University of Toronto because of its reputation, and on-campus spirit. "I was taken by the spirit of the campus and the passion the students have for the program," says Kaur. "I also really like the Professional Experience Year (PEY) that U of T offers because you have the option of 16 months of solid work time so you can make more of a long-term connection with an employer."

In addition to her academic program, Kaur is vice-chair of the ECE club, as well as the founder and driving force behind the student club Spark. The goal behind Spark is to fill the work environment and the engineering buildings with inspiration and innovation by exhibiting projects designed by the students. Spark hosts design challenges and workshops where ideas are brought to life. "Recently we completed an LED tiles project that lights up when stepped on," says Kaur. "We took the tiles that everyone made and we put them up for display in the lobby of the main building in our department. So now when I walk by it and I see people stopping to step on the tiles, that's very rewarding for me."

Last semester, Kaur participated in National Engineering Month, a province-wide student initiative that rounded up at the Ontario Science Centre with high school students in attendance. "That was great to see the students become really inspired and interested in engineering too," says Kaur.

While attending a speech recently, Kaur says the speaker's words resonated with her. "He told us not to let our studies get in the way of our education," says Kaur. "I realized at that moment that U of T has enabled me to do just that with all of the fabulous extra-curricular projects and activities I've had the luxury of being involved in. I've learned so much from every single one. I'm building a greater education."

Engineers and Entrepreneurship: Vincent Cheung (CompE PhD candidate), founder of ShapeCollage.

Professional Experience Year

The Professional Experience Year (PEY) internship program allows students to apply their engineering knowledge in a 12-to-16- month project-based professional internship. The length of the placement offers enough time to become involved in large-scale projects, build relationships with employers and achieve professional accomplishments and milestones. Students who elect to participate in the program make industry contacts, gain valuable career skills and significant professional experience before graduation.

The PEY internship program has been in existence for over 20 years, and during this time it has earned an outstanding reputation in both academic and industry circles. PEY offers students an outstanding education, a range of eligible engineering career paths to choose from and strong established industry partnerships.

Last year, PEY placed students in over 160 companies, which encompass broad geographical regions: Chile, Alaska, Germany, Switzerland, USA, Alberta, British Columbia, Newfoundland & Labrador and Japan.

Gordon Cressy Student Leadership Award
Angela Lee (ElecE MASc 1T0)
Winner 2011

#1

The ECE Department at the University of Toronto ranks first in Canada according to **QS World University Ranking**

SASWAT **PRADHAN** | third-year ElecE undergraduate

Neuroprosthetic Systems

Working to Improve the Lives of Injured Patients

For the second consecutive year, ECE has emerged victorious against every other discipline at U of T in Ye Grande Olde Chariot Race during Godiva Week 1T1! This couldn't have been possible without the individual ECE students who put their pride and bodies on the line for ECE. Our thanks to everyone who helped out, and look forward to seeing you again next year!

Currently working under the supervision of Professor Milos R. Popovic in his laboratory focused on research in the exciting new area of neuroprosthetic systems at the University of Toronto, undergraduate electrical engineering student Saswat Pradhan is researching ways to improve the quality of life for spinal cord injury patients through a procedure called functional electrical stimulation (FES). Dr. Popovic's laboratory is located at the Lyndhurst Centre at the Toronto Rehabilitation Institute which is partly funded by the Institute of Biomaterials & Biomedical Engineering, at the University of Toronto.

"Neuroprosthetic systems are devices designed to restore or replace functions of the human nervous system when it's damaged," says Pradhan. "In the research project I'm working on, the goal is to avoid atrophy of the muscles in patients who have lost control due to injury. A device that gives off electrical impulses is used to stimulate the patient's nerves in the affected area. In essence, we are imitating the natural brain function of sending signals to the muscles, by bypassing the injured area, and stimulating the muscles transcutaneously."

While the results of this treatment have proven to be very encouraging for spinal cord injury and stroke patients, there are inherent challenges and research professors Kei Masani and Dimitry Sayenko have been working with Pradhan and his colleagues to improve the procedure. "Of course the therapy is not a perfect replica of what the brain can do," says Pradhan. "Within a few minutes of treatment, muscle fatigue can occur, so that's not ideal. We are looking at new ways to use this procedure more effectively."

For most of Pradhan's student life, math and science have been his strength and the focus of his academic interest. So when it was time to choose a university program, he knew it would be engineering. "I chose electrical and computer engineering because that's really where I see the future heading," says Pradhan. "If you look at the world today everything is becoming digital. Everything incorporates some sort of chip or device. That's what we do in our department – we design different devices that power the world today."

Pradhan says once he got adjusted to the size of the university, he began to really enjoy U of T. "I thought the campus was huge when I first came here," says Pradhan. "Now I'm just really loving the research and enjoying the program. The professors are excellent, some of the best faculty members I've ever seen or heard of."

IEEE

U of T Student Branch

The IEEE (Institute of Electrical and Electronics Engineers) is the largest professional society in the world. With more than 320,000 members in over 150 countries, the purpose of the IEEE is to build a network of professionals and students in the electronics field and to provide them with the latest technological developments through conferences and published literature.

The IEEE Student Branch at the University of Toronto is the largest student branch in Canada and holds numerous events during the year ranging from plant tours and formal dinners with companies to technical seminars and academic info sessions aimed at preparing students for the professional and academic world.

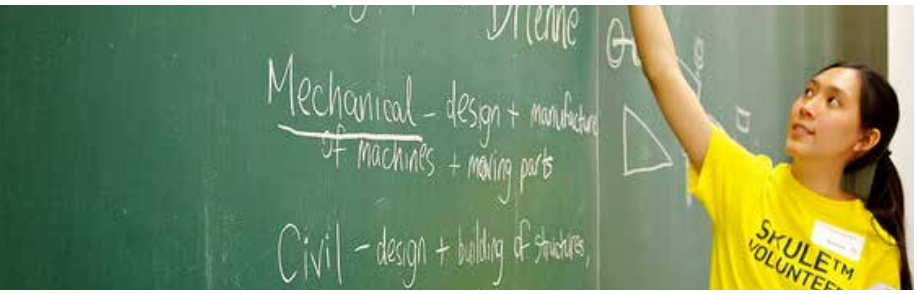
ECE PEY Placements 2000 to 2011

Year	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
Electrical	31	24	27	50	58	99	120	132	115	96	127
Computer	58	78	59	68	76	56	71	49	63	62	66

YIFEI **LIU** | third-year ElecE undergraduate

A Dream Realized

Drawing Inspiration From Peers and Professors



Mentors 03/11

Girl Guides meet with female mentors to learn first-hand about a career in engineering. One of the many student-organized initiatives at U of T.

Since Alex Yifei Liu can remember, computers have intrigued him. By the time he reached high school, he had already realized that he wanted to be a computer hardware architect in order to make a contribution, either to the industry or through research. It's this dream that led him to the University of Toronto's engineering program."There is a tremendous amount of talent and innovation in the ECE department at U of T," says Liu. "It's one of the best engineering programs in the world, and the professors are leading experts in their fields."

Currently, Liu is working with heterogeneous computing, which is a new way of implementing computations in computer hardware. Traditionally, software engineers have written computer programs that are run on standard processors such as the Intel Pentium chip. In heterogeneous computing, some parts of a program are run on a standard processor, while other parts of the same program are run on one or more alternative processors that are specifically tailored to perform well for certain types of computations such as mathematical computations. Liu's research involves the design and implementation of programs that can be run on such heterogeneous computing platforms.

"The hope is that heterogeneous computing will allow programs to run faster, as well as improve the energy-efficiency of computations, ultimately reducing cost and helping the environment at the same time," says Liu. "Right now the computer industry is combining different types of computing devices on a single chip. For example, AMD's new fusion processor combines a standard processor with a graphics processor and is designed so that the two types of processors can easily communicate and share data. Our work at U of T is particularly well-suited to target such future processors."

According to Liu, he draws his inspiration from his colleagues in the program with whom he will often toss around ideas to gain a different perspective. "They'll challenge me with a sort of hint or point out a way that I never thought of," says Liu. As well, of significant value to his academic career, is the direct access to professors. "This interaction, through regular group meetings, is very important because it allows me to learn more about what research is, and what graduate school is all about."

"By the time he reached high school, [Yifei] wanted to be a computer hardware architect in order to make a contribution, either to the industry or through research.

Undergraduate Headcount 2001 to 2010

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Full-time ECE	1,356	1,399	1,390	1,309	1,274	1,183	1,146	1,096	1,077	1,059
Part-time ECE *(includes PEY students)*	148	144	160	179	198	239	211	202	205	240
Total Head Count	**1,504**	**1,543**	**1,550**	**1,488**	**1,472**	**1,422**	**1,357**	**1,298**	**1,282**	**1,299**
% Visa	5.3%	4.5%	4.0%	5.0%	6.3%	6.6%	13.1%	16.3%	17.9%	19.0%
% Women	21.3%	20.3%	20.3%	16.6%	14.0%	12.5%	12.2%	12.9%	14.7%	15.3%

22

Are the number of lab facilities within the University of Toronto's ECE Department

#1

The ECE Department at the University of Toronto ranks number one in Canada according to Higher Education Evaluation and Accreditation Council of Taiwan **(HEEACT)**

Graduate Studies

The largest department in Canada, Edward S. Rogers Sr. Department of Electrical & Computer Engineering is ranked among the top ten in North America.

Throughout its history, the department has been witness to groundbreaking discoveries and developments in almost every area of electrical and computer engineering, at the core of which is the outstanding research conducted by graduate students in our on-campus, state-of-the-art laboratories.

Supervised by our faculty of more than 75 professors, many of which are leading experts in their fields, graduate students may choose from a wide range of research areas including biomedical engineering, communications, computer engineering, electromagnetics, electronics, energy systems, photonics, and systems control.

Degree programs offered lead to the Master of Applied Science (MASc), Master of Engineering (MEng), and Doctor of Philosophy (PhD) degrees.

The Master of Applied Science degree provides advanced study and research in a major field. This is a full-time program and requires the completion of courses, a thesis proposal, and a research thesis. The MASc is the recommended prerequisite for admission to a PhD program.

The Master of Engineering degree provides advanced training to individuals who wish to work or practice in the field of engineering. This course-based degree may be completed on a full- or part-time basis. It is not a research degree and is not the recommended prerequisite for admission to the PhD program.

The Doctor of Philosophy degree is intended for those who wish to pursue a career in fundamental or applied research. The PhD requires the completion of courses, a field comprehensive examination, a thesis proposal, and a research thesis. Applicants to the PhD must hold the equivalent of an MASc degree with thesis.

KARLA **KVATERNIK** third-year ElecE PhD candidate | Systems

Mathematical Theory

Aesthetically Generous, Yet Powerful and Practical

The Institute of Electrical and Electronics Engineers (IEEE) is the largest professional society in the world. With more than 320,000 members in over 150 countries, the IEEE creates a network of professionals and students in the electronics field and provides them with the latest technological developments through conferences and published literature. The IEEE Student Branch at the University of Toronto is the largest student branch in Canada.

It may not seem that mathematics shares much with art, but for Karla Kvaternik, a second-year PhD candidate with the Electrical & Computer Engineering at U of T, mathematical theory can often embody poetic qualities. "I can't help but find the crispness, the crystal clarity of a rigorous mathematical argument to be beautiful," says Kvaternik.

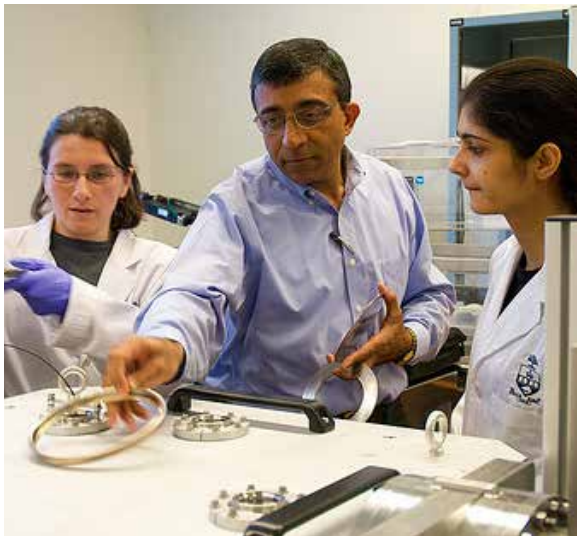
Although she appreciates the aesthetic qualities of theory, she is equally moved by its powerful potential to address important practical problems. It is this potential that motivates her work in the Systems & Control Group at U of T.

Currently she is developing a theoretical framework within which a set of agents cooperate to accomplish a collective task in a distributed manner. "Many of today's large-scale engineered systems such as the Internet for example, are so complicated that central control is infeasible," says Kvaternik. "The development of decentralized control and optimization strategies, and the prospect of introducing theoretical insights that could have implications for a diverse set of engineering applications is very exciting." Her work is expected to have applications in the design of local algorithms for large-scale networked systems such as power grids and communication networks.

Dedicated to the discovery of fundamental theoretical principles, Kvaternik is concerned about what seem to be recent funding trends that almost exclusively emphasize the development of specific, immediate application areas. Although she feels that the development of specific technologies is crucial to our economy, she worries that diminishing funding for fundamental research will have negative long-term effects. "Historically it's been the foundational theoretical innovations that have enabled technological revolutions," says Kvaternik.

Recently, Kvaternik published what appears to be the first proof of practical asymptotic stability of a certain distributed multi-agent optimization scheme. She has derived explicit bounds on the closeness of agents' trajectories to the collective optimum, and characterized those bounds in terms of important problem parameters. "My approach is more direct than that taken by previous authors," says Kvaternik. "The thing I like most about this result is that it is clean and simple; to my personal satisfaction, I thus consider it to have some artistic merit."

"Historically it's been the foundational theoretical innovations that have enabled technological revolutions," says Kvaternik.



Degree Programs

ECE offers programs of study leading to the Master of Applied Science (MASc), Master of Engineering (MEng), and Doctor of Philosophy (PhD) degrees. Please visit www.ece.utoronto.ca for detailed program requirements.

The Master of Applied Science (MASc) provides advanced study and research in a major field. The MASc is a full-time program and requires the completion of courses, a thesis proposal, and a research thesis. The MASc is the recommended prerequisite for admission to a PhD program.

The Master of Engineering (MEng) provides advanced training to individuals who wish to work or practice in the field of engineering. The MEng is a course-based degree and may be completed on a full- or part-time basis. The MEng is not a research degree and is not the recommended prerequisite for admission to the PhD program.

The Doctor of Philosophy (PhD) is intended for exceptional individuals who wish to pursue a career in fundamental or applied research. The PhD requires the completion of courses, a field comprehensive examination, a thesis proposal, and a research thesis. Applicants to the PhD must hold the equivalent of an MASc degree with thesis.

9,000+

U of T ECE Alumni Worldwide

242

The number of degrees granted in 2009-10 within the Edward S. Rogers Sr. Department of Electrical & Computer Engineering.

ERIC **ZHU** third-year ElecE PhD student | Photonics

Beyond Fundamental Science

Groundbreaking Fiber-optic Technologies Brings Employment to Entanglement

6

The number of buildings that comprise the ECE infrastructure.

Working in one of the world's leading laboratories for Emerging Fiber-optic Technologies (EFOT) at the University of Toronto, PhD Candidate Eric Zhu focuses his research on the utilization of quantum physics to develop secure, unbreakable encryption through the fiber-based generation and distribution of entangled photons.

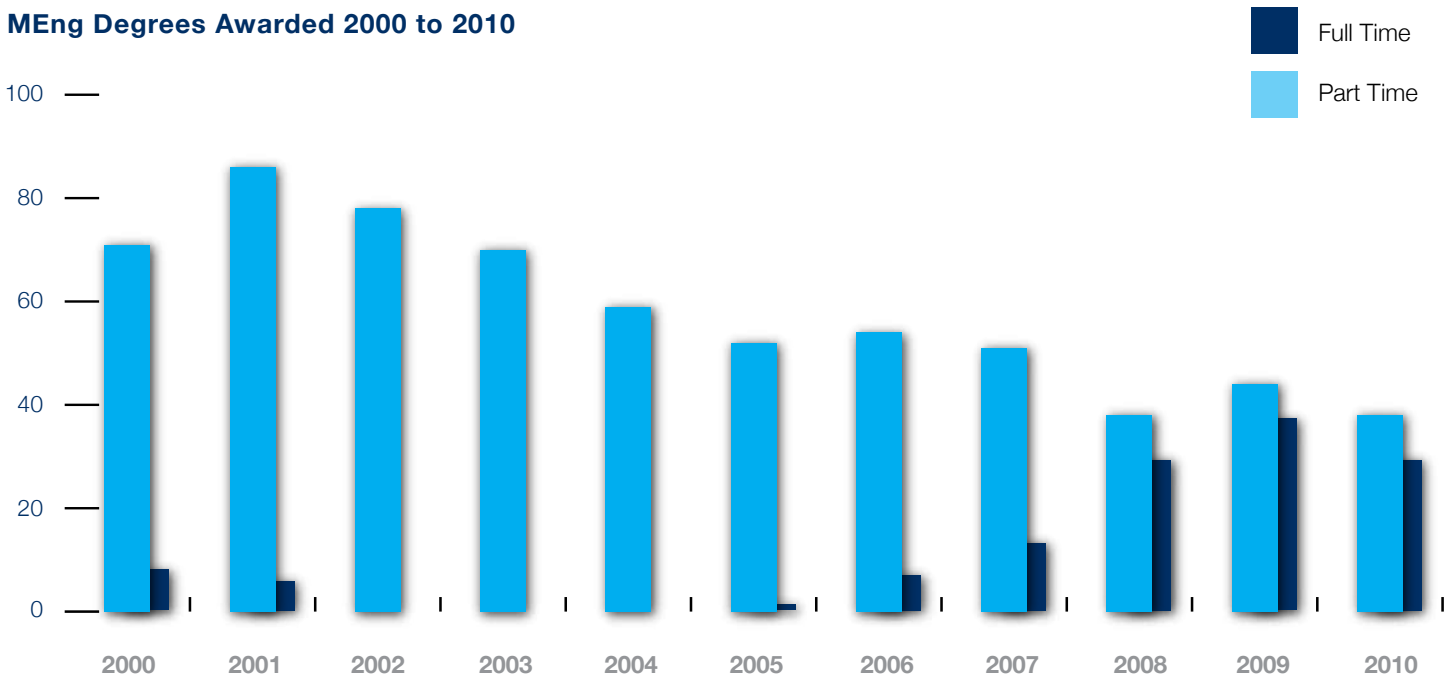
"Developing a reliable fiber-based source of entangled photons for quantum key distribution is my main focus," says Zhu. "Quantum key distribution allows for two parties to share a secret key with which they can then send unbreakable encrypted messages to each other. Entangled photons act as the bits that are distributed for this key. The physics of entanglement makes the key unconditionally secure, meaning that any attempt to eavesdrop will be caught. Right now, methods of generating entangled photons are too impractical or expensive to be used in real-world applications. My goal is to find a way to make a simple and compact source of entangled photons."

Recently, Zhu and his collaborators demonstrated the generation of polarization-entangled photons in a device known as poled fiber. This work was presented as a post-deadline paper at the Specialty Optical Fiber conference in Toronto earlier this summer.

Headed by Professor Li Qian, Zhu and his colleagues in the EFOT group aim to advance the closely related fields of quantum optics and quantum information. While it appears to be purely fundamental science, this realm of study has real commercial viability. Applications for this research include a wide array of practical uses ranging from secure communication to optical sensing for biomedical purposes. "If you replace the light source in optical-coherence tomography, a technique that's often used to image the human eye, with entangled photons, you get much better resolution," says Zhu.

In fact, Zhu equates the recent advances in the areas of quantum optics and quantum communications to that of the invention of the laser. "At the time of its invention the laser was not really appreciated," says Zhu. "Now of course we find lasers in just about everything. I see quantum optics and quantum communication as being just as important. It's the technology of the future. It will have great benefits for humanity – whether providing for unconditional security in communication, or superior optical sensing for the biomedical field. It promises to change our world for the better."

MEng Degrees Awarded 2000 to 2010



05/02/11

Professor Hum received the Gordon R. Slemon Award for his excellence in teaching design within ECE.

DI **NIU** fourth-year ElecE PhD candidate | Computer Engineering

Computer Networking Today

Smart Algorithms Based on Data Mining

13th

The ECE Department at the University of Toronto ranks 13th internationally according to **QS World University** Ranking

According to University of Toronto, Department of Electrical and Computer Engineering PhD Candidate Di Niu, the use of math to interpret real-world systems, and to harvest hidden value from operational data, is the essence of his inspiration.

"Because nowadays software and hardware have become a commodity, data is really the way to go in large-scale computer networking," says Niu. "Smart algorithms based on data."

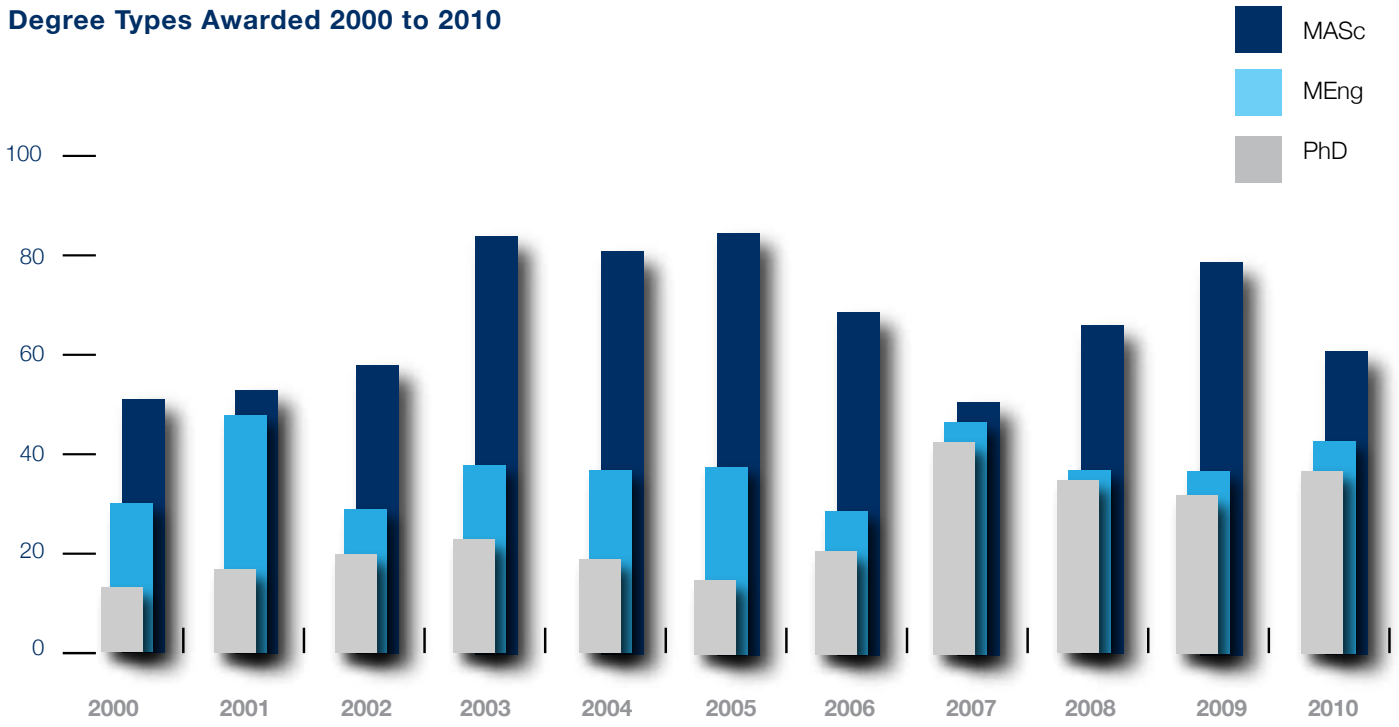
Niu is currently working on traffic prediction and management of video-on-demand (VoD) systems, in order to learn the dependencies among network events, infer demands and different performance metrics, and optimize the user experience while minimizing server resource consumption based on network monitoring, using statistical and machine learning.

"Through this research we are able to allocate and configure server resources wisely and optimally based on learned rules and predictions," says Niu. "The benefit to this is that we can save the cost of a VoD company on capacity investment while quantitatively confining the risk of under-provision in the event of excessive demands. We can even predict the variability and correlation of the bandwidth demands of different user groups, and statistically pack the workloads into servers or data centres in the cloud. As well, we are able to forecast network-wise performance degradation by monitoring signals exhibited from network events."

This data-mining-based technology also inspires the way that bandwidth resources should be priced on today's Internet. The unit bandwidth price of a VoD company depends on the anticipated correlation between the company's traffic and the market demand. Based on Niu's theory, a VoD company with demand negatively correlated to the market serves as a risk-neutralizer and pays much less than most other companies.

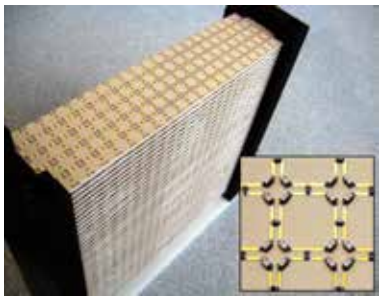
"My goal is to incorporate intelligent algorithms, based on data mining, into large-scale networking systems in order to have a significant impact on performance," says Niu. "It's a very exciting and dynamic area of study."

Degree Types Awarded 2000 to 2010



177+

Inventions produced by the ECE Department at the University of Toronto



The first three-dimemensional negative-index superlens using transmission-line metamaterials **(Iyer and Eleftheriades, 2008)**

JONATHAN **LAU** PhD candidate ElecE | successfully completed and will be conferred June 2012

Passion Meets Practicality at U of T

ECE Student Takes NSERC André Hamer Postgraduate Prize
Audrey Kertesz, ElecE MASc candidate

19th

The ECE Department at the University of Toronto ranks 19th internationally according to Higher Education Evaluation and Accreditation Council of Taiwan **(HEEACT)**

Devoted to the design and development of reconfigurable antennas, PhD candidate Jonathan Lau is working with a team in the Electromagnetics Group at the University of Toronto's Department of Electrical and Computer Engineering, under the supervision of Professor Sean Hum.

"What got me excited about the topic was the passion my supervisor has for electrical engineering" says Lau. "That and the fact that the topic is a mix of fundamental physics and applications. So it's tangible and that was important to me. It's hard to connect with imaginary textbook scenarios."

Under Hum's supervision, Lau is currently working on a lens for microwave frequencies that can be electronically tuned. "So the goal is to be able to tune this lens without having to mechanically change it," says Lau. "Electronic components tend to be more reliable than mechanical systems that require a lot of maintenance and take up a lot of space."

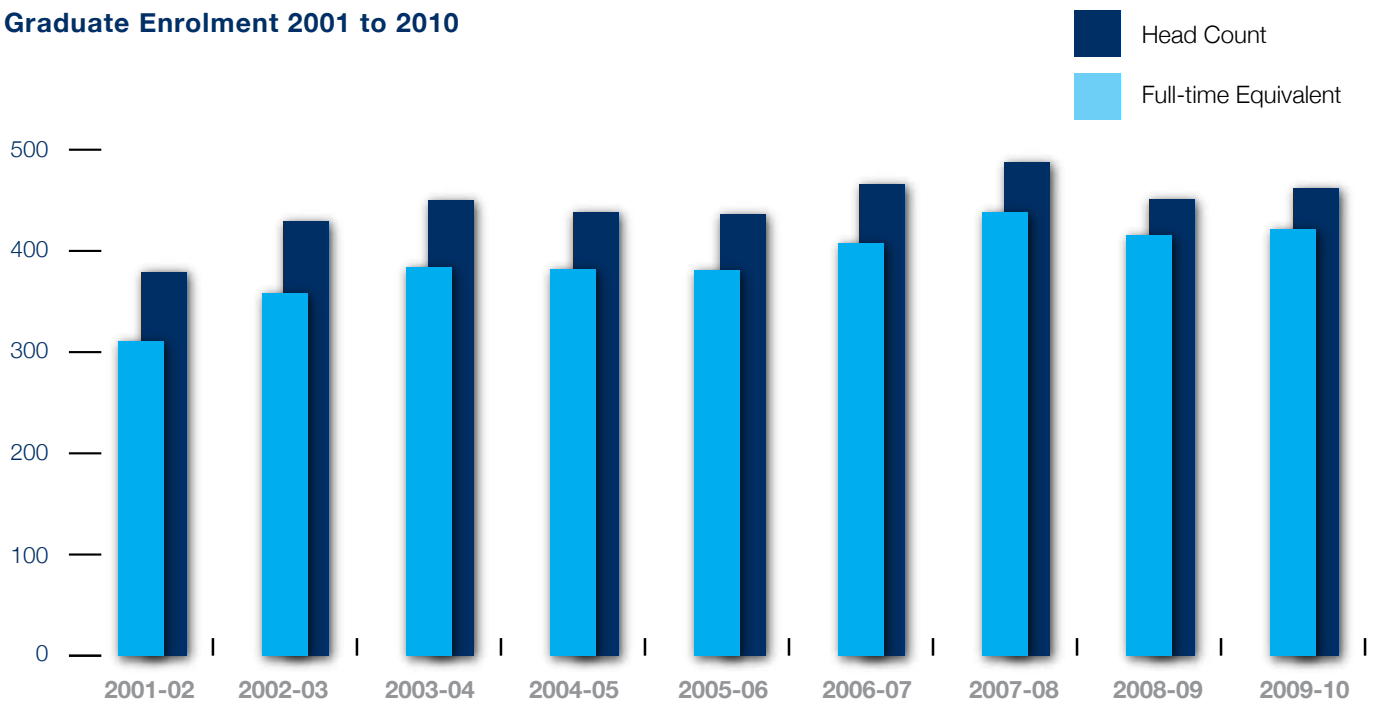
Practical applications for this technology include radar whereby mechanically moving parts would be replaced with electronic components reducing space, hardware and costs.

"Terrestrial communications is another application area," says Lau. "A lens could be fit onto the roof of a car so you could track a satellite while you're driving around. You would be able to get a good signal without a parabolic dish on top of your car pointing at a satellite."

At the University of Toronto, Lau and his colleagues work in an in-house laboratory, where models are built and tested under the supervision of Professor Hum. "There's a really great benefit to not having to send out our designs for fabrication," says Lau. "We build them right here on campus so there is a huge learning opportunity in that fabrication process that I might not have otherwise. We learn what is needed to make it from scratch. If you're just designing it from a theoretical standpoint, you don't think of the practical challenges that may exist."

When asked about his experiences at the University of Toronto, Lau says, "I've learned that there will always be more research. For me the real value from my learning here is the mentoring I've received from my supervisor, and how I've learned to mentor in-turn. This, and the relationships I've developed with my colleagues is what I truly value."

Graduate Enrolment 2001 to 2010



Discovery Grants CREATE Programs

The NSERC Collaborative Research and Training Experience (CREATE) Program supports the professional development of students and postdoctoral fellows through training programs that encourage collaborative and integrative approaches while addressing significant scientific challenges associated with Canada's research priorities. In 2009–2010, our Faculty was awarded almost $5 million from NSERC CREATE to fund three such programs over the next six years.

Research

Researchers at U of T continually strive to make discoveries that will impact industry and benefit society. We do so by tackling challenging fundamental and applied problems; working across and beyond disciplinary boundaries; partnering with industry, government, and other academic institutions globally; and training the research leaders of tomorrow.

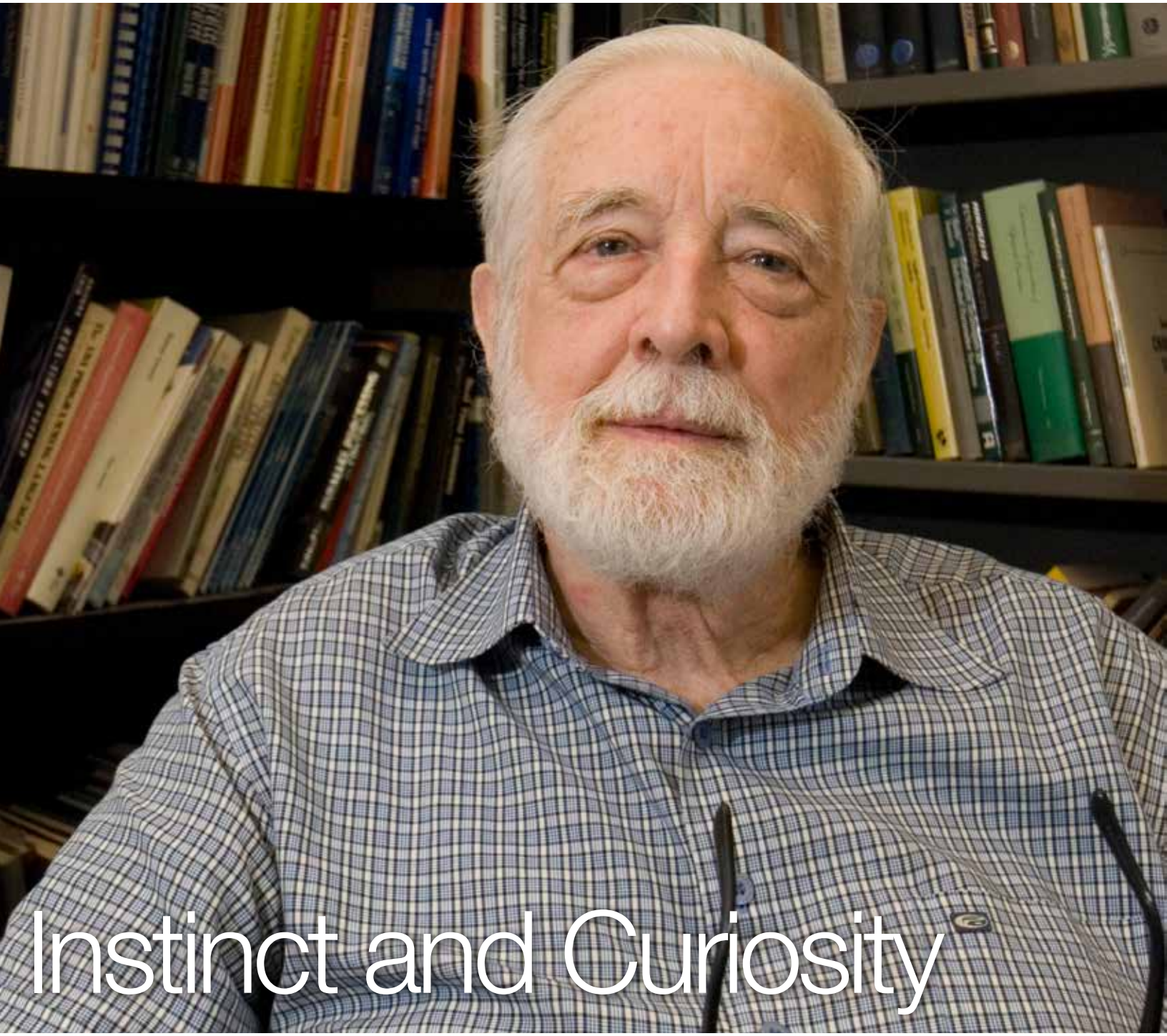
U of T Engineering's research is world-renowned. Most recently, the Times Higher Education World University Rankings placed engineering at U of T 13th worldwide. Our Faculty has maintained its position as Canada's top engineering school and one of the very best in the world.

We are particularly proud of our ability to identify areas of strategic importance to global industry and society, and pull together major efforts to address these important problems. Initiatives include:

- Our focus on the SmartGrid, the electrical grid that seamlessly incorporates renewables such as wind and solar, and uses the latest technology to improve the efficiency, importance, reliability, economics, and sustainability of electricity services. This initiative leverages our strengths in energy systems, systems control, algorithms, optimization, security, communications, networking, electronics, and photonics;
- Our emphasis on the technological, economic, and social dimensions of security and privacy in the mobile ecosystem and the emerging cloud;
- Our strategy to bring electrical and computer engineering expertise to important problems in biomedical engineering and medical devices, uniting expertise in sensors and stimuli, low-noise and low-power electronics, systems-on-chip, signal processing, systems control, optoelectronics, and computing.

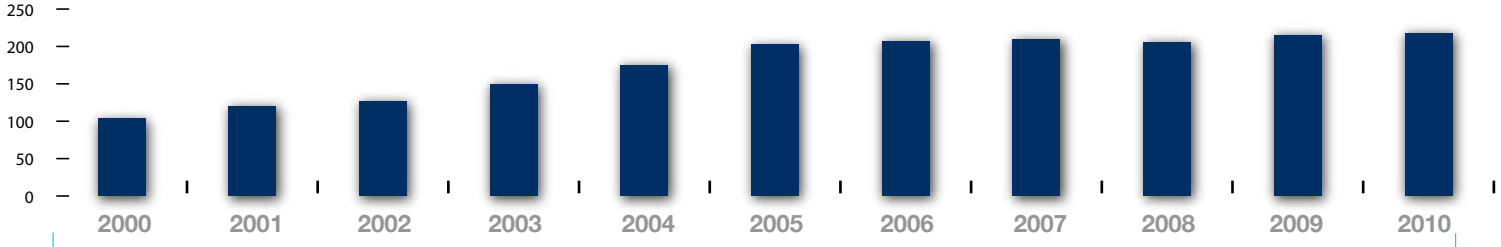
Our researchers partner with over 60 industry leaders worldwide, to stimulate, enable, and translate our research into application. We are extremely proud of the over two-dozen companies incubated right here in U of T engineering in the last decade alone. All of these companies, both large and small, are integral to our success.

ECE continues to seek unique ways to make a global impact, benefiting Canada and the world through advances that improve quality of life.



Instinct and Curiosity

Total Enrolment for PhD 2000 to 2010



For Dr. W. Murray Wonham, research in underlying theoretical principles in control science and engineering, has been a lifelong passion that has often resulted in unexpected applications. Case in point – a paper he wrote in 1964 on stochastic nonlinear filtering. While admittedly he wrote the paper, "just for the fun of it," it led to what is now known as the Wonham filter which plays a key role in quantum optics today.

"I follow the slogan: If you do decent theoretical work, the applications will take care of themselves. Don't worry about it," says Wonham whose advice for graduate students is, "Follow your curiosity, trust your instincts and don't worry about what the rest of the world might think."

Since 1956, Wonham's area of study has been the engineering and applied mathematics area also known as automatic control, and sometimes referred to as engineering cybernetics – a term coined by Chinese scientist Qian Xuesen.

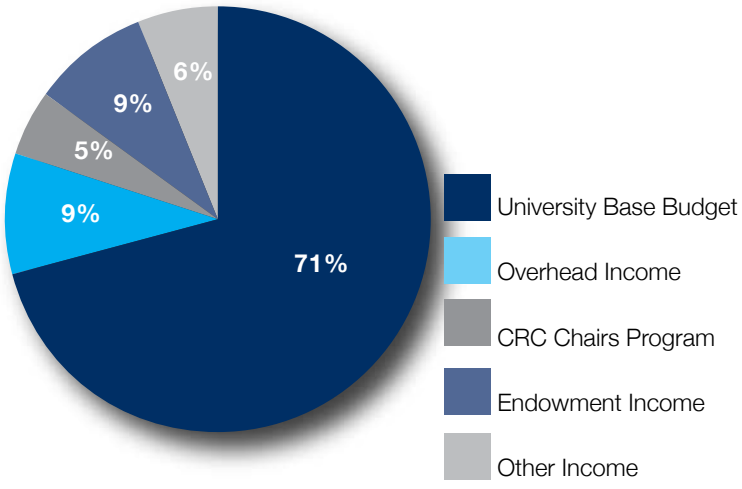
Over the years, the research Wonham and his team of graduate students have conducted has led to a number of applications such as the broadly accepted approach to linear controller design known as 'pole assignment', now incorporated in commercial software packages, as well as contributions to decoherence in quantum control, and to the design of nonlinear tracking systems. More recently, their results on supervisory control of discrete-event systems have been applied to the design of a telephone directory assistance call center and to an MRI scanner patient support system.

"We study the science and technology of feedback systems," says Wonham. "Such systems are designed to maintain some critical variable or variables within an acceptable range. For instance, an aircraft's automatic pilot corrects for wind disturbances that might otherwise drive the plane off course, perhaps disastrously."

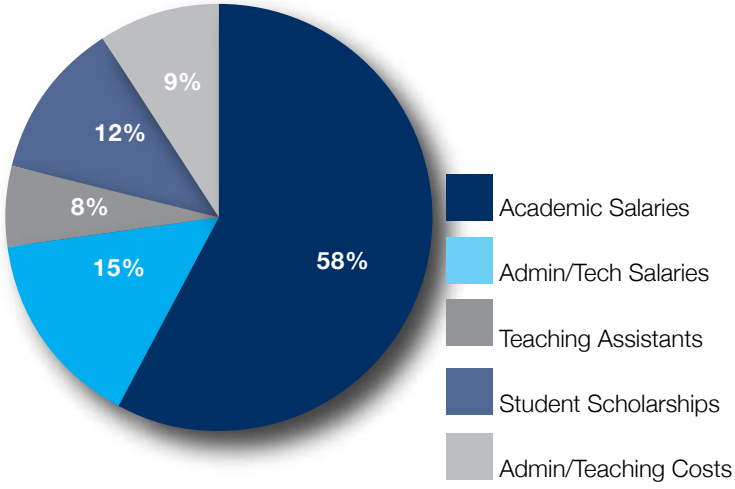
As well, the Wonham team is working on the pushbutton system in a modern automobile which, although randomly activated by the motorist, should be designed never to commit a logical error like hang-up or blocking. Such discrete-event systems and their control call for new and specialized techniques at the interface of control theory and computer science. "A major challenge is that these systems can be very large and complex," says Wonham. "For instance, the automobile pushbutton system may potentially enter many millions of different internal states or logical configurations. This may lead to almost overwhelming requirements on the computing power for control engineering design."

As to the contribution his lifetime of research has made, Wonham says simply, "I've always done it to gratify my personal curiosity and that of my students. Of course I'm always pleased when it stimulates others' research or helps with someone's application."

Total Operating Income 2010-2011 $24.5 million



Total Expenses 2010-2011 $24.5 million



#1

The ECE Department at the University of Toronto ranks #1 in citations in Canada according to **Thomson Reuters**

CRISTIANA **AMZA** Associate Professor | Computer Engineering Research Group

Chorus

e-commerce Meets e-health

28

spin-off companies sparked by ECE members since 1950

2010 • Arda Power Inc., FOTA Technologies **2009** • Chip Care Corp., Peraso Technologies Inc. **2008** • Arch Power Inc., Incise Photonics Inc., Simple Systems Inc. **2007** • Inometrix Inc., Modiface Inc., Viewgenie Inc. **2006** • InVisage Technologies Inc., Metabacus, Vennsa Technologies Inc. **2003** • ArchES Computing Systems Corp. **1999** • Accelight Networks Inc., Soma Networks **1998** • Right Track CAD Corp., Snowbush Microelectronics **1996** • OANDA Corp. **1994** • Trantek Power **1993** • SmartSpeaker Corp. **1992** • Condata Technologies Ltd., Gao Research & Consulting Ltd. **1985** • Katosizer Industries Ltd. **1980** • Almax Ltd., SatCon Power Systems Canada Ltd. **1968** • Electrical Engineering Consolidated Ltd. **1951** • Sinclair Technologies Inc.

The driving force behind Dr. Cristiana Amza's research, is her lifelong fascination with complex distributed systems, and the crucial problem of achieving coherent self-organization within such systems.

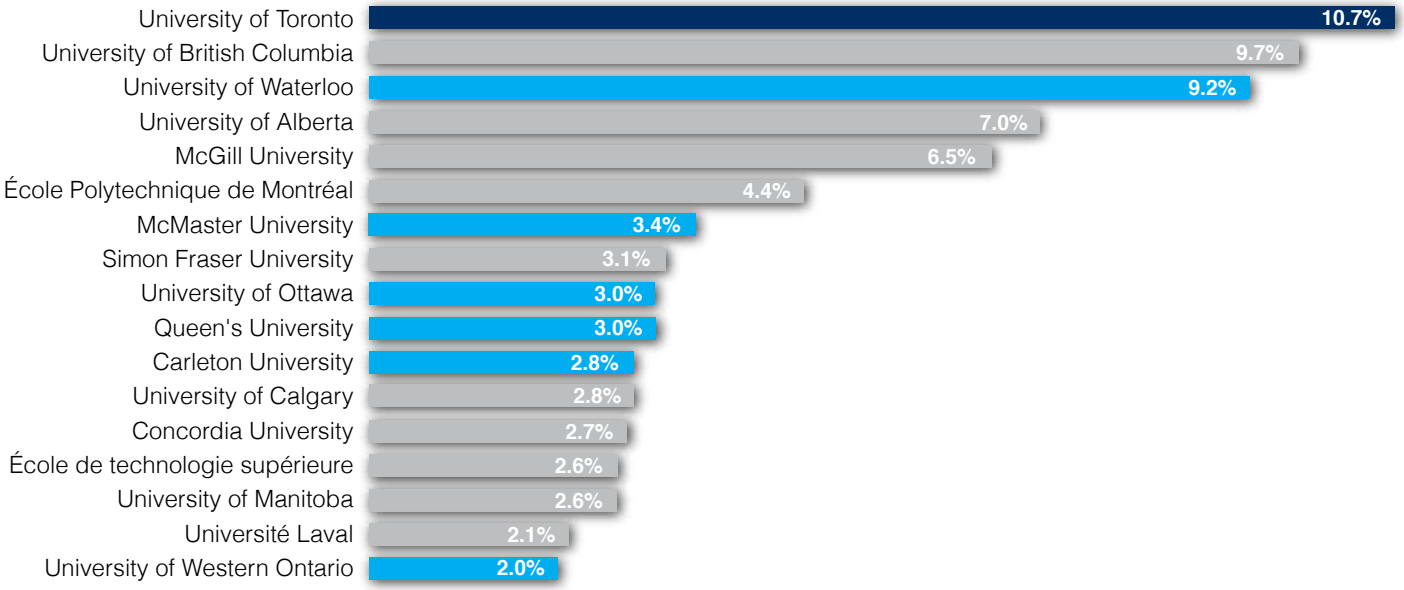
"I have always been inspired by human enterprises and systems, whether it be large groups of people having to cooperate with each other, or the human organism itself, and how the parts of the whole work together coherently to achieve a common goal," says Amza.

Amza and her team of graduate students have successfully built a state-of-the-art self-organizing Cloud infrastructure, called Chorus. Chorus is a networked computer platform providing web-based services and maintaining significant amounts of data in a consistent fashion. Chorus currently offers more flexible and customizable Cloud access for users than Amazon; it also offers a set of novel algorithms, languages and performance modeling and diagnosis tools towards cost-effective self-organization. While Chorus has its roots in hosting complex workloads for e-commerce and gaming, Amza's current goal is to extend its customization capabilities toward hosting biomedical images and data analytics for them.

"The challenge for medical experts is cross-correlating image data of many patients, for example brain MRIs, because the data is so massive," says Amza. "Our hope is to be able to host large amounts of biomedical data and thus enable medical staff from different communities to share knowledge. As well, there is a significant opportunity for us to contribute by utilizing our engineering skills and tools to extract patterns, trends, or uncover abnormalities and semantic correlations in e-health data."

Amza is also passionate about shaping the young minds of her students, and finding the right part for each participant. "This project has had such a wide range of applications and challenges, that it continually satisfies the many skill sets and interests of my students. Now that our Cloud infrastructure project has reached maturity, and is fully operational, we can focus on applications that can have a huge impact on society. It's an extremely dynamic, interdisciplinary learning environment for all of us."

Canadian Peer Universities vs. University of Toronto Share of NSERC Funding for Electrical and Electronic Engineering 2011 (Grant Year = April to March)



2

Awards given in 2011 to our department by the **IEEE**

Professor Edward Davison
Awarded the 2010 Canada Outstanding Engineer Award.

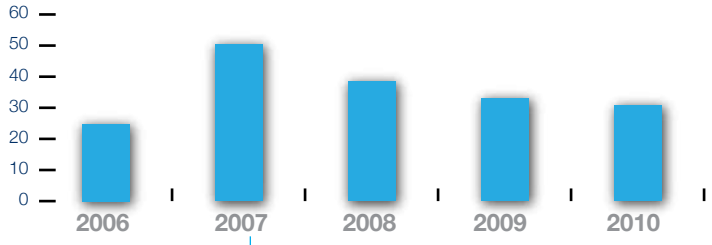
Professor Edward Sargent
Named Fellow of the IEEE for contributions to colloidal quantum dot optoelectronic devices.

REZA **IRAVANI** Professor | Energy Systems Research Group | holder of the L. Lau Chair

Exploring New Frontiers

ECE Invention Disclosures 2006 to 2010

The University's Invention Policy requires inventors to completely disclose their inventions. In most cases, rights to their inventions are then jointly owned by the University and the inventor.



In response to the rapidly increasing global demand for electrical energy, Professor Reza Iravani and his group of graduate students and research associates at the University of Toronto, are pioneering the development of some of the world's most leading-edge control, protection, and energy management strategies for integrating microgrids and supergrids in the electric power system of the future.

"Our core area of research is in electrical energy systems," says Iravani. "The central idea behind our work is to use power electronics and information and communication technologies for the integration of renewable and alternative energy resources in the electric power grid. The challenge is to find a way to generate, transmit, and distribute electrical energy to meet the increasing demand while simultaneously minimizing the impact on the environment."

"The challenge is to find a way to generate, transmit, and distribute electrical energy to meet the increasing demand while simultaneously minimizing the impact on the environment."

Iravani and his team are investigating solutions that will utilize renewable resources such as wind and solar, in combination with conventional power generation such as hydro, in order to maximize the use of the existing infrastructure and to guarantee sound and reliable operation of the electric grid.

"Due to the inherent intermittent nature of solar and wind power, we have to develop control and operational strategies so that the power grid can mitigate the impact of intermittency and meet the changing demand for electric power," says Iravani. Our challenge is to maximize utilization of renewable power sources and the overall power system efficiency while minimizing the environmental impacts.

"This research is important since electrical energy will be the main and dominant form of energy consumption in the future," says Iravani. "If we are successful with our approach, it will have a major effect in terms of how the next generation electric power systems evolve and operate."

Research Funding from 2005 to 2010

	2005	2006	2007	2008	2009	2010
Federal	$ 7,636,072	$ 10,457,844	$ 8,705,671	$ 8,449,358	$ 7,966,886	$ 8,820,445
Provincial	$ 3,757,117	$ 5,540,138	$ 3,703,586	$ 3,955,389	$ 4,862,973	$ 3,555,157
Industry	$ 2,455,661	$ 2,266,096	$ 3,363,559	$ 2,940,516	$ 2,814,325	$ 1,399,705
Other	$ 713,252	$ 575,955	$ 957,306	$ 813,281	$ 2,805,428	$ 3,076,194
Total	**$ 14,562,102**	**$ 18,840,033**	**$ 16,730,122**	**$ 16,158,544**	**$ 18,449,612**	**$ 16,851,501**

Best Paper

Professor Brendan Frey — Best Paper Award: Group's paper on "Deciphering the Splicing Code" named as a "Landmark paper" by Nature Biotechnology, January 2011

FRANK **KSCHISCHANG** Professor | Communications Research Group and Canada Research Chair in Communication Algorithms

Solving Engineering Problems

60

Our researchers partner with over 60 industry leaders worldwide, to stimulate, enable, and translate our research into applications.

With a focus on the area of digital communications, Professor Frank Kschischang and his team of ECE graduate students are using complex mathematical ideas to solve problems of practical engineering relevance.

"It's a fascinating interplay of beautiful mathematical concepts, some dating back to the 19th century, with the latest engineering ideas about design," says Kschischang. "My specific interest is in coding theory, or in finding ways to encode messages into cleverly-chosen sets of patterns – codes. These codes can be exploited at the receiver to decode the message, even when the received pattern has been distorted during transmission and corrupted by noise."

The subject is grounded in the field of information theory, which dates back to the seminal work of Claude E. Shannon in the 1940s, and which establishes fundamental limits on coding efficiency. Coding theorists strive to construct codes and decoders that can approach Shannon's fundamental limits, while satisfying practical engineering constraints. Remarkably, only in the last decade have certain families of codes been discovered that can achieve both goals simultaneously.

"Certain classes of codes are based on quite interesting mathematical structures," says Kschischang. "For example, my collaborator Ralf Koetter and I recently devised a new family of codes based on the evaluation of so-called linearized polynomials over a finite field, resulting in packings of points in so-called finite-field Grassmannians. We are confident that this finding may turn out to be useful in the design of new packet-transmission protocols for the Internet."

Because error-control coding schemes are needed in almost every data transmission link, Kschischang's work has many practical applications, ranging from wired channels, to wireless channels, to optical channels. "Decoding algorithms typically need to work quickly and so are often implemented in hardware," says Kschischang. "This has resulted in fruitful collaborations with Professors Glenn Gulak and Tony Chan Carusone on the design of high-speed decoder chips." A recent project, in collaboration with the federal Communications Research Centre in Ottawa and an Ottawa/Sunnyvale-based chip-design company, resulted in a family of error-correcting codes that establishes a new state-of-the-art for 100 Gb/s optical transport networks. These are optical networks in which the bits are encoded, transmitted, and decoded at the astonishing rate of 100 billion bits per second.

"This is a fascinating field of study," says Kschischang. "As communication systems continue to develop, there will be an ongoing need to design reliable and efficient information transmission schemes for a wide variety of channels. No doubt, there will be many future opportunities, and that's very exciting."

Publications Per Researcher

(Published papers only - divided by the number of professors listing published papers).

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Researchers	55	59	64	63	63	64	71	75	76
Publications	354	437	493	403	486	513	541	529	510
Publications Per Researcher	6.4	7.4	7.7	6.4	7.7	8.0	7.6	7.1	6.7

Best Paper

Professor George Eleftheriades — Best Paper Award: L. Markley, G. V. Eleftheriades, "Experimental verification of two-dimensional subwavelength-focused imaging using a near-field probe," Metamaterials, Karlsruhe, Germany, September, 2010.

STEWART **AITCHISON** Professor | Photonics Research Group and Vice-Dean, Research, Faculty of Applied Science & Engineering

Blazing New Trails To Discovery

Three ECE Students Among *The Next 36*

The Next 36 aims to transform the country's most promising undergraduates into Canada's top entrepreneurs through a mix of team work, business planning, the startup of a mobile-app business, mentoring, and three months of intensive entrepreneurship instruction.

U of T is a founding partner in *The Next 36*, launched last year by a group of business leaders, academics and entrepreneurs.

Blending leading-edge research in micro/nano fabrication and optics with innovative ideas that have real applications is leading Professor Stewart Aitchison and his team of graduate students to new areas of discovery from bio-medicine to banking security.

"We work with what is called enabling technologies in that they enable new areas of research," says Aitchison. "We can see applications for everything from food safety through to solar energy to bio fuels. There are whole ranges of new areas where those technologies and applications can serve humanity. It's as if we have a set of building blocks that can be put together to solve problems. That's very inspiring, and rewarding for us."

Because of the inter-disciplinary nature of their research, Aitchison's team is co-supervised by his colleagues in other areas of engineering studies such as photonics, electromagnetics and chemistry.

"Engineering has changed in that it's more problem-oriented now – not just physics or engineering or my students working in isolation on something that may or may not have some application down the road. We tend to work as part of a larger team looking at solving bigger scale problems," says Aitchison.

For example, Aitchison and his team are working with a network that is looking at plasmonics. That is the interaction of light with the electrons on the surface of metal where by a high electric field enables the sensing of miniscule volumes or quantities of material such as molecules or cells. The target of this nano technology is the early detection of leukemia and lung cancer.

Recently a member of Aitchison's team developed a breakthrough on-chip HIV test that is disposable and costs less than a dollar per unit. The test is particularly suitable for developing countries where there is little access to healthcare and HIV testing is expensive.

Another area of interest for Aitchison and his team is the development of devices for information and communications technology, or ICT. "We use a non-linear interaction to cause the frequency, or wavelength of a light beam to change," says Aitchison. "It's a technology that has applications in many areas such as gas sensing, agile optical networks or biomedical monitoring. Our approach is to develop an on-chip optical source, that's very small and cost efficient compared to the current bench top devices available today. It's a very exciting research area where the applications are virtually endless."

Making a Difference

When PhD candidate James Dou (ECE) was a Master's student, he couldn't have imagined that exploring lab-on-a-chip technology would lead him to addressing a dire need in developing countries.

"I was hoping to develop something that could improve human health around the world, but I didn't realize that we could design something that could make such a social impact on HIV patients," said Dou.

Under the guidance of Professor Stewart Aitchison, Vice-Dean, Research, he developed an affordable and efficient lab-on-a-chip for HIV monitoring in developing countries.

Today's HIV blood-testing devices, called a flow cytometer, can cost up to $100,000. Dou's patented lab-on-a-chip costs $5,000 to $10,000, and provides results in mere minutes.

The lab-on-chip has already gained interest from organizations in Malawi and Thailand, as well as AIDS Healthcare Foundation, the biggest AIDS-related charity organization in the U.S. With additional funding, the team plans to shrink its current prototype from a size of a breadbox to a handheld version. Their goal is to deploy 100 devices to organizations around the world in 2012.

Dou and his company ChipCare Corp., hope to then develop a similar device to monitor malaria and tuberculosis, among other diseases.

2011 Engineering Alumni Medal

Professor Emeritus **Kenneth Carless (K.C.) Smith** receives the Engineering Alumni Medal.
K.C. has contributed substantially to the field of electrical and computer engineering. Not only is he the co-author of the world's best-selling electronics-circuits text, he is also a distinguished Institute of Electrical and Electronics Engineers (IEEE) member, mentor to young academics — nationally and internationally — and innovator of critical technologies used in the areas of computers and health care.

Research Directory

Each research category has a corresponding colour. Search by colour to locate the lead researcher and then refer to the alphabetical listing that follows.

Communications

Communications Equipment
Communication Systems and Services: Planning, Organization, Services
Communications Technologies: Satellites, Radar

Computers

Computer Communications
Computer Software/Hardware

Engineering/Sciences

Aerospace
Electrical and Electronic Machinery and Equipment, including Computer Hardware
Ground: Road and Rail
Instrumentation Technology
Materials Sciences
Mathematical Sciences
Physical Sciences

Life Sciences

Advancement of Knowledge
Biomedical Engineering
Human Health
Life Sciences
Life Sciences, including Biotechnology
Medical Equipment and Apparatus

Information Technology

Information and Communications Services
Information, Computer and Communication Technologies
Information Systems and Technology

Energy

Energy Resources: Production, Exploration, Processing, Distribution and Use
Energy Storage and Conversion
Energy Efficiency
Alternative Energy Resources
Electrical Energy

Quick-Search by Colour-Coded Listing

Communications

• Communication Systems and Services: Planning, Organization, Services
• Communications Equipment • Communications Technologies: Satellites, Radar, etc.

Life Sciences

• Biomedical Engineering • Human Health • Life Sciences • Life Sciences, including Biotechnology

Computers

• Computer Communications • Computer Software/Hardware

Quick-Search by Colour-Coded Listing

Engineering/Sciences

- Aerospace
- Electrical and Electronic Machinery
- Ground: Road and Rail
- Instrumentation Technology and Equipment, Computer Hardware
- Materials Sciences
- Mathematical Sciences
- Physical Sciences

Information Technology

- Information and Communications Services
- Information, Computer and Communication Technologies
- Information Systems and Technology
- Information Technology

Information Technology

- Information and Communications Services
- Information, Computer and Communication Technologies
- Information Systems and Technology
- Information Technology

Information Technology

- Information and Communications Services
- Information, Computer and Communication Technologies
- Information Systems and Technology
- Information Technology

Energy

- Alternative Energy Resources
- Electrical Energy
- Energy Efficiency
- Energy Resources: Production, Exploration, Processing
- Energy Storage and Conversion

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Aarabi, Parham — Internet Video, Audio, and Image Processing

www.apl.utoronto.ca

In the past few years, we have seen an exponential increase in the amount of videos and images that have been recorded and placed on the internet. Smart mobile phones (Blackberry, iPhone, etc.) now enable seamless recording, transmission, and sharing of videos in near-real-time. Whereas just two decades ago there were a few video broadcasters and publishers, today there are millions, if not billions, of video broadcasters and online publishers. With all this visual content, how do we find what we want? How to we categorize the content? How do we develop search engines that bring order to visual content just as text-based search engines (Google, Bing, etc.) brought order to the textual web?

With videos and images, there are of course certain tags manually entered by users that define and categorize the video. However, the 10-15 words that usually accompany a video or image can hardly describe the entire content of the video, and at best help to generally categorize the video or mention a specific note regarding it. In fact, the vast amount of visual information online is untagged and inadequately described, and as a result is difficult if not impossible to find.

Finding all images and videos is but one problem. The appropriate categorization of visual content can result in more appropriate contextual advertisements (hence, leading to better monetization of visual web/mobile sites). It can help in finding duplicate versions of the same video or image (which is useful for copyright detection among other applications). It can also help identify the important parts of a video segment, or the most content-filled section of an image (which are useful for compressing videos and intelligently resizing images for mobile devices). The more information we can extractautomatically from images and videos, the more we can address a range of practical problems including better search, better (and more contextual) monetization, copyright detection, video compression, intelligent image resizing, as well as a broad range of other important applications.

Although different approaches for visual information understanding have been explored in the past, one of the most promising directions is by utilizing Extremely Large Datasets (ELD). ELDs allow for greater accuracy in extracting information from images and videos, but in return require substantially greater number of computations for each image processed. Examples of successful ELD systems include the Tiny Images image categorization system which used a database of 80 million tiny images for image classification, or the Tiny Videos framework which utilized a large library of videos for video classification. In both cases, the images and videos were resized to a 'tiny' representation in order to minimize the rather large computational load.

We aim to extend these research directions by exploring new hardware and software solutions that enable real-time image and video searching using large databases. Our goal can be described in the following two phases: (1) Algorithm research and development (including finding ways to utilize ELDs for better image and video understanding and improved visual classification accuracy). (2) Hardware Acceleration of the developed algorithms in order to enable accurate real-time searching of images and videos using ELDs. To summarize, using currently available images and videos that are either tagged or partially tagged, it is possible to develop highly accurate (and computationally demanding) systems that use this information for understanding and classification the vast amount of untagged images and videos. In turn, the computational load can be addressed through FPGA-based hardware acceleration which would enable the classification of an image or video to be performed in real-time.

Abdelrahman, Tarek — Architectural Support for Parallel Programming

www.eecg.utoronto.ca/~tsa

The last few years have witnessed the introduction and then dominance of multicore processors as the mainstream approach to improving performance. Multicores have more than one processor on a single chip. Today's multicores have four processors on a single chip and industry experts predict that by the year 2020 the number of cores on a chip will exceed 100. However, to exploit the performance potential of multicores, software must be developed to execute on multiple processors. This process, referred to as parallel programming, is a difficult one and is currently one of the major challenges in the field. This problem of parallel programming is exacerbated by the fact that multicores are designed by replicating the hardware of single core processors. We believe that novel multicore architectures are needed to ease the tasks of parallel programming.

The goal of this project is to explore architectural support for parallel programming. One example of such support is our recent work on the memory versioning scheme. In this scheme, hardware is added to each processor to monitor the accesses the processor makes to shared data. The hardware is designed in such a way that processors access shared data in exactly the same order as in a single processor execution. The result is a parallel programming model that requires little effort on the part of the programmer and delivers good performance. This is achieved at the expense of hardware that is dedicated to versioning. We continue to explore efficient implementation of this hardware as well as other novel approaches to supporting parallel programming at the architecture level.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Abdelrahman, Tarek
www.eecg.utoronto.ca/~tsa

Compiler Support for GPU Programming

Graphics Processing Units (GPUs) have emerged in the last few years as a promising platform for cost-effective and energy-efficient computing. These highly parallel systems are the core that processes data for graphics-intensive applications, such as computer games on almost every desktop computer. Recently, vendors such as AMD and NVIDIA have provided standard high-level programming interfaces that allow the use of GPUs for more general-purpose non-graphics computation. However, one of the major obstacles still facing GPUs today is the considerable effort needed to program them. This effort is needed to extract and package computations in the form of parallel kernels, to partition computations among threads, to explicitly manage the complex memory hierarchy that exists within the GPU and finally to deal with the various resource constraints that exist inside a GPU.

The goal of this project is to develop compiler support that eases the programming difficulty of GPUs. We have defined a directive-based language that provides users with directives that allow them to perform common tasks such as kernel definitio n, computation partitioning, data movement, local memory allocation, etc., directly to the sequential code base. Such an approach will make GPU programs easier to develop, to debug and to maintain since the sequential code base is maintained. We are exploring common optimizations patterns performed by GPU programmers and are developing compiler optimization to automate the applications of these patterns.

Abdelrahman, Tarek
www.eecg.utoronto.ca/~tsa

Dynamic Acceleration of Soft Processors

Soft processors have gained popularity as a means of implementing general purpose computations on Field-Programmable Gate Arrays (FPGAs) using the familiar sequential programming model. However, soft processors are slow compared to dedicated FPGA designs. In this project, we explore the dynamic acceleration of soft processors using traces. Our approach is to execute a program on a soft processor, detect at run-time hot paths of execution (i.e., traces) in the program and then dynamically synthesize circuits on an FPGA to speed up the execution of these traces. This approach has the advantage of leveraging the considerable resources on an FPGA to match the dynamic characteristics of an application in a transparent way. However, it faces several challenges. They include: (1) the efficient detection of traces, (2) the quick synthesis of a trace at run-time; the use of traditional CAD tools is prohibitive and (3) the dynamic reconfiguration of the FPGA to realize the synthesized trace circuit at run-time. Our goal is to address these challenges through a novel overlay architecture that we refer to as the Virtual Dynamically Reconfigurable FPGA (VDR-FPGA). We further use a trace synthesis approach that exploits that fact that traces are short straight-line segments of code, which makes them more amenable for analysis and optimization at run-time.

Adve, Raviraj
www.comm.utoronto.ca/~rsadve

Adaptive Signal Processing for Wireless Communications and Radar Systems

Adaptive processing in the physical layer in communication systems: Exploiting the spatial and temporal dimensions to improve the quality, capacity and reliability of wireless communication systems. Enabling cooperation for energy savings in wireless sensor and data reliability and/or access-point networks. Signal processing for radar systems: The detection, identification and tracking of tactical targets in stressful interference environments using advanced signal processing techniques.

Aitchison, Stewart
photonics.light.utoronto.ca/aitchison

Nano-Photonics for Optical Signal Processing and Sensing

Our research falls within three areas, (1) electron beam lithography and process development (2) photonic wires for wavelength conversion applications and (3) Photonic wires for optical sensing applications. In 2009, we officially opened our new electron beam lithography system which allows features down to 10 nm to define across large areas. The high beam current, and low stitching errors possible with this tool allow a wide range of structures to be patterned, including nano-structured surfaces for biology, sensing and photonics.

Optical frequency conversion, based on second or third order nonlinearities, provides a mechanism of generating new wavelengths and has applications in telecommunications for agile channel allocation in a wavelength division multiplexed system and for the generation of mid-IR wavelength for optical sensing. The use of high refractive index contrast waveguides to implement wavelength conversion has many advantages. The small core size increases the local intensity, the waveguide structure can be used to dispersion engineering the waveguide to enable phase matching and resonators can be used to further

enhance the conversion efficiency. Under this theme we will use the almost ideal like nonlinear properties of the III-V semiconductor AlGaAs to develop efficient wavelength conversion devices based second order nonlinearities (difference frequency generation) and third order effects (four wave mixing).

The ability to engineer the dispersion and field profile in a nanowire waveguide has applications in optical sensing. By narrowing the waveguide, incorporating a photonic crystal, or defect state it is possible to control the overlap of the optical field with the sensing material. Typically sensing can be done through a change in refractive index, or absorption of an intermediate material which is sensitive to the substance to be measured. For example: platinum for hydrogen detection. Using this approach it is possible to develop a single chip, with multiple sensors which could detect multiple gases, temperature, humidity and pressure.

Amza, Cristiana
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Automated Self-Management in Cloud Environments

The economy has been transformed by the delivery of Web services over the Internet in the past three decades. Behind the scenes of Web-based service delivery technologies are large scale, complex Information Systems. These Information Systems consist of thousands of servers, which store client data in a consistent and persistent manner, and are multiplexed among several applications.

Many aspects of content delivery still currently depend on manual fine-tuning and trouble shooting by humans. As a result, the service provider is strapped with huge human administrator costs for performance debugging, resource allocation to applications, and infrastructure configuration adjustments. This is a major impediment on the efficiency of this industry, by limiting reinvestment, research and development. To address this problem, we investigate innovative self-diagnosis and adaptive reconfiguration techniques for scalable and available Information Systems.

We have designed and developed novel on-line performance modeling and anomaly detection algorithms and tools that form the basis for self-configuration, self-tuning, and self-healing servers. We use these techniques in our data center laboratory towards automatically providing quality-of-service for a range of dynamic content services such as, e-commerce, on-line bidding and massively multi-player games.

Amza, Cristiana
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System Support for Parallel and Distributed Software Transactional Memory

Due to the increase in complexity and ubiquity of large-scale parallel and distributed hardware environments, simpler parallel programming paradigms become key. Transactional Memory is an emerging parallel programming paradigm for generic applications that promises to facilitate more efficient, programmer-friendly use of the plentiful parallelism available in chip multiprocessors and on cluster farms.

We developed and optimized libTM, a Transactional Memory library that can be used in connection with C, or C++ programs to facilitate more efficient, programmer-friendly use of the plentiful parallelism available in chip multiprocessors and on cluster farms. libTM implements Transactional memory (TM), for generic applications. libTM allows transactions on different processors (or machines) to manipulate shared in-memory data structures concurrently in an atomic and serializable (i.e., correct) manner. There is no need for the application to do explicit fine-grained locking, by acquiring and releasing specific locks on data items. Instead, a cluster-based run-time system automatically detects data races and ensures correct parallel execution for generic parallel programs. Any detected incorrect execution resulting from a data race is rolled back and restarted.

In this project we have focused on reducing the software overhead of run-time memory access tracking and consistency maintenance for Transactional Memory support. We currently support applications with highly dynamic access patterns, such as massively multiplayer games. We have shown that Transactional Memory not only simplifies the programming of these applications, but can also improve performance and scaling relative to that obtained by using traditional locking techniques for code parallelization for the same application.

Anderson, Jason
www.eecg.toronto.edu/~janders

A Self-Profiling Adaptive Processor– High-Level Hardware Synthesis

High current density in sub-100 nm ICs has created a power wall, limiting the rate of clock speed scaling in general purpose microprocessors. Attaining higher speed performance and improved energy-efficiency motivates the need to develop processors that are customized to specific applications. Performing computations in custom hardware can deliver orders of magnitude improvement in energy-efficiency and throughput. However, custom processor design, as with any hardware design, is difficult and time-consuming compared to software design. Moreover, hardware design in VHDL or Verilog lies outside the skill set of most software programmers. A further challenge is in identifying what custom hardware would be of benefit to the speed and/or power of an application, as this depends on the run-time and power profile of the application under specific datasets. There is a need then, for the rapid and automated design of processors tailored for particular applications.

We are building a self-accelerating adaptive processor by modifying the architecture of a standard processor to create the ability to profile the execution of its own code. Using this profiling ability, our unique processor will be able to identify sections of its code that require optimization. Specifically, the profiling results will drive the selection of program code segments to be re-targeted to custom hardware from their original high-level language implementation. C-to-RTL synthesis

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

will be used, with the RTL subsequently compiled by standard back-end tools. Once the hardware "compute accelerators" are available, the program binary will be modified to access the accelerators accordingly. Programmable logic devices, such as field-programmable gate arrays (FPGAs), are an ideal implementation platform for such adaptive processors, as FPGAs can be configured in milliseconds to implement any digital circuit. The reconfigurability of FPGAs also permits functionality to evolve over time, based on application needs.

Anderson, Jason
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Computer Hardware: Applications, Tools, Architecture, Circuits for Programmable Logic

Field programmable gate arrays (FPGAs) are programmable semiconductor chips that are part of that revolution, and poised to be present in every piece of electronic equipment within 10 years. The rapid growth of FPGAs stems from technology scaling that today allows billions of transistors to fit onto a single chip. Each advance in technology is tied to rapidly escalating complexity, such that building a custom chip now costs tens of millions of dollars, and is out of reach for all but a few large companies. FPGAs provide inexpensive access to advanced semiconductor technology, allowing innovation to happen across the spectrum, from small start-ups, to large industry to academia.

As they are programmable chips, FPGAs incorporate additional circuitry relative to chips that implement a single fixed function. A consequence is that FPGAs use more power than fixed-function chips and the advantages of FPGAs cannot be realized in the mobile electronics world. Our research aims to drastically improve the energy-efficiency of FPGAs to enable their use in the battery-powered electronic devices pervasive in society today.

Today, it can take hours or even days to implement a design in an FPGA, and our research seeks to reduce this time, to minutes or seconds. FPGA chips are regular -- the same circuits repeat in a tiled fashion on an FPGA. This regularity can be used to create patterns for how circuits should be implemented on the FPGA. Our approach is akin to taking a complex problem, breaking it into smaller problems, whose solutions can be rapidly looked-up in a library, and stitched together to form a good solution for the complex problem.

Balmain, Keith
www.waves.utoronto.ca/prof/Balmain/balmain.html

Anisotropic Microwave Materials and their Applications

RF tag interrogation systems are used for position determination in the automatic control of urban rail trains. Such systems consist of a Tag Interrogator Unit (TIU) which is attached to an antenna mounted underneath the rail car and transmits interrogation pulses to tags installed between the rails. The TIU operates in a complex electromagnetic environment that contains some components which are highly conductive, such as the rail car itself, the wheel bogie sets, the rails and rail spikes into the ground. Other components have lower but still significant conductivities and permittivities different from that of free space, such as the ground, the ballast, and the sleepers (ties). In the design of a positioning system it is important to gain an understanding of the influence of these components on the RF field distribution underneath the rail car, especially in the plane where the tags are located. Finite-element software is used to simulate the RF fields under the train in the presence of all components and particularly to predict the electric field distribution, most importantly in the plane of the tag, and the signal reflected by the tag. The results can be used to better understand the response of the TIU leading to improvements in the determination of the train position as well as in improvements to the design of such TIU systems.

Balmain, Keith
www.waves.utoronto.ca/prof/Balmain/balmain.html

RF Phenomena in Magnetized Plasmas

Magnetized plasmas that are encountered both in space and in the laboratory are highly anisotropic media which have a large impact on RF antennas operated in such media. One effect of a transmitting antenna in a magnetized plasma is the occurrence of luminous discharges that were observed during the 1995 OEDIPUS-C sounding rocket experiment as well as to laboratory experiments carried out in the past. In the OEDIPUS-C experiment, luminous discharges were observed close to the transmitting antenna early in the flight while Argon thrusters driving the separation of two sub-payloads were running. The formation of these RF-discharges as well as the unique shape of the resulting glow patterns are studied in order to better understand the processes that led to their occurrence. In the laboratory experiment, intended as a scaled-down version of the OEDIPUS-C RF antenna, similar RF-discharges were observed that extended as glowing band-shaped beams directed along the ambient magnetic field and extending all along the laboratory plasma column. Research consists of the evaluation of data from the OEDIPUS-C experiment and computational simulations of both the rocket experiment and the laboratory experiment, taking advantage of the vastly improved computer hardware and software now existing and which wasn't available in 1995. Eventually, improved laboratory experiments with emphasis on relating the computed and measured phenomena will be designed and carried out.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Balmain, Keith — Simulation of RF Tag Interrogator Units Underneath Urban Rail Trains

www.waves.utoronto.ca/prof/Balmain/balmain.html

RF tag interrogation systems are used for position determination in the automatic control of urban rail trains. Such systems consist of a Tag Interrogator Unit (TIU) which is attached to an antenna mounted underneath the rail car and transmits interrogation pulses to tags installed between the rails. The TIU operates in a complex electromagnetic environment that contains some components which are highly conductive, such as the rail car itself, the wheel bogie sets, the rails and rail spikes into the ground. Other components have lower but still significant conductivities and permittivities different from that of free space, such as the ground, the ballast, and the sleepers (ties). In the design of a positioning system it is important to gain an understanding of the influence of these components on the RF field distribution underneath the rail car, especially in the plane where the tags are located. Finite-element software is used to simulate the RF fields under the train in the presence of all components and particularly to predict the electric field distribution, most importantly in the plane of the tag, and the signal reflected by the tag. The results can be used to better understand the response of the TIU leading to improvements in the determination of the train position as well as in improvements to the design of such TIU systems.

Bardakjian, Berj — Bioengineering of the Brain

heart.ibme.utorontxo.ca/~berj/berj.html

The main themes of the research are within the general field of Neural Engineering, and in particular, bioengineering of the brain. The purpose is (1) to characterize both normal and pathological brain electrical activities, and (2) anticipate then abolish the pathological electrical activities in the brain, such as epileptic seizures. The approach is to characterize the spatiotemporal relations of the electrical activities in neuronal populations and use cognitive devices to classify the dynamical features of the biological neural networks in the brain. The developed cognitive devices will be implemented as low-power hardware to be incorporated into the biological neural networks in a closed feedback loop. This will be used to provide implantable devices as therapeutic tools for brain disorders.

Betz, Vaughn — Improved FPGA Architecture and CAD

www.eecg.utoronto.ca/~vaughn

My team seeks to find both better architectures and better Computer-Aided Design (CAD) tools for a type of integrated circuit - Field Programmable Gate Arrays (FPGAs). Field Programmable Gate Arrays are a type of computer chip that can be reprogrammed to perform any function. As the cost of creating chips with billions of transistors has risen to $100 million, most applications cannot justify a custom-fabricated chip and instead are best served by a reprogrammable chip. Our research seeks to find the best “architectures” for FPGAs -- what function blocks should they include, how should those function blocks be reprogrammed and how should they be connected with programmable routing? We also seek to find new algorithms and Computer-Aided Design tools to allow FPGA designs to be completed more quickly, and to run at higher speeds and make more efficient use of the chip. Finally, we are also investigating new areas in which FPGAs and other highly parallel computer hardware (such as graphics processors) can accelerate computation; a key application in this area we are currently researching is the modeling of photodynamic cancer therapy.

Broucke, Mireille — Control for Complex Specifications

www.control.utoronto.ca/~broucke

The field of Systems Control has traditionally been focused on steady-state control specifications in the form of stabilization and tracking. The goal of the project is to develop a theory of control for complex specifications, in particular enabling systematic methods of design and control of the transient phase of a dynamic system. These complex specifications may include safety and liveness specifications, logic-based specifications, and temporal specifications. Problems of control with complex specifications arise in all of the disciplines that apply Systems Control, ranging from robotics to process control.

Broucke, Mireille — Patterned Linear Systems

www.control.utoronto.ca/~broucke

Complex dynamic systems that are made of a large number of simple subsystems with simple patterns of interaction arise frequently in natural and engineering systems. There is generally no overarching theory that explains the phenomena exhibited by such systems. We have introduced a class of linear control systems called patterned systems which mathematically capture the structure of a collection of identical subsystems with a fixed pattern of interaction between subsystems. The project involves developing a control theory for patterned system, and our approach is based on the geometric theory of linear control systems. The aim of our study is to determine if patterned systems may provide a template for the development of a more unified framework for dealing with systems, typically distributed, which consist of subsystems interacting via a fixed pattern.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Brown, Stephen — CAD and Architecture for FPGAs

www.eecg.toronto.edu/~brown

My research is focused on many different aspects of field programmable gate array technology, including the design of the chip architectures and the algorithms that are used to implement circuits in these devices, as well as applications of FPGAs. In addition to my Faculty position at the University of Toronto, I maintain an active involvement in the Altera Toronto Technology Center, where I provide direction for the University Program that is offered by Altera. By combining my involvement in both the University of Toronto and Altera, it has been possible to develop research results that are both interesting from the academic point, as well as being of practical use when implemented in an industrial quality CAD tool. My current research effort is in the area of CAD flows for FPGA devices, and specifically in the development of new methods of efficiently compiling high-level language code (such as C code) into circuits that can be implemented in FPGA devices.

Chan Carusone, Anthony — Integrated Circuits and Systems

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Research in my Integrated Systems Laboratory strives to extend the rate, reach, and reliability of our communication links–whether they are between a satellite and an earthbound receiver, or between two integrated circuits just a few millimetres apart. Specifically, we develop integrated electronic systems that process information with high energy efficiency and/or speed. Projects combine signal processing concepts with integrated circuit design.

Chow, Paul — Programming Models and Architectures for Reconfigurable and Heterogeneous Computing Systems

www.eecg.toronto.edu/~pc

This research investigates approaches to computing using systems of multiple, heterogeneous computing devices. The heterogeneity addresses the need for special-purpose accelerators that provide performance or other efficiencies, such as more efficient energy usage. A key focus is the use of Field-Programmable Gate Arrays, a form of configurable hardware. Such systems can be found in an embedded device or in high-performance computing systems. Important issues being addressed are better methods for programming, testing and debugging, and system architectures.

Davison, Edward — Control of Large Scale Decentralized Systems

www.control.utoronto.ca/people/profs/ted/ted.html

Our research is focused on the control of large scale systems, where only limited information of the overall system is available to the control agents of the system. Such systems occur often in modern industrial society: e.g. in chemical engineering, electrical power systems, aerospace systems, transportation systems, building temperature control systems, large flexible space structures, pulp and paper control systems, as well as in other areas such as in management science and in biological systems.

Dawson, Francis — Improving Energy Efficiency of Energy Conversion Processes

www.ele.utoronto.ca/~dawson

The general research interests are in the area of modeling systems powered by electrical energy. At the component level, the current focus is on developing improved models that can describe the electric and thermal fields in electrochemical storage devices. The objective is to use reduced order multiphysics models to develop energy management controllers that can extend the life of an energy storage device. At the system level, the objective is to determine the best system architecture and control philosophy that leads to an optimal integration of energy storage devices and power converters, subject to a specific generating and electrical load profile. Other areas of interest include the modeling of thermoelectric and piezoelectric devices.

Eleftheriades, George — Artificial Materials (Metamaterials) from Microwave to Optical Frequencies

www.waves.utoronto.ca/prof/gelefth/main.html

We are developing paradigm-shift metamaterial devices and subsystems, and related technologies at RF/microwave and optical frequencies. Example devices include small antennas and multi-functional RF/microwave components, sub-diffraction imaging lenses and probes, invisibility cloaks and related 'transformation optics' lenses, plasmonic optical circuits, and nano antennas. Research includes both experimental work as well as fundamental theory.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Enright Jerger, Natalie — Semantically Rich Networks for Many-Core Architectures

www.eecg.toronto.edu/~enright

Parallel architectures are rapidly becoming ubiquitous. To leverage the computational power of these multiple cores, communication between cores or devices is essential. This project looks at streamlining the communication between cores via on-chip network innovations to increase its efficiency. With a semantically-rich interconnection network, we propose to provide the programmer and compiler with information about the communication capabilities on-chip to ease programmability. Today's on-chip interconnection networks are largely oblivious to the needs of the components they connect and serve the sole purpose of shuffling bits around the die. This work proposes to embed additional functionality, such as novel message passing support and support for reduction operations, both in the interconnection network as well as further integrate communication into other layers of the system.

Enright Jerger, Natalie — Simulation Methodologies for On-Chip Networks

www.eecg.toronto.edu/~enright

On-die communication fabrics represent a critically important aspect in the design of future many-core computer systems. As systems scale to increasingly large numbers of on-die agents, the on-die communication fabric will factor dramatically into both the performance and the power consumption of future architectures. This research focuses on two challenges in the design of on-die communication fabrics: Physically-aware performance and area optimization for communication fabrics and uncore, interconnect, and system power management. Specifically within these topics, we are exploring solutions to integrate cache coherence protocol traffic analysis within the early-stage on-chip network design space exploration and the integration of protocol-level information into the quality of service and DVFS mechanisms of the on-chip network. These two thrusts will span issues of correctness, energy/performance efficiency and scalability.

Francis, Bruce — Distributed Robotics: Application

sites.google.com/site/brucefranciscontact

During 2007-2009 we conducted a major application of our theory in collaboration with Professor Tim Barfoot of the University of Toronto Aerospace Institute and Jared Giesbrecht of Defense Research and Development Canada (DRDC), Suffield, Alberta. Motivating this research is a military situation in which a manned vehicle convoy traverses hostile territory to deliver supplies. We designed and tested a vehicle-following system to allow a convoy of full-sized autonomous vehicles with large inter-vehicle spacing to follow a manually-driven lead vehicle's trajectory without cutting corners on turns. Our testing was done on MultiAgent Tactical Sentry (MATS) vehicles that were provided by DRDC. Since there are no inter-vehicle communications to relay the lead vehicle's position, the goal of an autonomous follower is to track the trajectory of its immediate leader. The resulting design and field trials were successful enough to appear in the premier journal on field robotics.

Francis, Bruce — Distributed Robotics: Theory

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The methodology of control theory is to begin with a practical problem; to abstract the central issues and formulate an idealized, hypothetical problem; to develop, if necessary, new mathematical methods for its solution; and to work out a rigorous solution. Then one has a framework on which to do real applications.

My students, co-supervisors, and I began by formulating the hypothetical problem of rendezvous for point robots. This is entirely analogous to birds flying in a flock; the heading angles are all equal. The rendezvous problem is a challenge because there are no leaders, the robots do not have a common map and preferably should have identical stored programs, and there can be no human intervention.

We began with the simple strategy of cyclic pursuit. The theory of robot formations relies heavily on graph theory. We derived a new control-theoretic result: a necessary and sufficient condition on the graph for rendezvous to be achievable. We studied the cyclic pursuit strategy applied to unicycles. We found that stable formations could be achieved, where the unicycles are moving in a circle in the same direction. We confirmed this experimentally. We moved to the problem of formation control, for example getting four rovers to form a square, derived control laws, proved stability of the formation, and verified by experiments on real rovers. In our major theoretical work we studied the rendezvous problem when the robots can see only a fixed distance away. We gave the first mathematical proof of an algorithm for this case.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Frey, Brendan — Algorithms for Inference and Machine Learning

www.psi.toronto.edu

We develop new inference theories that can be used for probabilistic and statistical inference in large-scale systems, such as those that arise in telecommunications, robotics, genetics, genomics, vision, and signal processing. Professor Frey is co-author of an article that introduced the 'factor graph' and associated sum-product and max-product algorithms (IEEE Trans Info Theory 2001). A factor graph is a method for decomposing high-order probability models into simpler terms, so that the sum-product or max-product algorithm can be used to efficiently perform inference. A search for factor graph on Google returns over 40,000 hits. Other methods we developed include variational methods for inference in large-scale nonlinear Gaussian models (Neural Comp 1999), the 'wake-sleep' algorithm for unsupervised learning (Science 1995), cumulative distribution networks (NIPS, UAI 2008), and loopy belief propagation algorithms for low-level vision (CVPR 2000), phase-unwrapping of medical and satellite images (NIPS 2001), exemplar-based clustering (Science 2007) and facility location (AISTATS 2010).

Frey, Brendan — Data Analysis and the Affinity Propagation Algorithm

www.psi.toronto.edu

Summarizing data by identifying a subset of representative examples is important for scientific data analysis and in engineered systems. Such 'exemplars' can be found by randomly choosing an initial subset of data points and then iteratively refining it, but this only works well if that initial choice is close to a good solution. We developed a new method called 'affinity propagation', which takes as input measures of similarity between pairs of data points. Real-valued messages are exchanged between data points until a high-quality set of exemplars and corresponding clusters gradually emerges (Frey and Dueck, Science 2007).

Because of its simplicity, general applicability, and performance, the affinity propagation algorithm is widely used in science and engineering. In the past year, an on-line web tool we developed was accessed over 100,000 times by over 3000 users (unique IP addresses), 53,600 of which were from Canada. Google returns over 10,000 hits for the search term 'affinity propagation'. This method has been applied to solve problems in biology, genetics, genomics, medicine, physics, chemistry, telecommunications, electronics, archeology, economics and social networks.

Frey, Brendan — Deciphering the Human Genetic Code

genes.toronto.edu

Despite widespread claims that the human genome has provided a "book of life", it turns out that it is very difficult to understand how genes stored in the genome encode the actual genetic messages that control the life, death and ongoing activities of cells comprising all human tissues. In the words of the famous genomics researcher Eric Lander, "Genome: Bought the book, hard to read." Recently, Professor Brendan Frey and his research team discovered a fundamentally new view of how living cells "read the genome" and use a limited number of genes to generate enormously complex tissues such as the brain.

In a paper that was published in the May 6 2010 issue of Nature and featured on its cover, Dr. Frey describes research conducted by his team. They developed a computational technique based on probability, statistics and machine learning, and used it to reveal a second level of information hidden in the genome that can account for the exponentially greater complexity required to create a human being. The work of Dr. Frey's team was reported on in the Globe and Mail, the Toronto Star, CBC Radio, BBC Radio, and a variety of other national and international news.

Professor Frey leads an ongoing, multi-year project whose goal is to infer the coding mechanisms underlying the regulation of genes. The project involves experimental collaborators from the Centre for Cellular and Biomolecular Research at the University of Toronto, along with international collaborators. Several of the students and postdoctoral fellows that graduated from Dr. Frey's lab have subsequently taken faculty positions at leading universities, including UPenn, UNC and Harvard.

Frey, Brendan — Image and Video Analysis

www.psi.toronto.edu

We explore computational techniques for analyzing images and videos so as to automatically extract a representation of what's going on in the image or video. The methods developed are motivated by neuroscience and make use of large scale graphical models and inference algorithms, including those based on optimization, Markov chain Monte Carlo, and variational techniques. A movie showing the input and output of one of the algorithms developed in our laboratory is available here: http://www.psi.toronto.edu/images.old/figures/cutouts_vid.gif.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Genov, Roman — Portable, Wearable, and Implantable Sensory Biomedical Electronics

www.eecg.utoronto.ca/~roman

We are heading the Intelligent Sensory Microsystems Laboratory at the University of Toronto. Members of our laboratory conduct research on analog and digital VLSI circuits, systems and algorithms for energy-efficient signal processing with applications to electrical, chemical and photonic sensory information acquisition, biosensor arrays, brain-chip neural interfaces, CMOS imagers, parallel signal processing, adaptive computing, and implantable and wearable biomedical electronics.

Goel, Ashvin — Data Protection and Recovery

www.eecg.toronto.edu/~ashvin

This research aims to design computer systems that enable efficient data recovery (i.e., maintain data integrity and never lose data) in the presence of attacks and catastrophic failures. Our approach consists of systematically monitoring all components of the system and capturing critical data, thus allowing analysis of compromised systems and disaster recovery.

Goel, Ashvin — End-to-End Data Reliability

www.eecg.toronto.edu/~ashvin

The goal of this project is to ensure data integrity in the face of software bugs. Currently, the project is focused on improving the reliability of file-system software. When file systems are buggy, they can cause data corruption and persistent application crashes. We are developing a system that ensures that a file-system disk image will remain consistent in the face of arbitrary file-system bugs. The key idea is to verify all file-system operations that update the disk at runtime using a well-defined set of consistency properties. This is joint work with Professor Angela Demke Brown.

Gulak, Glenn — VLSI for Digital Communications

www.eecg.toronto.edu/~gulak

In the area of digital communications, we have continued to develop several practical ways to improve the performance and implementation of wireless systems that use multiple antennas (MIMO) for improved diversity and capacity. One of the key elements that we have investigated is the subsystem in the baseband known as the detector, which is responsible for data detection. A key contribution is the creation of an innovation that we call an on-demand K-Best algorithm (a breadth-first search technique) whose complexity scales linearly with constellation size. This innovation is key to supporting higher order modulation schemes such as 64-QAM and 256-QAM systems that will appear in next generation communication standards, necessary for Gbps performance. We have implemented and tested our algorithm in 0.13um CMOS and have generated the best known results published in the literature to date, with respect to data rate, power efficiency and area. Our results have been extended to soft detection and tested with CMOS prototypes for use with iterative FEC decoding schemes.

We have also made recent contributions to an important channel pre-processing block found in all MIMO systems, namely that of QR decomposition, a function needed for decomposing the channel matrix. Our key contribution in this area is the development of both algorithms and a 0.13um CMOS implementation that demonstrates the world's lowest (best) processing latency.

Another area of recent accomplishment is in a channel preprocessing element know as Lattice Reduction that can be used to mitigate scattering and antenna correlations that exist in practical MIMO systems. Lattice Reduction is a baseband signal processing algorithm to re-orthogonalize the signal space with the objective of improving BER performance. We have developed several algorithmic innovations and the world's first CMOS prototypes for Lattice Reduction; the concepts developed will particularly attractive for low-power implementations.

Future work is focussed next-generation wireless OFDM baseband signal processing algorithms and their high-performance low-power CMOS realization.

Hatzinakos, Dimitrios — Biometrics User-Centric Sensor Networks (BUSNET)

www.comm.toronto.edu/~dimitris/research/busnet.pdf

We propose to develop an integrated security architecture to effectively and efficiently secure and protect sensitive information and data within the domain of a care enterprise such as wireless health care and home care applications and services. Our proposal addresses the need for secure communication and authentication of personal information which is also characterized by enhanced privacy and confidentiality. The proposed security architecture, namely, 'Biometrics User Centric Secure Networks (BUSNet)' will implement novel biometrics-based security solutions and technologies that can be effectively integrated into a plethora

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

of wireless infrastructures. Specifically, this research initiative will be examining issues and developing solutions for processing of biometrics signals, biometrics registration and authentication, biometrics key generation and management as well as biometrics-based data authentication. Implementations of the proposed architecture using specific realizations of suitable wireless Body Area Network (BAN) configurations will be also developed, examined and analyzed in collaboration with our industrial partners. The proposed security framework constitutes an effective mechanism that integrates a novel security architecture and a cost effective networking configuration to develop a realistic, feasible and cost effective solution for secure transmission of sensitive information which are among the most fundamental requirements of modern and future health/home care services.

Hatzinakos, Dimitrios — Efficient Resource Allocation Strategies for Wireless Multimedia Communications

www.comm.utoronto.ca/~dimitris/research/multisignproc

One of the major objectives of future-generation communication networks is to provide high-quality multimedia content to users. This demand necessitates more efficient utilization of limited resources such as power and spectrum. While it is essentially to minimize consumption of limited resources, the conservation should not come at the cost of inferior quality of service (QoS). As a result, power and spectrum efficient strategies, which can also guarantee some level of QoS, are highly desirable. We propose a generalized framework of resource allocation, which enables efficient integration of various adaptation methods and strategies: efficient use of available bandwidth and power, adaptive modulation and coding coping with highly varying wireless channel conditions, as well as an integrated and multilayer design for overall performance gain. With dynamic resource allocation, improved flexibility and robustness can be obtained in the hostile wireless channel environments. Various channel distortions can be mitigated efficiently, accommodating various user needs successfully in a wide range of Scenarios. Depending on the application, a pre-selected level of QoS can be guaranteed while keeping resource consumption to a minimum. Together, these strategies offer an attractive communication framework of increased power and spectral efficiency, which will enable high-data-rate wireless multimedia communication to be an affordable and practical reality.

Hatzinakos, Dimitrios — Medical Biometrics

www.comm.utoronto.ca/~biometrics/medical/index.html

The cardiovascular system offers a variety of physiological signals that can be used as biometrics. While modality such as the electrocardiogram (ECG) is still relatively novel, it is increasingly garnering acceptance as a useful biometric tool, due to some unique characteristics. Existing solutions for biometric recognition from electrocardiogram (ECG) signals are based on temporal and amplitude distances between detected fiducial points. Such methods rely heavily on the accuracy of fiducial detection, which is still an open problem due to the difficulty in exact localization of wave boundaries.

To avoid fiducial points detection, the signal is processed holistically, using second order statistics. Our autocorrelation based method is a very simple and effective approach that does not require any waveform detection. It depends on estimating and classifying the significant coefficients of the Discrete Cosine Transform (AC/DCT) or the Linear Discriminant Analysis (AC/LDA) of the autocorrelation of heartbeat signals. The AC/LDA algorithm has been incorporated to a prototype system developed at the BioSec.Lab, the HeartID. HeartID is a Matlab based software with various functionalities, such as user enrolment, database handles, security level adjustment and identification / verification modes of operation.

Hatzinakos, Dimitrios — Self Powered Sensor Networks

www.comm.toronto.edu/~spsn

The University of Toronto, AD Telecom and SRADEL are partners in developing compelling materials, communication architectures, software, and other critical technologies necessary to create self-powered, ubiquitous, and wireless ad hoc sensor networks. Substantial benefits will be realized by the citizens of Ontario, as well as the general Canadian society, with the commercialization of a family of products that take advantage of these sensor networks, along with the novel energy harvesting and power generation technologies used to support them. The panoply of envisioned applications include effective, responsible and sustainable monitoring and governance in structural health, disaster relief, transportation, law enforcement, as well as public safety and security. During our collaborative effort, we will undertake three main tasks:

(1) Creation of sensor hardware that employs redundant architectures, fault tolerant methods, and nano-enabled materials to ensure system integrity, minimize sensed false-positives, increase sensor sensitivity, and ease interaction with short-range wireless radios. The proposed research will integrate these aspects in a flexible and low-cost hardware framework. Several types of optical, electrochemical and biological sensing techniques will be investigated, including a quantum dots composite based authentication-at-a-distance architecture with unambiguous authentication and visual association under all weather conditions, such as fog, rain, and snow.

(2) Creation of system software and middleware for the extraction, processing, and characterization of real-time sensed data. One of the unique contributions of this task involves the advancement of innovative mobile social networking technology, which has the secondary benefit of enhancing next generation voice, video, and data transfer in addition to security/privacy methodologies. U of T will leverage AD Telecom's current state-of-the-art extensive infrastructure for collecting massive amounts of sensor data in order to provide critical functionality for: i) Management of inconsistent and uncertain data; ii) Light-weight data integration; iii) Data cleaning and social network analysis; and iv) Various enhanced security functions for device authentication and data protection under a wide range of attack scenarios.

(3) Creation of innovative energy conserving, capture and storage technologies that use novel nanoscale materials, energy harvesting methods and renewable energy resources to supply consistent power to sustain autonomous sensor networks. The research on self-powered sensor energy systems will focus on five major areas: i) power conditioning and conservation; ii) electromagnetic energy harvesting; iii) solar energy harvesting; iv) vibrational-thermal energy harvesting; and v) energy storage. The ultimate target is low-cost, miniaturized, readily integrable, 24/7 energy generation systems that can sustain on the average a few hundred mW pulses, as well as support continuous current draw at mA scale. Several, if not all, of the energy generation techniques will undoubtedly be extended to the next generation, large-scale wireless technologies to further reduce dependence on fossil fuels and other environment-taxing resources.

Helmy, Amr
photonics.light.utoronto.ca/helmy/research

A Universal Trace Sensing Platform for Nanoparticles and Biological Samples in Solution and Gas Forms

This project is concerned with developing a universal platform for detecting and analysing substances in solution and gaseous forms in dilute concentrations using enhanced Raman spectroscopy. This capability can greatly enhance fields such as detection of toxic content, sensing biological samples in dilute concentrations as well as nanoparticles detection in the environment amongst others.

Raman spectroscopy is much more powerful than more commonly used optical detection techniques such as absorption and Photoluminescence. Raman provides unparalleled specificity to the detection as it conveys wealth of information about the chemical composition of the specimen under test. Raman spectroscopy provides a weak signal however. Numerous techniques have been developed to enhance the Raman signal emitted from a molecule particle or molecule. Most of these techniques either require complicated setup that does not lend itself to mobile sensing or they involve contaminating the specimen under test by adding contaminants such as metal nanostructures.

The technique provides orders of magnitude enhancement in the Raman signal while achieving this goal in a compact rugged platform that lends itself to mobile and bed-side diagnostics.The enhancement is achieved using a hollow core photonic bandgap fibre (HC-PCF). These fibres work on enhancing the interaction length between the substance under test and the laser pump which induces the Raman signal.

Helmy, Amr
photonics.light.utoronto.ca/helmy/research

High Power Diode Lasers

Bragg reflection waveguide lasers (BRLs) are essentially one-dimensional (1D) photonic bandgap (PBG) p-i-n structures, where light is guided by Bragg reflectors with light propagating parallel to the epi-layers. The core is a layer of the low refractive index material and the device operates at Bragg reflection waveguide (BRW) mode, not the conventional total interface reflection (TIR) mode. BRLs have been predicted to enable the realization of high power lasers and amplifiers due to single mode waveguides with larger mode volumes, high gain coefficient and strong mode discrimination. Moreover, this class novel PBG lasers have also shown the potential in applications related to¬ nonlinear frequency conversion, monolithically integrated optoelectronic integrated circuits (OEIC). Our group has demonstrated the first edge-emitting BRW laser-diode with low threshold current and high characteristic temperature. We are interested in developing high performance single-mode BRLs, second-harmonic laser, monolithically electrically injected optical parametric oscillators (OPO), and compact spontaneous parametric down conversion (SPDC) single-photon sources by integrating BRLs with nonlinear BRWs.

Helmy, Amr
photonics.light.utoronto.ca/helmy/research

High Power Electrically Injected Laser Chips in the Infra Red and THz

Physical sciences, information, computer and communication technologies, pollutants and toxic agents (waste, use 902), medical equipment and apparatus, information systems and technology.

Helmy, Amr
photonics.light.utoronto.ca/helmy/research

Parametric Photonic Intergated Circuits for All Optical Signal Processing and Quantum Optics Using Second Order Nonlinearities

Parametric processes based on second-order optical nonlinearities in III-V semiconductors are receiving attentions for the development of novel photonic devices such as integrated self-pump optical parametric oscillators (OPOs). The efficiency of parametric processes chiefly rely on the phase-matching technique to be employed. Due to the lack of natural birefringence in compound semiconductors, phase-matching can be challenging in these materials. Our group has

proposed and successfully illustrated the exact phase-matching of second-harmonic generation (SHG) using Bragg reflection waveguides (BRW) in AlxGa1-xAs material system. BRW phase-matching is an exact phase-matching technique which employs the modal dispersion properties of the interacting harmonics propagating as either a Bragg mode or as a total internal reflection mode. The technique benefits from large nonlinear conversion efficiencies thanks to the phase-matching of the fundamentals of both Bragg and TIR modes. In our group, we are interested to improve the conversion efficiency of the nonlinear processes by investigating advanced transverse Bragg reflectors as well as extending the technique to other second order nonlinear processes including sum- and difference-frequency generation.

Dispersion control is also significant in quantum optics in generating photon-pairs with frequency correlation properties using spontaneous parametric down conversion. In an integrated source of photon-pairs where all interacting harmonics are far from material resonances, waveguide dispersion can be large enough to set the mode dispersion to the desired value. One such waveguide parameter which allows significant variation of dispersion is the ridge size which can simply implemented using lithographical technique. Sources of biphotons with ultra-short and ultra-broad temporal correlations can be then be realized in an integrated platform to favour some emerging disciplines such as quantum optical coherence tomography and generation of photonpairs with high dimensional spectral entanglement.

Bragg reflection waveguides are used to achieve phase-matching for spontaneous parametric down-conversion in monolithic AlGaAs waveguides. Through the dispersion control afforded by this technique, bandwidth tunability between 1 nm and 450 nm could be achieved using the same vertical wafer structure. The tuning was achieved by patterning waveguides with different ridge widths and also by utilizing both type-I and type-II phase-matching conditions. This technology offers a promising route for realization of electrically pumped, monolithic photon-pair sources on a chip with versatile characteristics.

Helmy, Amr
photonics.light.utoronto.ca/helmy/research

Probing the Raman Properties and Sensing of Nano- and Bio-materials in Microfluidic Photonic Crystal Fibres

Conducting Raman spectroscopy in hollow core photonic crystal fibers (HCPCFs) results in significant Raman intensity enhancements (approx. two orders of magnitude) compared to direct sampling scheme in cuvette. This platform can be used as a useful method for ultra- sensitive detection of vibrational modes of chemical and biological molecules.

The enhancement technique in all liquid core waveguide platforms is mostly based on their use as waveguide to confine both the liquid and the optical field over a long distance and the degree of enhancement attained for a specific solution depends on the physical parameters of the waveguide.

The great potential of HCPCF for optical sensing originates from the increased light-matter interaction volume and efficient accumulation of the Raman scattering along the extended length of the HCPCF. The well-confined excitation interacts directly with the sample molecules while propagating along the length of the HCPCF and Raman scattering can be efficiently excited along the fiber's entire length.

Recently a detailed, non-destructive characterization of CdTe nanoparticles was carried out using Raman spectroscopy for solutions with QD concentration of 2 mg/mL, which is similar to their concentration during the synthesis process. By employing the HC-PCF platform for light-matter interaction, both the pump laser and the QD solution can be confined within the central core of the HC-PCF. Subsequently, the confined laser power within the core induces a strong interaction with the solution that is filled inside which allows an enormous amount of Raman signals to be induced and collected compared to the conventional Raman scheme. With this novel technique, Raman signals from aqueous or diluted solutions can be enhanced by 2-3 orders of magnitude without the use of additional metallic nanoparticles. This enhancement allowed clear vibrational modes corresponding to the structure and interactions of the QDs to be observed. These vibrational modes include those of the CdTe core, Te defects, CdS0.7Te0.3 interface, thiol agent and carboxylate-metal complexes. These modes are correlated with the crystallinity of the QD core, interfacial structure formed upon stabilization, QD-thiol interaction mechanisms, water solubility of the QDs and their potential bio-conjugation abilities.

Herman, Peter
photonics.light.utoronto.ca/laserphotonics

3-D Laser Fabrication: Enabling Nano-Optics for the Nano-Sciences

Nanoscience and nanotechnology define significant trends today that seek to exploit the new physical laws encountered as the structures and devices we make become smaller and smaller. Most attention is on the quantum effects that dramatically alter the electrical, magnetic, optical, mechanica– virtually all–properties of materials in surprising but exceedingly useful ways. Optical physics is playing a significant role in both these trends. Near-field, multi-photon, and confocal microscopy and laser tweezers are opening the frontiers of nanoscience by probing and manipulating individual nanostructures, while laser lithography is a nanotechnology used in high-volume manufacturing of nano-size transistor gates in microelectronic chips.

As this race to shrink the world goes forward, optical physics is also evolving with its own set of challenges to understand and to harness the new optical phenomena in nanostructures much smaller than the wavelength of light. Nanooptics has emerged as the new discipline that promises new optical materials (photonic bandgap crystals, metamaterials, plasmatronics) to guide light at dimensions below conventional diffraction limits or probe the electron wavefunction of protein molecules with powerfully enhanced optical resolution.

To this end, the proposed NSERC program seeks to invent a new means of laser optical beam delivery that will facilitate the fabrication of 3-D nano-optical systems. Near-field and phase-shifting techniques will be exploited in multi-level diffractive optical elements to design 'intensity defects' within 3-D periodic interfering laser patterns. Photosensitive optical materials exposed to these modified laser patterns will see nanooptic devices precisely embedded at the critical points of a 3-D periodic lattice to enable the nanofabrication of compact 3-D photonic crystal circuits, 3-D optical-domain metamaterials, and nanofluidic chromatography sensors for cell proteomics. This significant extension of laser holography promises a powerful advance in nanooptics and defines a new paradigm for high-volume manufacturing–contactless 3-D nanomolding–of significance to Canada's optics, biophotonics, and nanotechnology industry.

Herman, Peter — Intelligent Beam Control for Ultrashort Laser Manufacturing of Photonic and Biomedical Microsystems

photonics.light.utoronto.ca/laserphotonics/

The symphony of colours and light flashes generated during laser machining attest to the dramatic undulating physics evolving rapidly as material is transformed through various states of matter, heated to sun-like temperatures, shocked to explosive pressure, and finally ejected at supersonic velocity. Understanding and controlling such complex phenomena is a major science challenge and, regretfully, too poorly understood to benefit today's industry as it attempts to steer wanton laser processes into reliable nano-scale manufacturing methods for a new generation of smart medical devices, bio-sensors, and Telecomm products.

The proposed program aims to improve the fundamental understanding of laser interactions at the forefront of 'burst' ultrafast laser processing and self-focusing 'filamentation' machining–effects first discovered by our group. Our aim is to turn this understanding into 'intelligent' laser control methods that can manage the highly nonlinear light interactions in transparent materials and possibly open a new direction for three-dimensional manufacturing. A novel burst generator provides tailored laser profiles to build up heat accumulation and annealing effects to counter shock and other collateral damaging effects. State-of-the-art delivery systems with self-learning algorithms for spatio-temporal beam shaping are to be developed for dynamic focusing into transient plasma and defect centres that promise to control the size, position, stress, and morphology in various laser machining directions. Powerful 5-D spectroscopic and phase-contrast microscopy tools will uniquely harvest the rich optical signature of the laser physics to offer real-time monitoring as optical and microfluidic devices take shape. Femtosecond laser filamentation is a new opportunity for deep penetration machining and stress-induced scribing of transparent media like flat-panel display, silicon wafers, and lab-on-a-chip devices. The program aims to deliver new laser diagnostic and control systems for 3-D manufacturing of Telecom optical circuits, optical fiber assemblies, smart medical catheters, optical sensors, and other high value photonic systems for our Canadian partners.

Hum, Sean — Reconfigurable Antennas for MIMO and Compact Handsets

www.waves.utoronto.ca/prof/svhum/research.html

This project is exploring the development of reconfigurable antennas for use in compact terminals such as handsets. Such antennas can significantly improve signal diversity which is crucial for improving the performance of multi-input multi-output (MIMO) systems. They can also benefit handsets operating in highly dynamic environments where antennas with agile characteristics can be used to effectively deal with changing channel conditions. This type of technology improves the capacity and reliability of wireless networks.

Hum, Sean — Reconfigurable Aperture Antennas

www.waves.utoronto.ca/prof/svhum/research.html

This project focused on the development of aperture antennas producing highly selective antenna beams that can be electronically manipulated in a cost-effective manner by tuning elements composing the aperture. Aperture types include reconfigurable reflectors, lenses, and conformal surfaces. This technology has applications in satellite communications, RADAR, and other long-range communication links.

Hum, Sean — Ultra-Wideband Antenna Arrays

www.waves.utoronto.ca/prof/svhum/research.html

This project aims to develop reconfigurable beam-forming networks for ultra-wideband communication systems operating in the 3-10 GHz range. The basic idea is to use electronically agile networks that process signals in both space and time, in conjunction with an array of antennas, to realize high-gain antenna patterns for receivers which maintain their characteristics over an ultra-wide frequency band. Ultra-wideband antenna arrays can be used in communications, radar, microwave imaging, wireless localization, and many other applications.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Iravani, Reza — Real-Time, Simulation, Control, and Protection of Integrated AC-DC Power Systems

www.ele.utoronto.ca/~iravani

This work includes research and development of analytical and time-domain simulation tools, control and protection strategies/algorithms for: (1) interconnected AC power systems that imbed overlay High-Voltage Direct-Current (HVDC) grids, mainly for large-scale integration of wind and solar power, (2) microgrids with high-depth of penetration of distributed generation and storage units.

Jacobsen, Hans-Arno — Middleware Systems

msrg.org

This research aims to ease the development of scalable, reliable, and secure distributed enterprise applications. In pursuit of these objectives, he engages in basic research on event processing, publish/subscribe, service-orientation, aspect-orientation, and green middleware. In research and development engagements with various companies, he pursues projects on business process management, service delivery models, service and infrastructure management, and e-energy. Selected research projects include the PADRES Events & Services Bus (padres.msrg.org) for effective business process management, the eQoSystem project (eQoSystem.msrg.org) for declarative monitoring and control of SLAs (service level agreements) in enterprise applications and business artifacts, and the AspeCtC (ACC) project (aspeCtC.net) for increasing modularity in systems software and embedded systems.

Ongoing research seeks to add and improve enterprise-grade qualities of the middleware. The PADRES system is a distributed content-based publish/subscribe middleware with features built with enterprise applications in mind. These features include: (1) Intelligent and scalable rule-based routing protocol and matching algorithm ; (2) Powerful correlation of future and historic event; (3) Failure detection, recovery and dynamic load balancing (4) System administration and monitoring. As well, the PADRES project studies application concerns above the infrastructure layer, such as; (1) Distributed transformation, deployment and execution; (2) Distributed monitoring and control; (3) Goal-oriented resource discovery and scheduling ; (4) Secure, decentralized choreography and orchestration. A publish/subscribe middleware provides many benefits to enterprise applications.

Janischewskyj, Wasyl — Lightning Studies at the CN Tower

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The CN Tower, the tallest free-standing structure instrumented for observation of LIGHTNING, has been used by the CN Tower Lightning Studies Group (LSG), based in the ECE Department, for the last more than 40 years to record, significant to engineering, parameters associated with lightning strikes. Staff and students of the University of Toronto as well as those of Ryerson University and McMaster University, and occasionally Visiting Scientists and Visiting Professors from various parts of the world are members of the Group. Further to collecting data through measurement, graduate courses are offered and research is conducted in the area of Lightning Protection. Findings of the Group have been adopted in Canadian Lightning Standards and in documents of International Working Groups dealing with questions of Lightning in such technical societies as IEEE, CIGRE and IEC. In August of 2001 an International Workshop was held at University of Toronto at which the International Project on Electromagnetic Radiation from Lightning to Tall Structures (IPLT) was launched. There are now 12 countries participating in the Project. Our Group represents Canada and Wasyl Janischewskyj has been Chairman of the IPLT Steering Committee from 2001 to 2009.

Activities of LSG are continuing. Recent research findings include development of the Five-Section Model for representation of the CN Tower in computational processes, proposal of a procedure to account for variable speed of return-stroke propagation within the lightning channel and introduction of Cartesian coordinates in computation of the electromagnetic field radiated by a return lightning stroke to a tall structure. This latter development provides a convenient tool for computation of the electromagnetic radiation by a tortuous path of the lightning channel.

Johns, David — Advanced Interface Circuits for MEMS Technology

www.eecg.toronto.edu/~johns

Micro-ElectroMechanical Systems (MEMS) refer to tiny devices that combine micrometre-scale mechanical devices with micro or nano scale electronic circuits to sense physical quantities. Some recent examples of commercial applications for MEMS are pressure sensors used as microphones in devices such as cell phones and hearing aids, inertial sensors used in airbag deployment as well as positional control in handheld games and cell-phones, and gyroscopes used for image stabilization for cameras as well as angular velocity measurement in handheld games.

This research program investigates new circuits and architectures that will significantly improve MEMS power dissipation as well as improve accuracy performance. With improved accuracy, new applications can be developed that are not otherwise possible. For example, a highly accurate inertial sensor can be used to track position by integrating acceleration to obtain velocity and then integrating velocity to determine distance travelled.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Kherani, Nazir — High Efficiency Silicon Photovoltaics

www.ecf.utoronto.ca/~kherani

The objective of this project is to research, develop and integrate a set of thin film technologies that will lead to prototype demonstration of high efficiency silicon photovoltaic solar cells. The novelty of the research lies in the development and integration of unique, production worthy technology elements which will ultimately make it possible to attain the lowest cost per watt peak (Wp) of silicon based photovoltaic solar cells.

Silicon offers one of the highest photovoltaic energy conversion efficiencies. This property along with its stability, abundance, environmental compatibility, and technological maturity make silicon a prime material for photovoltaics. However, the challenge today is cost. Cost can be reduced by decreasing production and material costs and by increasing energy conversion efficiency.

The range of unique technology elements comprising this project are:1. development of high efficiency solar cell concepts with the objective of producing the greatest quantity of solar electricity per gram of silicon (i.e., thin silic; 2. use of low-temperature, high quality thin-film synthesis techniques with the objective of implementing low-thermal budget and high production rate processing; and 3. integrated development of PV cell concepts, photon harvesting techniques, and production processes compatible with the drive to continually reduce the silicon absorber thickness.

Kherani, Nazir — MicroPower Sources and Sensors

www.ecf.utoronto.ca/~kherani

The objective of this project is the development of micro-power sources and micro-sensors for various sensing applications with the ultimate realization of self-powered sensors.

One approach that we are currently pursuing is the development of a continuous vibrational piezoelectric energy harvester using a tritium-occluded-in-silicon beta-emitting source. Integration of the beta source enables a constant source of vibration thus overcoming the limitations of ambient vibrational sources. The vibrational energy harvester is based on aluminum nitride piezoelectric material. Current sensor development uses the aluminum nitride platform, investigating surface acoustic wave detectors with the use of various sensitizers.

Kherani, Nazir — NICE Composite Materials

www.ecf.utoronto.ca/~kherani

Nano-Integrated Carbon-Enveloped (NICE) composites are being developed (i) as smart coatings for energy conservation in buildings' applications, and (ii) as novel materials for photonic applications.

NICE composites, based on diamond-like carbon film, which is a silicon-compatible material, has thermal, mechanical, optical, and electrical properties that can be tailored over extremely wide ranges, yielding a versatile material for photonic, optoelectronic, and micro-electro-mechanical systems (MEMS) applications.

The objective of this project is to demonstrate NICE composites as a viable platform material for the development of smart coatings for building energy applications, and explore its viability as passive and active (rare-earth base photonic materials.

Kherani, Nazir — Photonic Crystal – Photovoltaics

www.ecf.utoronto.ca/~kherani

The aim of this project is to investigate photonic crystal - photovoltaic integrations with the aim of creating high-efficiency, economic, third-generation solar cells. The novelty of the research lies in innovative integrations of nano-materials and thin film semiconductors.

As thin film crystalline or nanocrystalline silicon solar cells are made thinner, light trapping at wavelengths near the absorption edge becomes increasingly important (e.g., absorption lengths are 10 mm and ~1mm for wavelengths of 800 nm and 1100 nm, respectively). Upon applying perfect random scattering on an incident silicon surface with a lossless back reflector, a maximum path length enhancement of ~50 is expected though in reality the actual value is closer to 10. Much larger path length enhancement factors, on the order of 103 to 104, however are required to effectively absorb the longer wavelength light. An alternative approach is light localization through the application of photonic crystals.

Photonic crystals (PC) are periodic dielectric structures that affect the behaviour of electromagnetic waves similar to periodic potentials in semiconductor lattices that affect the behaviour of electron waves. Through the exploration of a range of nano-integrations, we have recently proposed a novel class of transparent conducting porous nanocomposite films amenable to a variety of device applications. One application involves the use of a selectively transparent and conducting photonic crystal as an intermediate reflector for efficiency enhancement of tandem thin film silicon micromorph solar cells. Other application areas include bifacial PV, LEDs, and catalytic processes.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Khisti, Ashish — Signals, Multimedia and Security Laboratory

www.comm.utoronto.ca/~akhisti

Our research focuses on two areas that are crucial for the success of future wireless systems: Security and Multimedia. In traditional architectures, wireless links are the weakest links in security. Our research challenges this notion and strategically exploits the unique characteristics of wireless links at the physical layer to develop new security mechanisms. Our group is also investigating new wireless networks optimized for multimedia rich services that will play a key role in the future of human communications.

Kschischang, Frank — Error Control in Network Coding

www.comm.utoronto.ca/frank

Network coding, proposed by a small group of researchers ten years ago, has the potential to greatly improve the efficiency of information transmission in packet networks. The key idea of network coding is to generalize the operation of intermediate nodes in the network, changing their operation from routing to coding. Traditional network routers treat packets as fragile and distinct pieces of a message, to be switched along appropriate network pathways, and reassembled into a message at the receiver. Network coders, on the other hand, treat packets as robust and indistinct lumps of "evidence" which can can be mixed together (and not just routed) at intermediate nodes. Receivers gather evidence, and can infer which message was sent when sufficiently many clues have been received. The great advantage of allowing evidence to be combined at intermediate nodes is that this evidence can then better squeeze through network bottlenecks, allowing for greater transmission efficiencies than can be achieved through routing alone. In this work, we have developed several novel methods for error control coding in the context of network coding. In one interesting approach, information is encoded using a "codebook of vector spaces". Together with Ralf Koetter and Danilo Silva we have developed a family of Reed-Solomon-like codes, provided decoding algorithms, developed connections to rank-metric codes, and developed schemes to provide security against wiretapping. Our initial paper on this subject, published in 2008, received the 2010 IEEE Communications Society and Information Theory Society Joint Paper Award. Ongoing work seeks to develop these ideas at the "physical layer", with the potential for improved and robust transmission protocols in wireless mesh and relay networks.

Kschischang, Frank — Advanced Coding and Signal Processing in Fiber-Optic Communication Systems

www.comm.utoronto.ca/frank

Fiber-optic transmission systems are evolving at a rapid pace towards achieving greater spectral efficiencies. Coherent detection is supplanting noncoherent detection, polarization multiplexing and advanced modulation schemes are being implemented. Today's high-speed electronics enables very sophisticated signal processing and coding to be applied, even at extremely high data rates, yet there is a significant gap between what has so far been practically achieved and what is known to be achievable in theory. A first aim of this project is to investigate practical signal processing algorithms that mitigate channel impairments that dominate in optically- routed systems that operate at high spectral efficiencies in a WDM environment. Such systems are likely to employ inline chromatic dispersion mapping, but such mapping alone is unlikely to be able to fully compensate for fiber nonlinearity at high spectral efficiencies. Electronic pre- and post-compensation is thus likely to be needed. In particular, electronic back-propagation is a promising approach that may lead to an equivalent channel for which new coding and modulation techniques may be applied to practically achieve the desired spectral efficiencies.

A second aim of this work is to investigate the synergy that results from a judicious selection of coding and modulation techniques in conjunction with the receiver-side signal processing. It is well known in wireless communication that joint channel processing and decoding is beneficial (both from a performance and from an overall complexity point of view) compared with a system in which these receiver functions are separated. A central issue here is code design: how should the error-control system be designed to meet communication objectives while simultaneously providing assistance to signal processing functions at the receiver? A potential outcome of this work is a new approach to joint coding, modulation, and signal-processing that leads to the practical achievement of greater spectral efficiencies in optical transmission systems.

Kwong, Raymond — Dependability and Security in Control and Multimedia Systems

www.control.utoronto.ca/people/profs/kwong

Control and multimedia systems have become increasingly sophisticated and complex. Failures in these systems can lead to large financial losses or even catastrophes. For control systems, our research combines advanced tools from control and artificial intelligence to detect failures or discover previously unknown faults. We integrate diagnostic information to reconfigure control systems so that they are dependable even when failures occur. We seek to make multimedia systems more secure by designing new strategies to embed forensic information that protects copyrights, is resilient under content manipulation attacks, and deters piracy.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Lehn, Peter
www.ele.utoronto.ca/~lehn

Power Electronics to Enable More Sustainable Electrical Energy Networks

Professor Lehn's research lies in the area of medium and high power applications of power electronics to form more reliable, cost effective and sustainable electrical energy systems. Of specific interest is the development of converter systems and network architectures for low cost, low loss integration of wind, solar, and energy storage resources, including plug-in hybrid/electric vehicles. Improving robustness and power quality of the electrical grid via intelligent control of power electronically interfaced sources and loads is a major focus. Research into high power applications revolves around exploitation of established and emerging HVDC and FACTS technologies to improve utilization and stability of power transmission systems.

Leon-Garcia, Alberto
alberto.leongarcia@utoronto.ca

Autonomic Service Architecture

We are developing an architecture for a new network and service management and control system that largely manages and controls itself, and is able to accommodate a multitude of existing and future applications, thus promising to be highly cost efficient and flexible. This ideal self-regulating management and control system would be responsive to ever changing demands and even equipment failure, and would autonomously regulate and optimize configurations of data flow, be able to protect itself from harmful impact - and even have the capabilities to self-heal.

Leon-Garcia, Alberto
www.vani.utoronto.ca

Connected Vehicles and Smart Transportation

The ORF Research Excellence project on Connected Vehicles and Smart Transportation is a collaborative project between industry, government and academia to develop an information gathering and sharing platform to enable smart applications for transportation and transit in the public and private domains. The CVST systems leverages the sensing capabilities of mobile devices and public sector sensors to provide real-time state information that enable users to make decisions that reduce travel time, increase productivity, and reduce energy consumption and vehicle emissions.

Leon-Garcia, Alberto
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Design of Converged Communications and Computing Infrastructure

We are developing future network architectures that are application oriented, that have the flexibility to simultaneously support multipleprotocol stacks, and that operate over a converged computing and communications infrastructure. In order to enable at-scale experimentationwith novel protocols and applications, we have developed application oriented routers that provide virtualized computing and communicationsresources, and that when interconnected provide a network test bed. We are also developing a service-oriented control and management system that allows the creation of multiple, simultaneous converged networks for testing and developing new protocols and applications.

Leon-Garcia, Alberto
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NSERC Strategic Network on Smart Applications on Virtual Infrastructures

The NSERC Strategic Network on Smart Applications on Virtual Infrastructures is a partnership between Canadian industry, academia, government, education research networks and high performance computing centres. SAVI is developing a virtualized converged computing and communications infrastructure that can support the rapid deployment of large-scale distributed applications. A key innovation in SAVI is the notion of a smart edge that complements remote datacenters to build an extended cloud. A major goal of SAVI is to develop a national testbed to support experimentation in Future Internet protocols and architectures as well as future large-scale applications.

Leon-Garcia, Alberto
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Optical Networks for Ultrascale Datacenters

We are designing optical networks that can provide connectivity for future datacenters that can interconnect several million servers. At this scale, power consumption, footprint, and space for Ethernet cabling become severe challenges that can be addressed through the deployment of optical multiwavelength transmission and switching technologies.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Levi, Ofer
biophotonics.utoronto.ca

Optical Bio-Sensors and Biomedical Imaging Systems

Our research interests include developing biomedical imaging systems and optical bio-sensors based on semiconductor devices and nano-structures, and their application to bio-medical diagnostics, in vivo imaging, and study of bio-molecular interactions. The goal of our work is to integrate sensor components into miniature functional bio-sensors and apply them to novel biology and bio-medical applications. As such, our research is interdisciplinary and include semiconductor device physics, optics, micro- and nano-fabrication, chemistry and applications in biomedical diagnostics, cancer studies and neurobiology.

Li, Baochun
iqua.ece.toronto.edu

Agile Cloud Computing via Multi-Level Performance Inference

Cloud computing systems need to be judiciously managed to scale up to multiple geographically diverse data centres, each with tens of thousands of servers, networking switches, and storage systems. At this scale, energy costs have already become more than a third of the overall costs of maintenance and upkeep. As clients are served with a large number of service-oriented applications — such as on-demand media streaming — running on such cloud computing systems, it is crucially important to operate these systems at the maximum energy efficiency, to achieve the vision of green cloud computing. In this project, we will establish and design a fundamental inference framework that forms a basis towards these goals. Leveraging time-sequential graphical inference models, this framework can (1) forecast the demand in each service instance, (2) predict the workload at each individual server node, and (3) characterize the dependencies between the quality of service when delivered to clients and the incurred bandwidth and energy costs. Underlying all these inference tasks is a simple intuition — a node's future behavior is predictable through observations of its current (or historical) states. Our inference framework only needs each server node and client to collect direct and limited observations from its neighborhood, and can be re-trained online.

Li, Baochun
iqua.ece.toronto.edu

Magellan: Charting Large-Scale Commercial Peer-To-Peer Streaming Systems

In the Magellan project, we seek to extensively measure and analyze a large-scale peer-to-peer (P2P) streaming system, in collaboration with UUSee Inc., a leading P2P streaming solution provider in China. Magellan is based on large volumes of traces (more than a terabyte over a period of one year) collected from the UUSee streaming system, involving millions of users, with a snapshot of the entire system every ten minutes. The methodology and scale of this work is unprecedented in P2P streaming research. Our research in Magellan investigates P2P streaming topologies, characterizes P2P streaming flows, provisions server capacities, and predicts the scale and performance in the near-term future.

Li, Baochun
iqua.ece.toronto.edu

Nuclei: Many-Core Network Coding on the GPU

In the Nuclei project, we have successfully implemented an accelerated multi-threaded implementation of network coding, to take advantage of both multiple CPU cores with aggressive multi-threading, and SSE2 and AltiVec SIMD vector instructions on x86 and PowerPC processors. We have shown a 20x performance improvement over the baseline implementation. Further, by taking full advantage of modern Graphical Processing Units (GPUs) with hundreds of computational cores, we have managed to push the performance envelope of network coding by showing a further 10x performance improvement over the best possible performance without GPUs.

Liang, Ben
www.comm.utoronto.ca/~liang

Resource Management and Optimization in Wireless Networks

In next-generation heterogeneous wireless networks, the increased number of networked devices and the broadband nature of application demands will aggravate the need for efficient resource sharing. The goal of this research is to develop fundamental theories, networking algorithms, and communication protocols for efficient allocation of spectrum, hardware, and power in high-throughput wireless networking environments. Our investigations include stochastic optimization, distributed computing, and cooperative communication.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Lie, David — Computer Systems Security

www.eecg.toronto.edu/~lie

Cloud computing offers a new exciting form of service to users in need of compute infrastructure. It provides users a pay-as-you go model, and allows users to outsource costs such as management, power and cooling, procurement and provisioning. Unfortunately, cloud computing poses serious security concerns. Users want to ensure the security of their data and code while executing in the cloud. At the same time cloud providers want to protect their infrastructure from being abused. We are working on a new paradigm that will offer users unprecedented flexibility to control how and where their data is stored in the cloud, while at the same time give them the benefits of mobility, durability, availability and elasticity that cloud computing has to offer.

We are exploring security and usability issues in modern mobile phones. Today's smart phones have more computing power than yesterday's work stations. However, they fit in your pocket, travel with you wherever you go, and are involved in a multitude of daily activities. In addition, capabilities on the phones allow them to track your location, record conversations and maintain a list of people you interact with. While these are useful, mobile phones also pose a grave security threat to privacy and security, larger than that of any other computing device. In this research, we explore the development of mobile phones to make them more secure, improve their power utilization and overall usability.

Liebeherr, Jorg — Network Architectures and Services for a Mobile World

www.comm.utoronto.ca/~jorg

With their ability to create large scale self-organizing networks on-the-fly peer-to-peer overlay networks have shown to be a disruptive technology, that has enabled new application services in support of content distribution, streaming, and social networking. We believe that the role of self-organizing overlay networks can be much greater, and that the full potential of this technology remains largely unexplored. In our research, we explore the potential and fundamental limits of a network architecture for mobile users that is entirely based on the principles of self-organizing overlay networks. The architecture is characterized by the coexistence of virtually unlimited numbers of mostly mobile users in peer networks that can quickly grow to arbitrarily large sizes and adapt to changes in the number of peers and substrate networks.

Lim, Teng Joon — CUDA for Wireless Communication Simulations

www.comm.utoronto.ca/~limtj

Wireless communications systems are growing ever more sophisticated in order to provide increasingly demanding users with the service quality they expect. As a result, the signal processing and other functions in a transmitter and receiver are very complex, e.g. it is now standard for systems to adapt their modulation/coding formats to the channel, employ error control codes that are theoretically close to optimal, and so on. In order to design such systems, it is necessary to simulate them in software before prototyping them in hardware. However, due to the system complexity, end-to-end performance simulations using the popular software package Matlab is very time-consuming, often requiring a few days of continuous computations for even quite routine simulations. Sometimes it would be simply infeasible to perform these simulations for realistic parameter values and so researchers would resort to simulations of very small systems (two users only for instance). In this project, we have been using Nvidia's CUDA platform to leverage the parallel processing feature of graphical processing units (GPUs) to perform these simulations. The goal is to provide a toolbox of often-used functions that other researchers can apply in their simulations. With speed-up factors up to several hundred over C programs run on conventional serial processors, this approach is very attractive and is fast catching on in many computationally intensive research fields.

Lim, Teng Joon — Downlink Transmission with Noisy Channel Information

www.comm.utoronto.ca/~limtj

A base station transmitting to multiple users can perform much better when it knows the channel to each user, e.g. it can process the signal it transmits so that each user receives its own signal without interference. However, having accurate channel knowledge is practically impossible, as the channel must be estimated with finite accuracy, and those estimates used after a finite delay during which time the channel may have changed. The characterization of the performance of transmitter precoding in the presence of inaccurate (or noisy) channel information, and the design of precoders that explicitly account for these inaccuracies, are the objectives of this project. Its outcomes will be design guidelines that tell system designers when precoding using noisy channel information is beneficial, and a superior design that always performs better than conventional methods because it models the noise in the channel information explicitly to a reasonably accurate approximation.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Lim, Teng Joon
www.comm.utoronto.ca/~limtj

Opportunistic Communications through Spectrum Sensing

The finite band of electromagnetic spectrum that is suitable for wireless communications is growing more crowded every day, with much of it already dedicated to licensed users such as radio and TV stations, cellular service providers, and emergency services. However the nature of many of these communication systems make it impossible for them to use their assigned bands efficiently, e.g. data communications occurs in bursts with silent periods in between, and TV channels are not used in some parts of the country due to low demand. In this project, we explore the possibility of opportunistic communications through intelligent sensing of the spectrum (e.g. sensors acting cooperatively). In particular, we design schemes for sensing spectrum availability in the shortest possible time, and we calculate the throughput and probability of interfering with the licensed user of various spectrum sensing methods. The outcome of the project will be an understanding of the feasibility of opportunistic communications for various application scenarios, and enhanced spectrum sensing methods to maximize system performance.

Lo, Hoi-Kwong
www.comm.utoronto.ca/~hklo/index.html

Quantum Cryptography: from Theory to Practice

We seek to build high-speed (> 1 Gbit per sec) unbreakable secure communication systems based on quantum mechanics. “The human desire to keep secrets is almost as old as writing itself.” With the advent in electronic businesses and electronic commerce, the importance of secure communications via encryption is growing. Standard encryption schemes are based on unproven computational assumptions. In contrast, quantum code-making offers perfect security in communication based on the laws of physics. Our goals are to dramatically improve both the performance and security of practical quantum key distribution systems. We do so through system building and studying hacking strategies and counter-measures.

Maggiore, Manfredi
www.control.utoronto.ca/~maggiore

Advanced Motion Control in Robotic Systems

Motion control problems are ubiquitous in industrial manufacturing and advanced robotics. Examples include the design of autopilots for unmanned aerial or land vehicles, the control of haptic interfaces, and the control of medical exoskeletons for patients with severe leg injuries. What these problems have in common is the fact that their solution does not involve the stabilization of an equilibrium or the tracking of reference signals, as is the case in classical manipulation. Rather, these problems require the enforcement of certain constraints between the states of the system. Classical control theory is not equipped with methods to solve this new class of problems, and in fact existing algorithms for motion control are the result of ad hoc considerations for specific systems. Without general methods to synthesize motion controllers, modern robotic systems will not attain their full potential. The objective of this research is the development of systematic methodologies and algorithms to solve motion control problems for a large variety of electromechanical systems. One of the potential applications is the control of walking motion for biped robots.

Maggiore, Manfredi
www.control.utoronto.ca/~maggiore

Development and Control of an Autonomous Co-axial Helicopter

In the aerospace industry there is a growing interest in unmanned aerial vehicles (UAV) for a wide variety of civil and military applications, as well as for scientific activities. In particular, unmanned helicopters are attracting significant attention in this industry because their ability to hover makes them ideal for monitoring and surveillance applications. Helicopters, however, are difficult to control because, unlike airplanes, they are naturally unstable. Such instability is reflected in the fact that if the pilot does not perform continual corrections, the helicopter will tend to roll over and lose control. In collaboration with Quanser Inc., we are developing a small co-axial helicopter which is highly maneuverable and completely autonomous. Leveraging recent theoretical advances in the field of nonlinear control, we will also design an autopilot to make the aircraft perform complex maneuvers without any human intervention.

Mann, Steve
www.eyetap.org/research/medr.html

Augmented Reality Will Never Work, and That’s Why We Need Mediated Reality

Augmented Reality, whether by handheld iPhone applications that we’ve developed in our lab and elsewhere, or by eyePhone (electric eyeglasses), has been shown to be problematic by causing information overload. What we’ve learned is that an older concept called ‘Mediated Reality’ overcomes these problems. We’ve developed various mediated-reality iPhone apps as well as eyeglass apps, etc., that help people see better and find their way better. This research emphasizes fundamentals of physics, computer science, and engineering. This research is also coupled closely with the undergraduate and graduate course, ECE516 http://wearcam.org/ece516/

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Mann, Steve
InteraXon.ca

Brain-Computer-Interaction (BCI) and EEG-based Cyborg Technologies

Brain-Computer-Interaction (BCI) systems developed as part of the wearable computing and cyborg technologies efforts have been widely deployed in industry. Our work was showcased at the Vancouver Olympics as part of Ontario House, and continues to be adapted into various products around the world. BCI based on the Chirplet Transform (http://wearcam.org/chirplet.htm) has been the subject of a recent PhD thesis and a number of research papers. See http://www.eyetap.org/publications.

Mann, Steve
wearcam.org/comparam.htm

Comparametric Equations and High Dynamic Range (HDR) Imaging

High Dynamic Range imaging has many applications such as in electric eyeglasses. On the pure-math side, there's the theory of comparametric equations. On the practical side, there's applications in extending the dynamic range of imaging devices such as electric eyeglasses and portable cameras and cellphones, etc.. See 'Comparametric Equations with Practical Applications in Quantigraphic Image Processing', IEEE Transactions on Image Processing, Vol 9, No.8, August, 2000, which you can download fromhttp://www.eyetap.org/publications.

Mann, Steve
www.eyetap.org

EyeTap Electric Eyeglasses, Personal Safety Devices and Systems

The EyeTap electric eyeglasses cause the eye itself to become both a camera and display for computer-mediated reality that achives augmented reality but also goes beyond it, to not only augment, but to also modify, and thus help people see better, find their way better, etc.. Not only the wearable face-recognizer that puts virtual nametags on people, etc., but also the mediated vision that helps people see better and improves their personal safety.
See http://www.eyetap.org and http://glogger.mob.

Mann, Steve
glogger.mobi

Lifeglogging: Lifelong Videocapture

Since early childhood I've been wearing a computer system that captures my life. In the 1990s I miniaturized this into a necklace with fisheye lens and various sensors (http://wearcam.org/neckcam.htm) and presented this work to Microsoft as the Keynote Address of CARPE in 2004. Microsoft has subsequently manufactured a similar product called SenseCam. Others such as DARPA, HP Labs, and Nokia have also been building on this lifeglogging work which is also known by many other names such as lifelogging, lifeblogging, CARPE, or lifestreaming. We now have a community of more than 80,000 'cyborgs' on http://glogger.mobi and research continues into the mobile multimedia iPhone apps, as well as versions built inside the eye socket of the blind.

Mann, Steve
FUNtain.ca

Musical Instruments and other Human-Machine Interface Inventions

This research looks at innovative human-machine interaction based on arrays of air jets, or the like, to create volumetric tactile input devices such as 'air typing', in which the fingers move through space and interact with air currents. We've also developed a computer keyboard that has no moving parts. In place of each key is a finger hole, supplied by a system that detects restrictometric parameters of air flow of waste air from the CPU fan. The research is based on Karman Vortex shedding across bluff bodies, like the shedder bars in the hydraulophone (underwater pipe organ), and turbulences as a form of input and output medium. This research goes beyond what's possible with hydraulophone; take a look at this vid and then imagine the possibilities when we miniaturize it and use air instead of water: **http://vimeo.com/14018088.**

Mann, Steve
wearcam.org/absement/examples.htm

Physics-Based Modeling using Presement and Absement

Velocity is the time-derivative of position or displacement; differentiating once more gives acceleration. But what happens when you take the time-integral of displacement. The result is something called absement. Integrating again gives absity. Integrating once more gives abseleration. Absement, absity, and abseleration arise in fluid flows. For example, the amount of water flowing through a valve is the absement of how open the valve is, i.e. the time-integral of the openness. Other examples of absement arise in hydraulophonic sound production (sound from vibrations in water); see http://wearcam.org/absement/.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Mojahedi, Mo
www.waves.utoronto.ca/prof/mojahedi/mo.html

Engineering the Electric and Magnetic Dispersive Responses of Artificial Media

Much of our modern conveniences are the consequence of our ability to control and modify the behaviour of naturally occurring materials and to design and manufacture artificial materials and systems with novel properties. In electromagnetic theory, materials and systems' behaviours are characterized according to the so called "dispersive effects." Depending on the researcher's area of interest and expertise, he or she may use different terminologies such delays, indices, or velocities to characterize the same dispersive effects. Despite these different nomenclatures, we may note that fundamental and important relations exist among the various delays, indices, and velocities. Dispersion Engineering paradigm formulates our attempts to control and manipulate the aforementioned various delays, indices, or velocities–the dispersive effects–by synthesizing artificial materials and designing novel systems, which in turn allow us to control and manipulate the amplitude and phase of voltage or current waveforms and/or electromagnetic pulses in order to achieve a desired outcome. For example, the paradigm of dispersion engineering has been use to demonstrate unusual behaviours such as negative or superluminal group delays and negative refractions. In addition to scientific interest in such unusual behaviours, dispersion engineering has been used to design more functional microwave devices such as broad band phase shifters, efficient antenna arrays, and interconnects with reduced latency, to name a few.

Mojahedi, Mo
waves.utoronto.ca/prof/mojahedi/mo.html

Nano-Plasmonic and Nano-Photonic Devices

Rapidly performance of computers is expected to reach its fundamental limits in terms of speed, bandwidth, power consumption, and electromagnetic interference. Partially, problem lies in degrading performance of electrical interconnects. Unlike transistors, for which their functionality increases by miniaturization, electrical interconnects functionality degrades substantially with miniaturization. It has been suggested to replace the electrical interconnects with optical interconnects where the latter do not suffer from signal latency, limited bandwidth, or high power consumptions as compared to their electrical counterparts. However, there is a major problem with optical interconnects and waveguides. The optical mode size, and hence the device size, is approximately proportional to the operational wavelength. In other words, while transistors with dimensions of approximately 50 nm are common today, the micron size of optical devices makes their integration with electronics difficult. Surface plasmon polariton (SPP)–surface waves at the interface between a metal and dielectric–may provide a solution. These plasmonic waveguides, similar to optical interconnects, have small latency and large bandwidth but unlike the optical interconnects they can easily be miniaturized. However, plasmonic waveguides have their own challenges. Chief among these are: (1) large propagation losses and (2) lack of various efficient and integrated plasmonic devices such as polarizers, directional couplers, and bends, to name a few. In order to overcome the losses associated with SPP while maintaining a small device size, our group was among the first to propose a hybrid plasmonic waveguide (HPWG). The HPWG can be viewed as an optimized structure exhibiting a compromise between loss and mode size. Moreover, fabrication of our HPWG is compatible with the existing silicon technology. Our HPWG can be used as a building block for the next generation plasmonic devices such as TM- and TE-pass polarizers, polarization independent couplers, and other novel components.

Moshovos, Andreas
www.eecg.toronto.edu

Bandwith Efficient DRAM Controllers in Non-Coherent Systems

Embedded and mobile hand held devices have been proliferating enabling applications that were not possible or cumbersome with the big iron machines of the past. Each new generation of these devices offers more capabilities enabling new applications: While early mobile devices were capable of simple tasks and low bandwidth communication, today's devices offer many more capabilities such as multimedia, navigation, and digital photography. As their capabilities are increasing, novel applications will be possible such as health monitoring. For these possibilities to materialize, mobile and embedded systems need to become more powerful while maintaining reasonable up-time. A mobile system today contains several compute engines that are all supported by an external memory device. As the computation needs increase, more data needs to be fed to these engines. The link between these engines and the memory is the memory controller. The memory controller can greatly affect how much data and at what energy cost the memory can provide. This work will develop memory controller technologies that will boost data feeding capabilities while taking power into account. The goal is to develop the memory controller technology that will be used in future generation mobile devices in support of more demanding applications while allowing the device to stay on for longer periods of time.

Moshovos, Andreas
www.eecg.toronto.edu

Exploiting Multi-Megabyte On-Chip Memory Hierarchies

Several technology and application trends favor chip multiprocessor (CMP) architectures which integrate multiple processor cores, a memory hierarchy and interconnect onto the same chip. CMPs could be used for commercial servers and for end-user systems as they can support both multi-program and parallel/multithreaded workloads. They can also be used as the building blocks for shared multiprocessors (SMPs). Designing high-performance and power-aware memory hierarchies and interconnects is imperative for CMPs in order to meet the memory demands of multiple processors and applications while not exceeding power constraints. Continuing application trends towards larger memory footprints, multi-program workloads and the ever increasing speed gap between on-chip

and off-chip memory compound to put further pressure on the on-chip memory hierarchy and interconnect. Furthermore, on-chip integration presents us with new trade-offs and opportunities for optimizations that need to be exploited to deliver the expected performance/watt. Additional opportunities are provided by stack-die and on-die DRAM technology that may be used to incorporate multi-megabyte caches.

The key questions addressed by this research are: (1) How do we manage these multi-gigabyte caches; are the techniques that are currently used still adequate, or is there room or need for rethinking these decisions? (2) Can we exploit this tremendous wealth of on-chip storage to further optimize performance above and beyond of what is possible by simply caching instructions and data? Accordingly, the proposed research comprises two thrusts: The first considers the use of coarse-grain tracking for achieving performance that is otherwise not possible with conventional cache management techniques. The second, exploits the on-chip caches to store program metadata in addition to instructions and data. Program metadata is information collected at runtime about program behavior that can be used to anticipate and optimize for future program demands.

Moshovos, Andreas Power-Aware Cache-Based Structure Design

www.eecg.toronto.edu/~moshovos

Computing devices comprise processing elements that process digital information and memory elements for storing digital information. Due to technological constraints memory tends to be significantly slower than the processing elements it supports. Accordingly, virtually all modern computing devices employ caches, which are additional small and fast temporary memories that serve to accelerate most references to the otherwise slow memory elements. In recent years, power dissipation has emerged as an additional critical design constraint in computing device design; power limits performance for all devices and up-time for portable devices. Low power dissipation and performance are at odds; high performance typically comes at the price of high power dissipation. Caches account for a significant portion of total power dissipation (e.g., 25% to 45% of a modern processor) and due to semiconductor technology trends, their power dissipation is expected to increase in relative terms. Accordingly, there is a need for developing techniques to reduce their power while maintaining performance and usability. In addition, virtualization is emerging as a key technology for future server systems. Caches will play an important role in virtualization as they can accelerate accesses to memory from devices without intervention from the processor (this is necessary to achieve adequate performance). Accordingly, there is a need to understand and develop caching mechanisms for supporting this aspect of virtualization. In addition this project investigates the caching and communication architecture for fused CPU and graphics processor systems.

Nachman, Adrian Millimetre-Wave Imaging System

www.eecg.utoronto.ca/~sorinv/mm_wave_lab.html

This is a joint project with Professor S. Voinigescu's group. It seeks to integrate their breakthrough design of novel silicon systems on chip, (capable of transmitting and receiving very high frequency electromagnetic waves) with novel inverse scattering and compressed sensing algorithms to produce a millimetre wave imaging system.

Nachman, Adrian MRI- Based Impedance Imaging

www.currentdensityimaging.org

This ongoing project seeks to image electric properties of tissue with novel use of Magnetic Resonance Imaging apparatus. It is joint research with Professor M. Joy's laboratory, where Current Density Imaging was first invented. Recent progress includes the first electric conductivity images of the heart in live animals.

Najm, Farid N. Power Grid Verification

www.eecg.utoronto.ca/~najm

With increased power dissipation and reduced supply voltage, modern large microprocessors chips draw over 150 Amperes from the external supply! These levels of current are unprecedented in microelectronics, and are a key challenge for design. Apart from the design issues of delivering a well-regulated low voltage supply at such high current, a key problem for designers is to make sure that the increased voltage drop and/or rise (due to IR-drop and/or Ldi/dt drop) in the on-chip power/ground grid do not lead to functional failures. Another big problem is to design the grid so that the grid metal branches do not suffer from electromigration failures. We are aware of at least two industrial instances, a DSP core and a large microprocessors, where the chip had to be redesigned because functional failures on silicon were caused by current-induced noise on the power grid. However, checking the grid node voltages and branch currents is very time-consuming and expensive, so that it is often incompletely done, or not done at all. We are developing efficient techniques for verifying that the voltages and currents of the power/ground grid are safe and within user specifications and, in case the grid is found to be unsafe, for redesigning and optimizing the grid to achieve safety.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Najm, Farid N. — Variations-Aware Timing Verification

www.eecg.utoronto.ca/~najm

In advanced IC design, a myriad of sources of manufacturing process variations have become significant enough to affect chip performance. Likewise, variations of other (non-process) variables, such as supply voltage and temperature, have to be included, leading to the acronym PVT which represents process, voltage, and temperature variations. Of paramount importance is the impact of PVT variations on circuit timing, and the resulting yield loss when circuit timing exceeds certain limits for some parts. While ASIC manufacturers need to meet the specified performance at all corner settings of the PVT parameters, and microprocessor companies can afford to do speed binning around the nominal PVT design point, both camps are concerned about the variability of circuit timing, and the resulting timing yield loss. We are working on verification of circuit timing in the presence of timing variability

Ng, Wai Tung — Smart Power Integration and Semiconductor Devices

www.vrg.utoronto.ca/~ngwt

Our focus is on the integration of power devices, smart power integrated circuits, and power management systems. We have worked extensively on the development of CMOS compatible HV fabrication processes for automotive and consumer applications in the 40-100V range. Our VLSI power management work includes the demonstration of Dynamic Voltage Scaling systems using various integrated DC-DC converters with soft-switching topology, predictive dead-time control and with dynamically adjustable power transistor size for power conversion efficiency optimization.

Pavel, Lacra — Dynamic Optical Network Control and Self-Optimization

www.control.utoronto.ca/~pavel/LP_research2.htm

We seek to create new algorithms for automatic, dynamic network self-optimization by using system theoretical and control methods and incorporating both energy efficiency and transmission performance criteria. These algorithms will be implemented in protocols for self-management and will allow on-demand wavelength capacity to be set up, re-configured and re-adjusted with minimal human intervention. The system theoretic approach of our research will lead to scalable tools and techniques that take into account the full interaction between the various layers in a dynamic adaptive network and ensure a robust network performance.

Plataniotis, Konstantinos N. (Kostas) — Privacy Enhancing Face Recognition

www.dsp.utoronto.ca

This research encompasses novel ideas in security, biometrics, privacy, and smart data management principles. It creates a radically new digital asset distribution paradigm where privacy enhancing solutions are used to minimize privacy risks, strengthen regulatory oversight, and promote public confidence.

Plataniotis, Konstantinos N. (Kostas) — Privacy Protected Video Surveillance

www.dsp.utoronto.ca

The proposed development is a privacy protection system for video surveillance. It protects the personally identifiable visual information of subjects appearing in video surveillance footage by performing reversible encryption on the corresponding pixel regions (e.g., the face). This is a unique and effective privacy enhancing solution that can be applied immediately after video capture, but is reversible with the provision of a secret key, thus negating the need to store the unprotected original video footage in case an incident investigation occurs.

Plataniotis, Konstantinos N. (Kostas) — Signal and Image Processing for Stereoscopic Cameras, Biometric Sensors and Laser Radar Applications

www.dsp.utoronto.ca

We seek to provide support for development efforts in the areas of: (1) Signal-image processing for 3-D imaging applications in the frequency regimes of Visible and Infrared stereoscopic camera systems and Biometrics Sensors; (2) Image and Data fusion for the above multi-sensor systems; (3) Implementation of the signal-image processing developments for Biometrics sensors, (i.e. face tracking features using stereoscopic cameras, vital signs from EEG and ECG sensors) and imaging aid systems for helicopter landing operations in visually degraded environments.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Poon, Joyce — Active and Passive Silicon Photonics

www.ecf.utoronto.ca/~poon

We analyze, design, fabricate, and measure optical waveguides, modulators, and lasers implemented in silicon and hybrid InP-InGaAsP-on-silicon platforms. The devices can be simultaneously ultra- low-power, high-speed, and compact, which have applications in chip-to-chip and on-chip optical interconnects. Under this theme, our main projects are: 1. High-speed (> 10 Gb/s) microring modulators and lasers; . 2. Athermal optical devices on silicon-on-insulator; 3. Electron device modelling for optical modulators.

Poon, Joyce — Active Plasmonics

www.ecf.utoronto.ca/~poon

Abstract: Surface plasmon polaritons are coupled electromagnetic and electron density oscillations at the interface between a metal and dielectric. They can tightly confine electromagnetic energy to subwavelength length-scales. We are combining nano-sized features in metals with highly tunable materials exhibiting metal-dielectric transitions to create optical switches and modulators that can be activated at low energies. Under this theme, we have the following projects:1. Picosecond modulation dynamics of localized surface plasmon resonances 2. Surface plasmon waveguide modulators.

Prodic, Aleksandar — Power Management and Integrated Switch-Mode Power Supplies

www.ele.utoronto.ca/~prodic

Traditionally, low-to-medium switch-mode power supplies (SMPS), used in cell phones, computer systems, communications, vehicles, medical devices, and other application consuming power from a fraction of watt to several kilowatts have been controlled by analog means. Mostly, due to the operation at high switching frequencies and requirements for low-power cost-effective implementation. As such, they suffer from limited flexibility and are not best-suited for integration with modern digital systems.

Our research has developed enabling technologies for implementing digital controllers in high-frequency low-power SMPS, and is currently focusing on fully utilizing the digital control advantages as well as on the development of novel converter topologies.

Qian, Li — Fiber-Optic Sensing

www.ecf.utoronto.ca/~qianli

We utilize photonics technology to create instrumentation for fiber-optic sensing and metrology. Our frequency-shifted interferometry technique has been demonstrated to have a variety of applications, such as dispersion measurement, fiber length measurements, multi-point optic sensing for stress and/or temperature sensing used for civil structures, multi-point chemical gas sensing for environmental monitoring as well as industrial monitoring in hazardous environments, and liquid level sensing in cryogenic environment required in space applications.

Qian, Li — Nonlinear Optical Devices– Ultrafast Switching and Frequency Conversion

www.ecf.utoronto.ca/~qianli

Many photonic devices rely on nonlinear optical properties of materials. For example, ultrafast switching devices that operate in the 100 GHz range and beyond, utilize the ultrafast nonlinearity of optical materials. They can be widely used in high-speed data communication and signal processing. We are developing a sophisticated model for nonlinear optical materials that possess ultrafast and resonant optical nonlinearity, and use the model for the design of compact, ultrafast, optical logic gates for signal processing.

Nonlinear optical devices are also used for frequency conversion, which has wide applications in lasers and optical communications. We are developing fiber-based frequency converters that would create new types of lasers in the wavelength region (mid IR) that is difficult to access by conventional means. Such lasers may be used for environmental sensing and biomedical applications.

Qian, Li — Quantum Communication

www.ecf.utoronto.ca/~qianli

Quantum physics introduces revolutionary ideas that enable the creation of new tools and methods unimaginable previously. For example, in communication, quantum technology offers unbreakable communication security. Transforming fundamental quantum concepts into practical tools is, however, not without considerable challenges. We are developing advanced engineering tools, devices, and systems that utilize quantum concepts and implementable with existing fiber-optic technologies. These include a specialized optical homodyne detector for quantum key distribution, a fiber-based entangled photo pair source, and fiber-based quantum key distribution systems.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Rose, Jonathan
www.eecg.toronto.edu/~jayar

Acceleration of Protein Co-Evolution Detection for Determining Interactions in Software and on FPGAs

The MatrixMatchMaker algorithm was recently introduced to detect coevolution between proteins using pairs of phylogenetic distance matrices, and has numerous advantages over existing methods of coevolution detection. Co-evolution detection is a method for determining which proteins interact. We have developed a revised algorithm, which recasts the coevolution problem as multiple maximum clique subproblems on a graph of protein pairs, and achieves a 400x speedup with comparable accuracy to the original algorithm. We are proceeding to accelerate this algorithm further, by building special purpose computation hardware on FPGAs.

Rose, Jonathan
www.eecg.toronto.edu/~jayar/research/architecture.html

Architecture of Field-Programmable Gate Arrays

Field-Programmable Gate Arrays (FPGAs) are pre-fabricated chips that can be programmed to perform any digital hardware function. They reduce the time it takes to manufacture an integrated circuit from months to seconds and the cost of a prototype from millions of dollars to under $1000. As well, they play an essential role in the wireless, automotive, consumer and industrial markets, with total FPGA annual sales approaching $5 Billion. They enable essentially all hardware development including the emulation of high-volume processors and ASICs, and as the key technology for medium-volume systems.Our research explores FPGA architectures, focusing on heterogeneous architectureswhich mix the efficiency of full-fabrication silicon with the programmability of an FPGA. This effort will require new CAD algorithms and architectural description capabilities in our world-renowned FPGA architecture exploration software.

Rose, Jonathan
www.eecg.toronto.edu/~jayar/research/CAD.html

Computer-Aided Design for FPGAs

FPGAs present new problems in Computer-Aided Design that sometimes differ from those in other implementation media such as Mask-Programmed Gate Arrays, Standard Cells and full-custom design.

We are currently engaged in a large-scale collaborative effort to enhance our world-leading FPGA architectural exploration software to become a complete flow from the Verilog Hardware Description Language through to placement and routing, and timing analysis. It is called the “Verilog to Routing” (VTR) project. The new CAD software has the ability to describe far more complex FPGA architectures, including FPGA logic blocks with arbitrary hierarchy, modes of operation and interconnection structures.

Rose, Jonathan
www.eecg.toronto.edu/~jayar

Computer Vision Acceleration with FPGAs on Mobile Devices

Modern Mobile devices are revolutionizing how we interact in our environments. A key technology that would enhance this interaction would be to have a smartphone that could see in the way that humans do, as is the goal of the Computer Vision research field. Much of that research does not seek methods that operate usefully in real-time on powerful computers, much less the computers on mobile devices. In this project we seek to explore the use of FPGAs as computational accelerators for vision problems - such as object recognition or object tracking - on mobile devices.

Rose, Jonathan
www.eecg.toronto.edu/~yiannac/VESPA

Overlay Architectures for FPGAs

There are two crucial issues facing the use of FPGAs today: first, the amount of time it takes to compile a design into the FPGA, and second, the difficulty of learning the programming model implied in typical digital systems design. This broad research project is engaged in several methods of dealing with these two problems. First, we are looking at many methods of building soft processors (processors built on an FPGA fabric) that are much easier to program, as it is a programmable overlay on top of the programmable fabric. Second, we are beginning to explore methods of synthesizing pre-synthesized, placed and routed modules that reduce the need for time-consuming optimization.

Sargent, Edward
light.utoronto.ca

A Biochip for Gene-Based Disease Detection

We are building integrated circuits for the detection of a panel of biomarkers that indicate the early onset of specific types of disease. We configure nanostructured electrodes on a conventional integrated circuit; functionalize these electrodes with a nucleic acid probe having a sequence complementary to the target molecules of interest; and sensitively detect hybridization when it occurs. We are applying the chip to the early detection of cancer, and to the sensitive and rapid detection of ‘superbugs’ such as MRSA at the point-of-need.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Sargent, Edward — Low-Cost High-Efficiency Photovoltaics 

light.utoronto.ca

We seek to create low-cost high-efficiency solar cells. Our approach employs colloidal quantum dots - semiconductors that are synthesized and processed in the solution phase, and that, through quantum size-effect tuning, allow the sun's full spectrum to be absorbed.

Sarris, Costas — Computational Electromagnetics 

www.waves.utoronto.ca/prof/sarris

For many years, research on computational electromagnetics has focused on improving the modeling of fundamental building blocks for complex, real-world systems. However, translating our detailed knowledge of component parts to their impact on the behaviour of the systems they belong to, defines a new frontier for computational physics. This frontier of multi-scale modeling involves the integration of potentially heterogeneous models over the wide range of scales present in most physical problems. Our research is inspired by these challenges to address fundamental questions, devise novel techniques and investigate their application in critical areas of electromagnetics, optics and communications. Hence, we conduct basic research on novel multi-scale/multi-physics computational methods for electromagnetics from microwaves to the nanoscale. Applications of interest include wireless channel modeling, wave-propagation in meta-materials, plasmonics, carbon nanotube/graphene based structures, electromagnetic compatibility/interference (EMI/EMC) problems and modeling under uncertainty.

Sheikholeslami, Ali — Circuits for Spin Electronics 

www.eecg.utoronto.ca/~ali

Spin Electronics (or spintronics) is a new and emerging field of science and engineering that exploits the spin of electrons, in addition to their charge, for the purpose of information storage, transport, and manipulation. The ultimate aim of research in spintronics is the discovery and invention of new devices, such as spin transistors, and their integration into semiconductor technology so as to create better functionality and performance at lower cost and complexity. The purpose of this research is to explore circuit techniques for spin-based devices that are suitable for nonvolatile memory applications, replacing conventional memory technologies such as DRAM, SRAM, Flash, and EEPROM.

The basic structure of a spin-based memory cell is a magnetic tunnel junction (MTJ) that consists of two ferromagnetic layers separated by a thin layer of insulating material. One of the two ferromagnetic layers is a thick layer whose magnetization if fixed. The other one is a thin layer, also called free layer, whose magnetization can be switched between a direction that is either parallel or anti-parallel to that of the fixed layer. This corresponds to storing a digital 1 or 0 in the cell. Reading the stored bit is achieved by examining the resistance of the cell. This resistance is low for the parallel state and high for the anti-parallel state.

There are several challenges in the operation of the MTJ device that must be addressed before the spin-based memory could compete favourably against Flash. Our goal, in this research, is to devise circuit techniques in order to circumvent the device shortcomings and ease the requirements on the underlying technology.

Sheikholeslami, Ali — High-Speed Wireline Signaling 

www.eecg.utoronto.ca/~ali

This research targets circuit design for high-speed chip-to-chip signaling, backplane signaling, and optical communication. It includes circuit design for transmitter blocks (such as muxes, pre-emphasis, and drivers), and receiver blocks (such as equalizers, and clock and data recovery).

Smith, Peter W. E. — Ultrafast Photonics 

www.ecf.utoronto.ca/~upl

My teaching and research interests have centered on the study of ultrafast photonic and nonlinear optical effects in materials and the development and characterization of ultrafast optical devices for all-optical switching and signal-processing.

A number of materials systems have been investigated including bulk and composite semiconductor materials, semiconductor optical amplifiers, organic polymers, inorganic crystals, and colloidal semiconductor nanocrystals. We have found that with suitable preparation and treatment, many of these materials can be made to exhibit large optical nonlinearities with very rapid (picosecond or sub-picosecond) response times. Such materials will form the basis for a new generation of ultra-rapid all-optical signal-processing devices. These devices, because they operate at ultrafast rates in the optical domain, would eliminate the "electronic bottleneck" that limits the capacity of current-day data communications systems.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Sousa, Elvino — Autonomous Infrastructure Wireless Networks

www.comm.toronto.edu/~sousa/sousa.html

The research focuses on our vision for 4G wireless networks. This vision stresses the deployment aspects of the physical layer including features that allow the physical layer to autonomously configure itself after the deployment of bases stations or access points by users. The base stations and access points are deployment in a random manner by users and the network infrastructure is built and grows organically. This approach to wireless network deployment will greatly reduce the cost of base stations/access points and result in networks with much greater capacity which is required for the emerging broadband wireless services. This vision imcompases the current industry developments referred to as femtocells. The work is also related to what is referred to as cognitive radio.

Steffan, Gregory — Making Programming Multicores Easier

www.eecg.toronto.edu/~steffan

The microprocessor technology road-map predicts a future with tens to hundreds of processors per chip and beyond, but with limited clock frequency improvements and potentially simpler individual processors. We are developing compiler and analysis tools for making these multicore processors easier to program, in particular by exploiting "optimistic parallelism" via support for "transactional memory" (TM). TM provides an easier, optimistic alternative to locks for critical sections–allowing programmers to avoid deadlock and fine-tuning when synchronizing code, and also allowing critical sections to execute in parallel whenever they operate on independent data. We have designed and evaluated new software and hardware systems for TM support, targeting both conventional multicore systems as well as FPGA–based multicore systems.

Steffan, Gregory — Overlay Architectures for FPGAs

www.eecg.toronto.edu/~steffan

Field-Programmable Gate Arrays (FPGAs) are pre-fabricated integrated circuit chips that can be programmed to become any digital circuit. They are now widely used in all types of communications, computer and industrial hardware because their economics are often vastly superior to the use of fully-fabricated chips. Our goal is to allow software programmers to more easily program FPGAs for high-performance applications, by developing new 'overlay' architectures for FPGAs: structures programmed onto FPGAs that are themselves programmable. We have developed several scalable, customizable, and easy-to-program overlays for different computing domains, including customizable soft processors, soft multiprocessors for packet processing, soft vector processors, and current work on a GPU-like engine that will support programming with OpenCL.

Stumm, Michael — System Software Performance Optimizations

www.eecg.toronto.edu/~stumm

Our primary objective is to make improvements to operating systems so as to significantly improve kernel and application performance. Currently, we are primarily targeting multicore-based systems. Our general approach is to exploit Hardware Performance Counters (HPCs) that today are an integral part of all processors and use them to measure overheads and identify bottlenecks online and in real time. We then feed the information gathered from the HPCs to the system resource managers so that they can make informed decisions on how best to use system resources from a performance point of view. Using this approach, we recently introduced exception-less system calls to Linus, that improved the throughput of Apache by over 100% without any modification to Apache, and we improved the throughput of MySQL by 40%.

Tate, Joseph (Zeb) — Online Parameter Estimation for Wind-Driven Doubly-Fed Induction Generators

www.ele.utoronto.ca/~zeb

The rapid increase in variable generation technologies such as wind and solar power throughout many nations' power grids has the potential to significantly reduce reliability. To ensure this does not happen, power companies must run a multitude of simulations that identify potential problems before they occur in the real system. The ability of these simulations to accurately inform decisions is only as good as the models being used, and the lack of confidence in dynamic models is one of the main problems associated with these new generation technologies. For several reasons–such as model order reduction to make simulations tractable, the reluctance of generator manufacturers to release detailed models or parameter sets, and the relatively high installation of wind generation–the accuracy of wind generator models is becoming increasingly important for planning engineers. This project is looking at ways to use ambient wind power generator measurements (i.e., without introducing artificial stimuli to the system) to determine wind parameter models for use in simulation-based studies. Thus far, we have been exploring the performance of various nonlinear parameter estimation schemes, in particular the Extended and Unscented Kalman Filters (EKF and UKF, respectively), to select the most appropriate algorithm for this application. We have seen via simulation with high-bandwidth sampling that, for a relatively simple DFIG model, the UKF is generally superior to the EKF in both robustness and speed of convergence, confirming the UKF's superior performance when applied in other disciplines. Two extensions are currently being investigated first, the impact of reduced bandwidth sampling (e.g., using 30-60 samples per seconds) and secondly, testing of the UKF estimator with acmeasurements.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Tate, Joseph (Zeb)
www.ele.utoronto.ca/~zeb

Phasor Measurement Unit Data Characterization and Compression

Phasor measurement units (PMUs) are the primary smart grid component being added to the North American transmission network (i.e., the high-voltage network used for large, inter-area power transfers). One of the main reasons these units are being introduced is to enable wide-area situational awareness and control of the power grid. These applications will require substantial investments to be made in cyber-infrastructure, and this research project is looking at ways to both characterize PMU data and use this characterization to achieve high levels of data compression. Results obtained thus far indicate that accounting for the unique characteristics of PMU data can lead to significantly higher lossless compression ratios in comparison to generic lossless compressors.

Tate, Joseph (Zeb)
www.ele.utoronto.ca/~zeb

Power System Simulation using Programmable Graphics Processing Units

Modern power grids are comprised of millions of individual nodes, which are interconnected in a variety of ways (e.g., transmission lines, transformers, switches, power electronic converters, etc.). At each node, there may be anywhere from zero to hundreds of sources and sinks of electric power, each with its own complex model (e.g., consider a modern household which may include slowly varying electrical loads such as clothes washers in parallel with rapidly changing loads such as CPUs). Because of the complex physical structure of the power grid and the components to which it is connected, simulation of power grid behavior can be a challenging task. Presently, evaluation of system events is done on an ad hoc basis, in which planning engineers have to guess at both the likelihood of events occurring and the impact on the rest of the network. Reducing the solution time of power system simulations allows planners & operators to consider a wider variety of events and/or more detailed modeling of power system components, and this has led to a renewed interest in algorithm design & implementation for power system simulations. This project focuses on the development of power system simulation software which targets a particular parallel computer architecture-programmable graphics processing units (GPUs). These processors pose several unique challenges due to the hundreds of cores on each chip and the unique game-driven memory access patterns; as a result, prior work in both serial and parallel power system simulation cannot be immediately adapted to these architectures. Thus far, we have developed a GPU-based linear solver designed to solve the large, sparse, ill-conditioned systems that are typically solved during power system simulations. Preliminary results have shown that the GPU is a viable architecture for power system simulations and the utilization of polynomial preconditioners combined with Krylov-subspace-based solvers can offer significant gains over serial code. Future work will be focused on profiling and optimization of the already-developed algorithms and the development of a complete power system simulation package which is based on GPU-accelerated computing.

Tate, Joseph (Zeb)
www.ele.utoronto.ca/~zeb

Wind Impact Metrics for Short-Term Power Grid Operations

One of the main challenges associated with the increasingly widespread introduction of wind generators is figuring out ways to control their inherent variability. While operators have always had to deal with uncertainty in electricity utilization, availability of generation resources has traditionally been either controllable and/or known in advance. As the supply mix moves more towards variable generation resources such as wind and solar power, operators will have to learn ways to anticipate problems and take corrective actions in order to maintain system reliability. This research focuses on ways to quantify and visualize the potential impact of wind generator variability over short time horizons (e.g., 4 hours into the future) so that operators can have a better understanding of potential problems on the network. Because the potential impacts on the grid are heavily dependent on both the levels of wind generation & their distribution throughout the system, most of the work thus far has focused on development of accurate ARMAX models that account for the non-independence of wind generators' outputs. Once these models have been developed, the next stage of this project will focus on formulation and calculation of metrics that use the forecast statistics to highlight bout potential grid problems and suggest appropriate preventive controls.

Trescases, Olivier
www.ele.utoronto.ca/~ot

Battery Management for Electric Vehicles

Despite numerous technological innovations, the proliferation of EVs in Canada is primarily limited by the range and cost of today's vehicles. Reducing the cost and extending the range of EVs is a major multidisciplinary challenge faced by the global automotive industry. Advances in light-weight materials, battery chemistry, battery management and power electronics are needed to meet future customer expectations and convert entire fleets from gasoline to EV technology. Another major hurdle in the widespread acceptance of EVs is the uncertainty in the lifetime and reliability of the battery pack, especially in the harsh Canadian climate. This has delayed the adoption of Lithium-Ion based battery technology until very recently; despite vastly superior energy density compared to Ni-MH batteries used in the first generation hybrid vehicles.

Making better use of the energy capacity by increasing the system efficiency is the key to reducing the overall size and cost of the EV battery. Regenerative braking (Regen) is often used in electric vehicles to capture kinetic energy that is otherwise wasted in the brake pads when the vehicle comes to a stop. Instead of simply applying the mechanical brakes during deceleration, an EV equipped with a Regen system uses the motor as a generator in order to transform mechanical energy into stored charge in the battery. Even the latest Lithium-based batteries have a relatively poor ability to quickly absorb energy without affecting long term

LEAD RESEARCHER | **RESEARCH TITLE** | **COLOUR KEY**

performance. The maximum output power of modern Li-Ion batteries is typically at least 3 times higher then the maximum input power. Repeatedly using Li-Ion batteries to both absorb this large negative burst of power during Regen and provide large positive power burst during acceleration can significantly raise the pack temperature and accelerate aging. Automotive-grade Ultracapacitors (UCaps) have been recently developed as a complimentary energy storage technology to batteries. Commercial Ucaps have input and output power densities on the order of 12 kW/kg, which is at least one order of magnitude higher then Li-Ion batteries. On the other hand, the 6 Wh/kg specific energy of these Ucaps is at least 10x worse then Li-Ion batteries, leading to the concept of using a hybrid storage system comprised of a smaller Li-Ion battery and an Ucap. Using this approach, the battery serves purely as an energy tank, while the Ucap is sized to meet the surge input and output power requirements. Effectively managing the energy flow between the Ucap, the battery and the motor requires new power electronic topologies and advanced control schemes. The main goal of this project are to develop new models, control schemes and power electronic converters to extract the maximum performance from modern EV energy storage systems.

Trescases, Olivier
www.ele.utoronto.ca/~ot

High-Frequency Digitally Controlled DC-DC Converter ICs

As the world faces unprecedented environmental challenges, energy efficiency and power-management have taken centre stage. Switched-mode power supplies (SMPS) are the key enabling technology for efficiently delivering the tightly regulated supply voltages required by today's modern mixed-signal (digital+analog) integrated circuits (ICs) and systems. The SMPS acts as the interface between the energy source, such as a battery, and the load ICs. A typical SMPS uses a combination of high-speed, low-resistance semiconductor switches, energy storage components, sensors and control circuits to regulate one or more output voltages in the presence of disturbances. State-of-the-art SMPS have a power conversion efficiency above 90%. The resulting low heat dissipation allows multiple SMPS to be integrated with their load circuits into a single IC. The clear trend in SMPS research is toward adaptive digital control-loops, increased integration within system-on-chip (SoC) applications, higher efficiency over the full operating range and higher switching frequency, resulting in smaller energy storage components. The long-term goals of the proposed research are to make tomorrow's power management systems, smaller, more efficient, more robust, and more reliable, while reducing electromagnetic interference (EMI) and environmental impacts. The research focus is on new high-frequency control schemes, system-level optimization, thermal management, low-power mixed-signal circuits and power MOSFET optimization.

Trescases, Olivier
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Power Converters for High-Efficiency LED Lighting

Electric lighting accounts for approximately 11 % of the world total power consumption. The development of cost-effective power management circuits for compact fluorescent bulbs (CFLs) has led to drastic improvements in lighting efficiency. While CFLs are clearly an improvement over archaic incandescent bulbs, they are difficult to dim, they contain poisonous mercury and the chromatic properties of the light are less then ideal. High brightness (HB) LED modules are rapidly emerging as a promising candidate to replace CFLs in numerous lighting applications since HB-LEDs are mercury-free, scalable and can be easily dimmed. The main goal of the project is to develop smart digital switched-mode power supplies (SMPS) to optimize the lighting efficiency and chromatic properties in HB LED systems using closed loop thermal and optical feedback. The targetted controller can efficiently regulate the electrical-to-optical energy conversion process under a wide range of operating conditions.

Trescases, Olivier
www.ele.utoronto.ca/~ot

Power Electronics for Photovoltaic Applications

Solar energy has long been recognized as one of the most abundant forms of clean renewable energy. Countless research efforts around the globe are contributing to the steady decline in the cost of photovoltaic (PV) power, with the promise of reaching grid parity in the near future. This is a complex target, as the price of conventional energy sources are constantly in flux and heavily dependent on government subsidies. The penetration level of solar power is rapidly increasing in most developed countries due to government incentives and multi-disciplinary technological advances. The exponential growth of PV technology presents a tremendous opportunities for all companies in the semiconductor supply chain, ranging from discrete power devices to mixed-signal control ICs. Performing maximum power point tracking (MPPT) on a PV array is used to continuously optimize the total harvested power under time-varying temperature and illumination fluctuations. It has been demonstrated that performing distributed MPPT (DMPPT) on a per-panel or even per-cell basis, instead of using a single MPPT controller across the entire PV array can substantially improve the total system efficiency under partial shading conditions. The main goals of this project are to quantify the benefits of DMPPT for different levels of granularity and to develop new high-efficiency power electronic converter topologies and control schemes for both mono-crystalline Silicon and multijunction III-V PV systems.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Truong, Kevin
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Computational Tools for Protein Sequences, Structures and Networks

Cells are composed of protein signaling networks that perform biological functions such as regulating cell growth or catalyzing biochemical reactions. As a result, the malfunction of proteins often causes human illnesses such as Alzheimer's disease, heart disease and cancer. My long term research goal is to create synthetic protein signaling networks that will allow us to one day manipulate cell biology with the same precision as electrical circuits and computer networks. To accomplish this goal, my proposal will focus on developing computational tools for studying protein sequences, structures and signaling networks. First, to infer the function of a protein sequence, the Smith Waterman (SW) algorithm is used to find its similarity to proteins of known function. As sequence databases grow larger, faster sequence comparison approaches are required such as using accelerated field programmable gate array (FPGA) hardware. To make the FPGA solution more affordable, I will develop FPGA hardware for accelerating the SW algorithm using fewer resources while maintaining a comparable speed. Next, to study the protein signaling kinetics within cells, fluorescent protein biosensors are powerful tools but the design of these biosensors is often trial and error. Using a computational tool to model the conformational space of protein biosensors, I improved the design however the tool was not quantitative. To address that problem, I will include molecular factors that select preferred biosensor conformations. Lastly, to design synthetic protein networks or model larger existing networks, I will develop a computational tool for simulating the spatial and temporal kinetics of protein signaling networks. Together this work will yield insights into protein sequences and their networks that will ultimately aid in developing therapies for human illnesses.

Truong, Kevin
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Live Cell Imaging and Control of Caspase Kinetics Using Engineered Proteins

Over the past decade, members of the caspase family of proteases have been extensively studied for their critical role in apoptosis. The caspase family displays rich spatial and temporal kinetics in living cells such as cascading activation and differential subcellular expression. While such characteristics confound many biosensor designs, it accentuates the strengths of fluorescent protein biosensors. By employing the principle of fluorescence resonance energy transfer (FRET), protein biosensors can be created to image the kinetics of caspase activation in living cells. Furthermore, we can control the exact moment that caspase activation occurs within the cell using an inhibitory protein of caspase that is engineered to be switchable on [Ca2+]. This goal will be accomplished by addressing a series of three aims: first, targeting caspase biosensors to subcellular organelles (Aim 1); second, imaging caspase cascades in living cells (Aim 2); finally, engineering proteins to control caspase activation based on XIAP (X-chromosome-linked inhibitor of apoptosis protein) and a Ca2+ binding protein called calmodulin (CaM) (Aim 3). This work will pioneer designs for engineered proteins that will provide new tools for fundamental studies in cell biology.

Valaee, Shahrokh
www.comm.utoronto.ca/~valaee

Localization of Wireless Terminals in Indoor Environment

Location based services (LBS) are emerging as new applications on mobile phones. In LBS, the main challenge is to locate the user, especially in indoors and covered areas where the GPS service is not available or has unacceptable error. In this research we estimate the location of a mobile phone using the strength of signals arriving from WiFi access points. We have designed and developed the system on three WiFi-enabled phones and PDAs and have tested it in an office building at the University of Toronto, in a shopping mall in north Toronto, and in Canadian National Institute for Blind (CNIB). The system has a tracking and navigation system that uses voice instruction to guide individuals with visual impairments to find their way in indoor environments.

Valaee, Shahrokh
www.comm.utoronto.ca/~valaee

Wireless Communications in Vehicular Environment

In 2000, an estimated 6,394,0000 motor vehicle crashes were reported to the police in the US. Based on a series of in-depth investigation of police reports and on-scene investigations, human factors were found to be the definite cause for 70.7% of the crashes. Most of those accidents could have been prevented if there were proper devices installed in cars that allowed vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) communication. The goal of our research is to create vehicular ad hoc networks (VANET) that can be used to enhance safety on roads and to provide telematic services such as road conditions, traffic congestion, and mapping.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Veneris, Andreas — CAD for VLSI Verification, Debugging, Test and Synthesis 

www.eecg.utoronto.ca/~veneris/AndreasVeneris.htm

The semiconductor industry has products reaching all aspects of commercial and consumer markets domestically and internationally. The rapid growth of this industry in the past 30 years is in part attributed to advances in the Electronic Design Automation industry community that develops Computer-Aided Design (CAD) tools to aid the engineer designing such complex high-performance devices. The research of our group centers around the development of CAD software that expedites the verification, debugging, synthesis and testing of computer chips. Our research has been funded by major government and industrial partners, and it has been awarded in premiere conferences for its impact to the community.

Venetsanopoulos, Anastasios — Research in Telecommunications, Signal and Image Processing, Multimedia and Biometrics 

http://en.wikipedia.org/wiki/Anastasios_Venetsanopoulos

Four research topics: Multimedia (image compression, image and video retrieval); Digital Signal/Image Processing (multichannel image processing, nonlinear, adaptive and M-D filtering, knowledge based processing and recognition, 3-D imaging, biomedical applications); Telecommunications Biometric Research.

Voinigescu, Sorin — Digitally-Enhanced Analog Equalization Techniques for 50-110 Gbps Wireline Applications 

www.eecg.toronto.edu/~sorinv

This research focuses on the development of new high-data rate wireline communication circuits and systems based on mm-wave DACs. The goal is to take advantage of MOSFET layout segmentation in deeply scaled nanoscale CMOS technologies to realize arbitrary waveforms for transmitter equalization directly at frequencies in the 50-110 GHz range. In receivers,oversampling with 100+ GHz clockwill be employed to recover the clock and data information and to recondition the signal before transmission.

Voinigescu, Sorin — High Efficiency mm-Wave Transmitter Array 

www.eecg.toronto.edu/~sorinv

This research focuses on novel transmitter array architectures based on high-efficiency direct mm-wave digital modulators. The goal is to deliver 64 QAM modulated transmitters with over 65% Power Added Efficiency and over 36, 30 and 26 dBm of output power at 45 GHz, 94 GHz and 138 GHz, respectively.

New circuit topologies, IQ correction techniques and ci and free space power combining and modulation schemes are being contemplated. Both SiGe BiCMOS and 45nm SOI technologies are being investigated for the practical implementation.

Voinigescu, Sorin — Silicon SoCs in the 100-500 GHz Range 

www.eecg.toronto.edu/~sorinv

This research focuses on developing characterization, modelling and design methodologies, as well as circuit topologies and system architectures for future integrated systems operating in the virtually un-chartered 100-500 GHz band.

Envisioned applications are in industrial sensors, automotive radar, active and passive imaging, remote sensing, environmental monitoring, radio astronomy and very high data rate wireless communication. On-die noise source-pull test set-ups have been developed for the extraction of the noise parameters of 400-GHz SiGe HBTs in the 110-170 GHz band. The first three integrated systems that have already been demonstrated in the lab are: 1) a 120 GHz high resolution position sensor with above IC antenna fabricated in a SiGe BiCMOS process and which works over 2-5m, a) 160 GHz radio transceiver array with on-die antennas operating as a 4Gb/sradio and as a Doppler radar, and 3) a 165 GHz passive imaging receiver with sub 0.3 K temperature resolution and consuming 82 mW.

Wong, Willy — Sensory Neuroengineering 

individual.utoronto.ca/willy

My interests are in the area of neuroscience, signal processing and sensory engineering with particular application to speech and hearing. My work lies at the intersection of biomedical, computer and communications engineering. Students working in my group typically have an interdisciplinary approach with interests in signal processing, algorithm design, modelling and psychology.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Wonham, Murray — Supervisory Control of Discrete–Event Systems

control.utoronto.ca/~wonham

Our research is on supervisory control of discrete-event systems, that is, logic control of systems described in a framework of automata and formal languages. We focus on system architecture and "intelligent" computing techniques as a means of confronting state-space explosion and exponential complexity. Specifically, architectures include monolithic (as a "worst" case), refined to decentralized, distributed, hierarchical and their combination as heterarchical system organizations; while computing includes modeling and algorithmic development using state-tree structures, an adaptation of state charts. Existing applications by ourselves and others include manufacturing workcells, chemical engineering processes, automobile pushbutton systems, and industrial diagnostic systems.

Yu, Wei — Cooperative Wireless Cellular Networks

www.comm.utoronto.ca/~weiyu

My research focuses on the use of cooperative communication techniques for capacity improvement in wireless cellular networks. We design future wireless networks in which base-stations can cooperate with each other and where relays are deployed within each cell to enhance the performance of mobile terminals. From a theoretical perspective, we investigate the information theoretical capacity of relay networks and networks with transmitter or receiver cooperation. From a practical perspective, we design optimal scheduling, beamforming, power control, and multiuser detection strategies for multicell networks. Cooperative techniques promise to enhance cellular coverage and to mitigate interference, thereby improving the overall performance of the cellular network.

Zhu, Jianwen — Compiling Software to Silicon

www.eecg.toronto.edu/~jzhu

My research focuses on highly automated methods to design high-volume system-on-chips, as well as field programmable gate arrays (FPGAs). The automation is achieved by solving a series of optimization problems that ultimately allow the design of integrated circuits as "easy", and as "fast" as programming software in C/C++, while not compromising performance of circuits. More specifically, these methods can help chip design companies to quickly design hardware processing engines in today's smart phones. These engines, such as video codecs, graphic processing units, security and baseband processors, are the key differentiators that allow smart phones to provide rich user experience under the tight energy budget of batteries. Likewise, these methods can help telecom and IT infrastructure equipment vendors, by utilizing FPGAs, to improve the performance, and lower cost of equipments that power the next generation internet and wireless infrastructure.