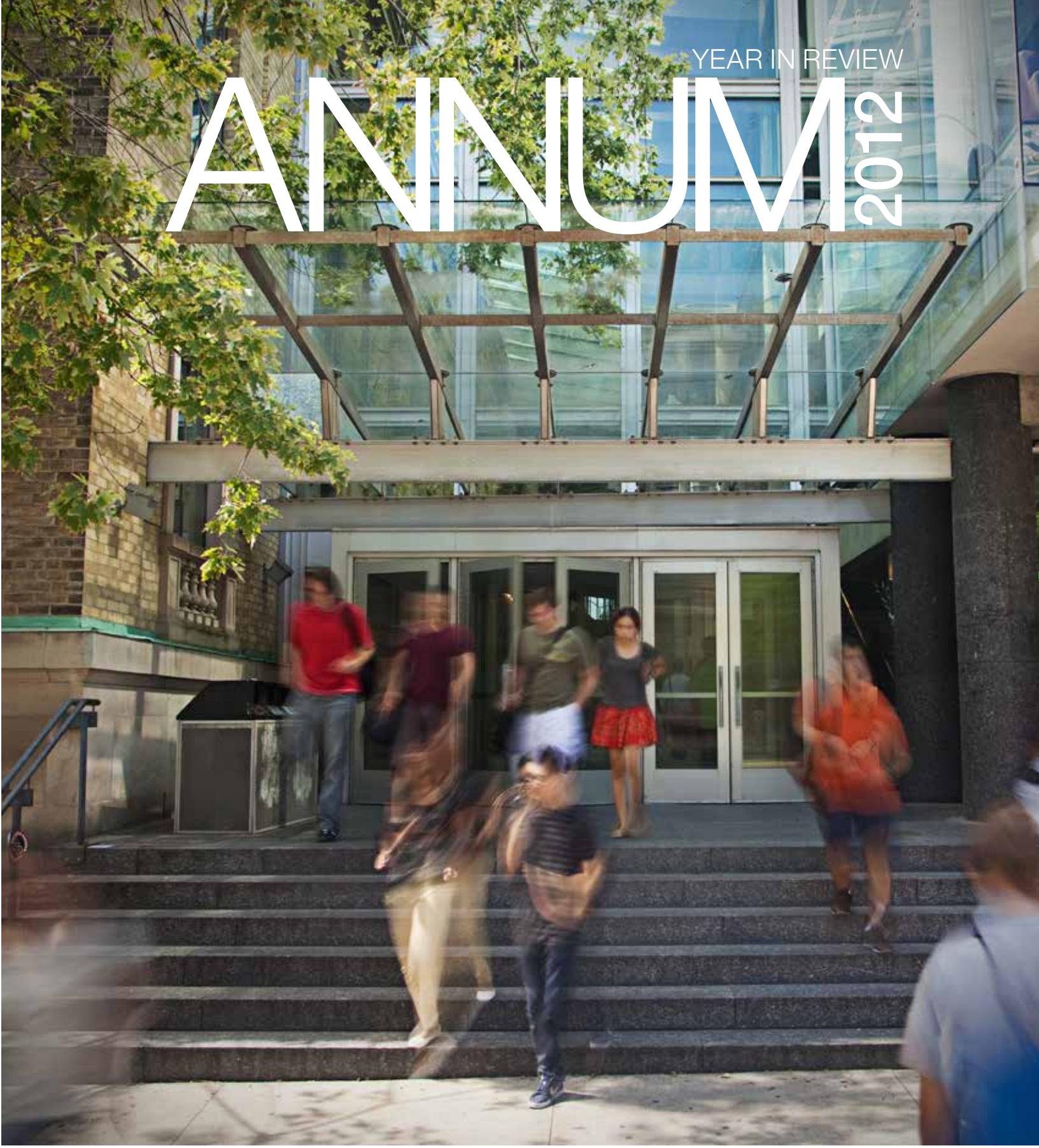
YEAR IN REVIEW

ANNUM 2012



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

Table of Contents

As Department Chair, I am delighted to share with you our annual report for The Edward S. Rogers Sr. Department of Electrical & Computer Engineering (ECE) 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 one of the largest ECE departments in the country, with an operating budget of about $30M, 78 faculty members (100, including our Professors Emeritus), more than 1,130 undergraduates, and approximately 500 graduate students.

Our undergraduate programs draw some of the best students from around the country. In recognition of the breadth of the field, our curriculum is flexible, allowing our students to customize their education according to their areas of interest. Our programs also boast a strong emphasis on hands-on and project-based learning, extensive laboratories and various design-focused courses.

Research is 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 $18M, 21 named research chairs and approximately 36 PhDs awarded annually, the department buzzes with innovative research ideas and projects. This creative energy, in turn, benefits our undergraduate programs 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 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. 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.

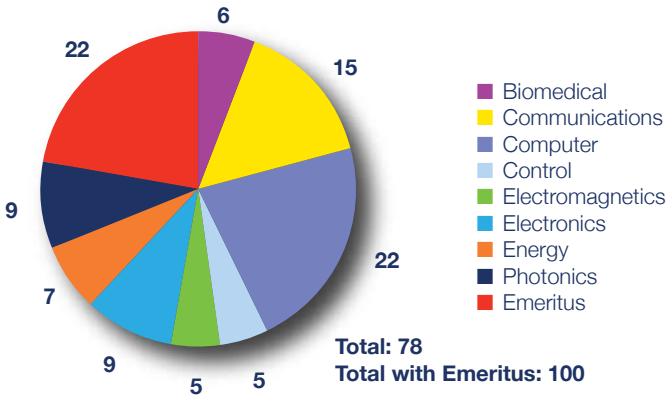
Farid N. Najm, Professor and Chair

Our Story

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.

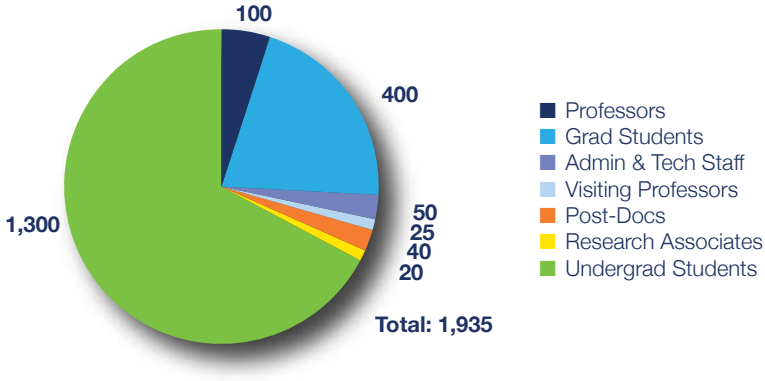
With the return of First World War veterans in the fall of 1919, the department saw enrolment swell from 241 to 819 students. A practical undergraduate curriculum was offered at this time, similar to that of the mechanical colleges in the United States. It was this North American model under which the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

Our Faculty



Total: 78
Total with Emeritus: 100

Our Community



Total: 1,935

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.

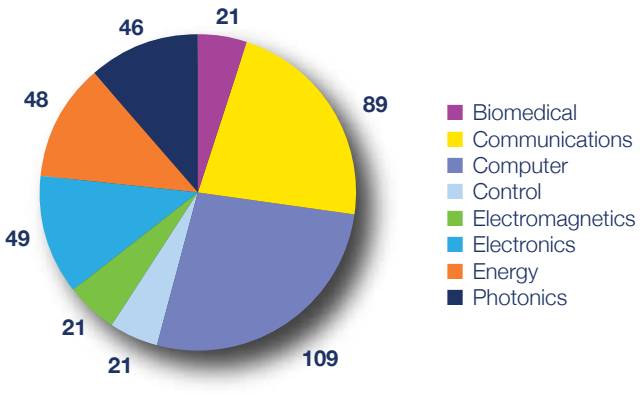
Early research groups included those based in classical electromagnetic theory, followed by control engineering, dubbed systems disciplines, in the 1950s. Shortly thereafter came communications engineering, and electronic device and circuit engineering. In 1962 the department formed the Institute of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

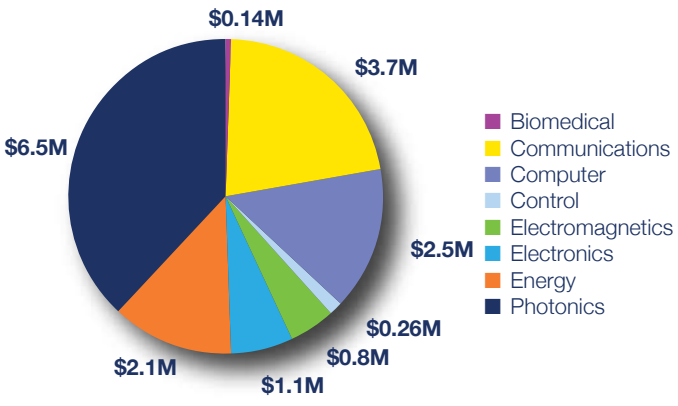
2,700

Square meters of lab space for undergraduate teaching in the ECE department.

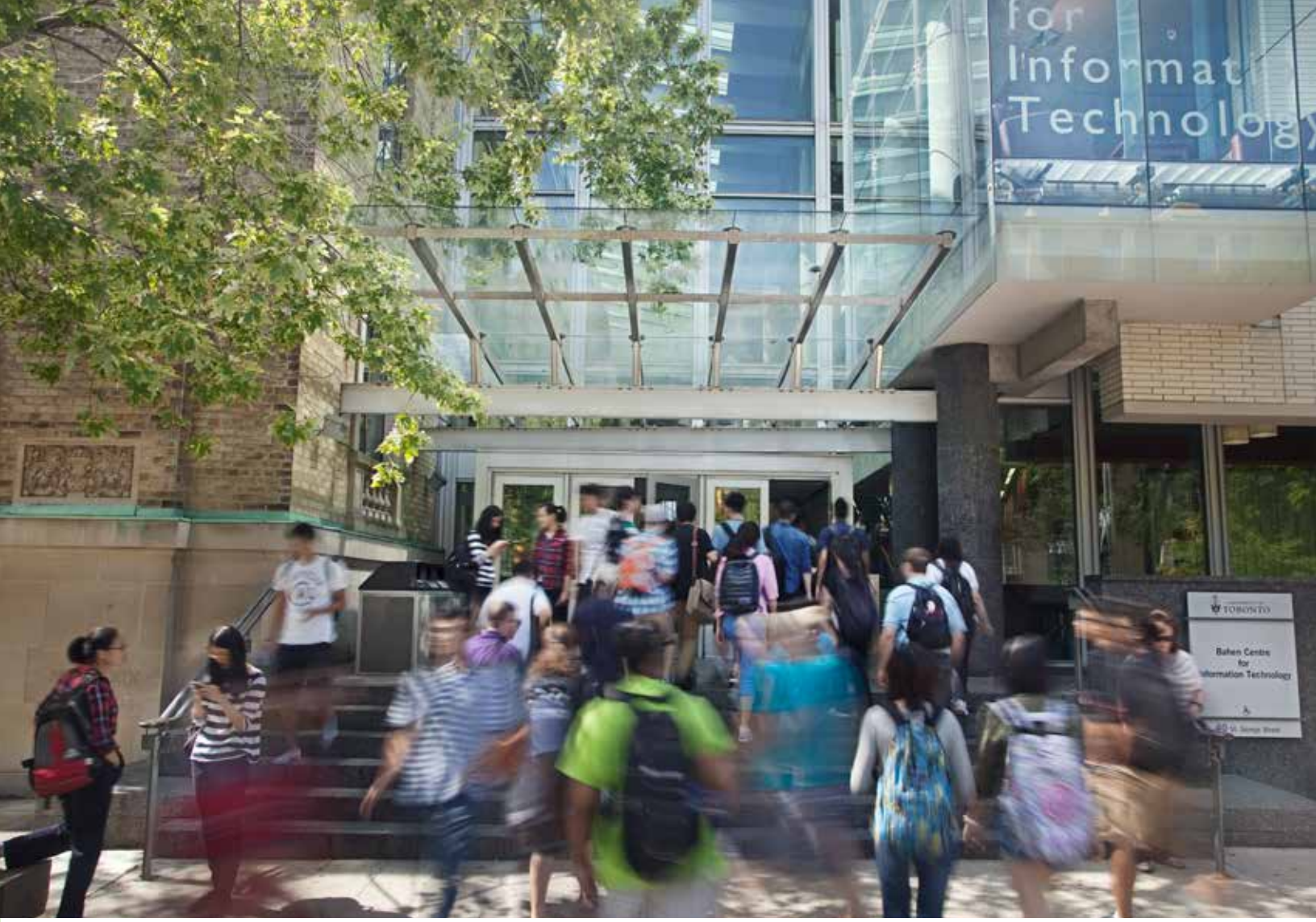
Our Graduate Students



Our Research Funding



Undergraduate Studies



Offering the broadest curriculum in Canada, including the Electrical Engineering and Computer Engineering programs, 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, they also supervise vibrant on-campus research laboratories, facilitating a seamless transfer of knowledge from the lab to the classroom.

As undergraduate degrees, Electrical Engineering and Computer Engineering offer the widest range of career opportunities. Seated at the heart of most technical advances made today, electrical and computer engineering are truly the engines that power 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 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; and Computer Software.

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

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

Empowering a Passion for Power

MIKE **RANJRAM** | Electrical Engineering 1T2+PEY

It wasn't just the prestige of being enrolled in the engineering program at the University of Toronto that attracted Mike Ranjram over three years ago, it was the promise of the opportunity to be an integral part of actual research projects, even as an undergraduate. "The professors really spoke to me about being able to make a difference early in my academic career," says Ranjram. "They have made good on that promise. I have been given a lot of leeway and control over projects, and that's so important to me."

Ranjram's area of interest is power. Working in the Energy Systems Lab under the direction of Professor Peter Lehn, he has successfully built a high step-up, high efficiency DC-DC converter with maximum power point tracking (MPPT) for use in photovoltaic applications. "Power is such an important field but we're never really exposed to the details of power systems," says Ranjram. "People generally don't talk about what it means to transmit a voltage from Niagara Falls to where you live, and the complications of that. But it's so important. And what I've found is that power is such a diverse field to work in. There's so much information you need to know about in other fields of engineering such as control, analog circuits and electromagnetics, for example."

Ranjram finds that his enthusiasm is shared by many of his peers. "The great thing about being a part of such a large community at U of T is that you find people who are passionate about every field of engineering, even if it isn't the most popular field."

With a focus on making his converter as efficient as possible while also minimizing cost, Ranjram's motivation lies in the very real need for sustainable power, and the demand for technology that would make sustainable energy more viable. "We need a way to produce power more efficiently, and at a lower cost," says Ranjram. "This makes my work meaningful because it's not just about completing a research project, it's about the betterment of humankind and the future of the planet."

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.

The PEY internship program has been in existence for more than 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: Canada, Chile, Germany, Japan, Switzerland and USA.

#1

The U of T ECE department ranks first in Canada according to **QS World University Rankings.**

NSERC Undergraduate Summer Research Award

The Natural Sciences and Engineering Research Council of Canada (NSERC) offers a number of summer (May to August) research fellowships 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.

ECE PEY Placements 2002 to 2013

Year	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13*
Electrical	27	50	58	99	120	132	115	96	127	135	103
Computer	59	68	76	56	71	49	63	62	66	70	80

* As of August 9, 2012

Today's Research Challenges Create Tomorrow's Opportunities

LAURA **SHEN** | Computer Engineering 1T5

"What I love about research is that it challenges you to discover something really important," says Laura Shen, a second-year computer engineering undergraduate. "And what's so appealing about my area of study, fiber optics technology, is that it's where communication is going. It's the future."

Shen is currently conducting research under the supervision of Professor Peter R. Herman in the Photonics Group of The Edward S. Rogers Sr. Department of Electrical & Computer Engineering. She was awarded the Edith Grace Buchan Undergraduate Research Fellowship by the department to gain exposure to leading-edge research and the opportunity to work on a research project at the University of Toronto during the summer of 2012. The project involved optimizing the fabrication of femtosecond laser-written optical waveguides.

"This is a challenging task that requires balancing the losses that occur when light is coupled into the waveguide and the losses that occur when the light propagates in the waveguide," says Shen. "The number of laser pulses, pulse energy and scan speed are varied simultaneously during the waveguide fabrication. The subsequent optical characterization and analysis reveal the effect of each parameter." Through her analysis, Shen is able to provide feedback to help guide the next set of experiments. "Once the lowest loss waveguides are found, they will be integrated into optical fibers as part of a novel fiber strain and temperature sensor and as optical taps that will allow a small fraction of light to be pulled out of the fiber for analysis."

A new research direction in the lab is to create photonic devices inside of optical fibers using femtosecond lasers. One of the fundamental components required for this research direction is the optical waveguide, which will carry optical signals from one point to another.

Shen's goal is to continue on to complete her undergraduate degree and then graduate studies. "At the University of Toronto, there's a real sense of being an engineer," says Shen. "Even at the undergraduate level, we are able to apply our learning to real practice. It's a hands-on learning environment. The graduate students and my professor are very helpful and inspiring mentors. They take time out of their busy schedules to help and encourage me to accomplish so much."

10

Number of undergraduate teaching labs within U of T's ECE department.

Veolia World Solar Challenge

In 2011, the University of Toronto Blue Sky Solar Racing's 6th generation car, Azure, competed alongside 37 teams from 22 countries in the Veolia World Solar Challenge (WSC). The endurance race crossed 3,000 kilometres of the wild Australian Outback.

When not busy testing Azure, the group is showcasing their project at local and national community events. Throughout the summer of 2012, the team attended events such as the Canadian Undergraduate Technology Conference, Windfall Ecology Fair, Engineering Clubs Day and the UTSU Clubs Day. These events gave students an excellent opportunity to meet the team and learn first-hand how to become involved. Recently, the Azure team has been approached by various media and were featured in newspapers and on the Discovery Channel's science and innovation news program, Daily Planet.

Azure placed 24th in 2011, and will enter a new and improved vehicle in the 2013 WSC. While still in Australia, the team was already brainstorming ideas for the next generation vehicle as they are determined to return in 2013 with yet another world-class solar car.

- **250 kg (without driver) with a top speed of 100 km/h**
- **Pseudo 3 wheel configuration**
- **Plan-view aerodynamic drag coefficient (C_d,plan) = 0.01**
- **Monocrystalline Si A300 SunPower cells**
- **Carbon fibre aerobody**

Undergraduate Enrolment, 2003 to 2011

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Full-time ECE	1,390	1,309	1,274	1,183	1,146	1,096	1,077	1,059	1,096
Part-time ECE *(includes PEY students)*	160	179	198	239	211	202	205	240	256
Total Headcount	**1,550**	**1,488**	**1,472**	**1,422**	**1,357**	**1,298**	**1,282**	**1,299**	**1,352**
% International	4.0%	5.0%	6.3%	6.6%	13.1%	16.3%	17.9%	19.0%	22.5%
% Women	20.3%	16.6%	14.0%	12.5%	12.2%	12.9%	14.7%	15.3%	16.9%

High-tech Signing

Justin **Wee** | Electrical Engineering 1T3

It's hard to imagine how limiting a world without sign language would be for people who are deaf or hard of hearing. In fact, the use of manual signs and facial expressions has been widely accepted as an effective communication tool since the 1600s. However, for Justin Wee, a fourth year undergraduate in the Biophotonics Group at the Institute of Biomaterials & Biomedical Engineering and The Edward S. Rogers Sr. Department of Electrical and Computer Engineering, enabling people who are deaf or hard of hearing to leverage technological advances of today is not only a research focus, it's a passion.

"My area is biomedical control systems," says Wee. "So I am very interested in applying what I have learned in electrical engineering to the healthcare sector of society to help people have a better quality of life."

Wee is currently in a design project group that is working on making a visual sign language translator app for smartphones. "We have a camera that captures a person performing sign language, and it is able to translate the signs that they do into English words. This encompasses a lot of image processing of many different frames of signs, and using a probability model, we are able to determine with a high percentage chance that these are the words being signed."

Wee believes that within five years the program will be more involved with a greater vocabulary, and able to translate most of a conversation with minimal error.

"It's very motivating and exciting," says Wee. "Everyone on the team is really enthusiastic about the project. Right now there is still a great communication barrier for the hearing impaired and my hope is that this program will be able to be ported through a smartphone and will help everyone converse with those who must rely on sign language."

Wee credits his professors with piquing his interest in this area. "The motivating factors for me are my professors who incorporate their own research and lab work into their lectures," says Wee. "They are so knowledgeable and I have had the pleasure of being inspired by their fabulous work, such as controlling a wheelchair with brain waves. It keeps me really interested and inspired to go on with my own research."

The Lady Godiva Memorial Bnad

The Lady Godiva Memorial Bnad, or LGMB, is a student-run band consisting chiefly of University of Toronto engineering students. The use of the term bnad is a reference to the inability (or unwillingness) of engineers to spell correctly (see Skule).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. It is primarily a spirit group and secondly a musical group. The bnad is often introduced, incorrectly, as the Lady Godiva Marching Band, despite the fact that they never march.

Institute of Electrical and Electronics Engineers

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 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 sessions aimed at preparing students for the professional and academic world.

Former ECE student Dr. Haiping Lu has been chosen to receive the 2013 IEEE Computational Intelligence Society (CIS) Outstanding PhD Dissertation Award for his project titled “Multilinear Subspace Learning for Face and Gait Recognition.”

According to the IEEE CIS, “This award recognizes outstanding PhD dissertations that have contributed to the advancement of the theory and/or applications of computational intelligence.”

Purple

U of T engineers have been known to show their Skule spirit by painting thmesleves purple. The legends say that in the glorious era of the mighty British Royal Navy, when Her Majesty’s Ships were sent out to explore, conquer and claim exotic lands, engineers identified themselves with bright purple arm patches. 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.

From Research to Real-World Problems

SERA **BENJAMIN** | Computer Engineering 1T3

For Sera Benjamin, fourth-year computer engineering student, the most intriguing aspect of her program is the opportunity to work on projects that apply research to real-world scenarios. “Seeing the final work in progress is so exciting,” says Benjamin. “In some instances we work with actual clients who have a problem that needs solving. For example, we conducted an energy audit, reached a design decision and then presented it to the client. The whole process was such a great learning experience on so many levels. In another case, we created a storage server for multiple clients, as well as set up the database within the server. That project was particularly challenging, but a lot of fun, and a unique experience at the same time.”

This past summer, Benjamin worked on the early stages of developing a localization application, or a type of indoor GPS, that would be used in large facilities such as malls or airports. Using an Android smartphone, wifi access points are scanned and sent to a server that then queries the database and returns the appropriate map to the user. Depending on the building, or what floor the user is on, a dot will appear to pinpoint their location. “The pinpointing of the location is done with the help of various algorithms created by other graduate students,” says Benjamin. The app is currently being developed for Android phones, but the plan is for it to be available for iPhones down the road. “This research is in the very early stages so the finer details such as authentication may or may not be implemented. Currently, we have to manually input all of the maps for each floor and teach the device to identify a lot of the points within the map. So there’s still a lot of work to do.”

Says Benjamin about the relationships she has forged and the overall environment at ECE, “The work is challenging but the professors make it interesting because they are so keen at ensuring that we understand everything as we go along. They’re a great resource for us because they make themselves readily available for extra help whenever we need it. In terms of my peers, we’re a group of hardworking students, but the friendships are very strong, and everyone’s focus is on success.”

Women in Science and Engineering

Open to all University of Toronto students, staff and alumnae, the co-ed student organization entitled Women in Science and Engineering, or WISE, offers activities and outreach programs designed to facilitate networking opportunities between students and professionals from a variety of industries.

The group provides a welcoming, supportive environment through social events that foster positive relationships during university and afterwards. For example, the Life After Graduation series of conferences is focused on giving engineering students a glimpse into the diverse range of choices they have after graduation, from careers to graduate school.

Similarly, the Professional Schools Conference, focusing on Law and Medical School, gives students a chance to interact with professional students studying in those fields.

Tours and excursions to research facilities such as the Hospital for Sick Children, and Lucent Technologies Canada are organized by WISE to encourage students to tap into the vast knowledge and experience that can be garnered from connecting with successful professionals in the field.

WISE also holds several workshops on campus throughout the year, offering essential career tips including resume writing and interviewing techniques and best practices for leveraging networking events.

Established in 1999, WISE arose as a forum for peers to share their experiences. With support from the University and student body, this chapter of a national association has developed into a recognized campus organization.

15th

U of T's ECE department at the University of Toronto ranks 15th internationally according to Higher Education Evaluation and Accreditation Council of Taiwan (HEEACT).

Tulika Gupta
(Electrical Engineering 1T2), Gordon Cressy Student Leadership Award Winner, 2012

Gupta has organized WISE workshops and worked with Engineers Without Borders.

Gupta has also educated high school students on issues of poverty and water scarcity.

Graduate Studies

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

Our graduate students are supervised by more than 80 professors, and can choose from a wide range of research areas including biomedical engineering, communications, computer engineering, electromagnetics, electronics, energy systems, photonics and systems control.

ECE offers the following gradute degrees: Master of Applied Science (MASc), Master of Engineering (MEng), and Doctor of Philosophy (PhD).

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. For more information see **www.ece.utoronto.ca/graduates-home/**

Harnessing the Wind

DALIA **HUSSEIN** PhD Student | Energy Systems

"What I appreciate most about the opportunity to complete my PhD at the University of Toronto is the huge support I receive from the university and my professors," says Dalia Hussein, a fourth-year graduate student with the Energy Systems Group at the University of Toronto. "The resources we have at our disposal are of the highest quality. The equipment in the labs includes everything I could possibly need, and the materials available in the library are excellent."

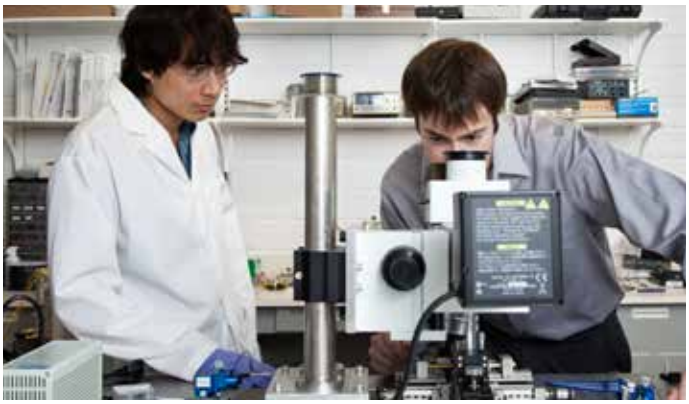
Hussein is doing her research in the area of modeling and simulation of wind power plants. She is interested in developing an equivalent model for wind power plants (WPPs) to study their behavior in response to electromagnetic transients in the power system. The motives behind this work were the limitations associated with existing equivalent models and the computational inefficiency of WPP detailed models. They require detailed modeling of each component within the WPP (typical WPP consists of hundreds of components) and hence require massive computation resources and time.

"Through my work I was able to develop a computationally efficient equivalent model of WPP that contain wind turbine generators of Type-4 (direct drive machines)," says Hussein. The accuracy of the developed model was verified through comparing its simulation results with those of a benchmark system implemented in detail. The developed equivalent model drastically reduces the computational time and burden, as compared to the detailed system, for example from five hours to 110 seconds, without compromising the accuracy of the results. "In the current stage of my work, I am extending the developed equivalent model to include WPPs that contain wind turbine generators of Type-3 (Doubly Fed Asynchronous generators)."

Hussein finds working in this area promising."I believe this is the era of generating electricity from renewable resources," says Hussein. "In the long run it will be cheaper and it is crucial for the environment. There is a lot of potential for research here because there are lots of problems that need study. There are no easy solutions."

In addition to a challenging academic career, Hussein also juggles the demands of motherhood. "It's not an easy task because I want

to spend as much time as I can with my child while fulfilling the requirements of my career," says Hussein. "Fortunately I have a supportive husband. As well, my supervisor, Professor Reza Iravani, is very understanding of my situation, and that has been so important to my being able to meet all the demands. In the end I believe all of the effort will be worth it because I will be a good role model for my child, and for other parents too."



3

ECE Students Among *The Next 36*

The Next 36 is a prestigious entrepreneurship leadership initiative helping to launch business careers for promising Canadian undergraduates.

It aims to transform participants into Canada's top entrepreneurs through a mix of teamwork, business experience and intensive entrepreneurship instruction. U of T is a founding partner in The Next 36, launched by a group of business leaders, academics and entrepreneurs.

During the eight-month program, the students work in multidisciplinary teams to develop, launch and sell a product or service for the mobile or tablet market. The students also receive entrepreneurship training and mentorship from world-class business leaders.

The eight-month program provides up to $80,000 from top venture capitalists, a comprehensive offering of in-kind resources and instruction from some of the world's top faculty.

Zerzar Bukhari, Electrical Engineering 1T3

Freddy Chen, Computer Engineering 1T3

Alexandru Litoiu, Electrical Engineering 1T2

6

Number of buildings that comprise the ECE infrastructure.

4,400

Square meters of research labs in ECE.

Teaching

Professor Jonathan Rose (ECE), is the recipient of the 2011-12 Faculty Teaching Award.

Breaking Boundaries to Reach New Frontiers

JASON **GRENIER** PhD Student | Photonics

It's said that the 21st Century is that of the photon. And to Jason Grenier, PhD candidate, Photonics Group, University of Toronto, these are exciting times. His doctoral research, supervised by Professor Peter Herman, focuses on the area of ultra-fast laser processing for use in communications, medical diagnostics and sensing.

Ultra-fast lasers offer a unique opportunity to fabricate light-guiding structures with more advanced filtering and sensing capabilities anywhere inside an optical fiber. Microfluidic channels, or micron-sized pipes in which fluids can flow, can also be laser fabricated allowing light guiding structures to probe the fluid to make sensitive measurements. Grenier's goal is to create compact and functional optical microsystems for sensing that underpins the possibility for creating complex laboratory diagnostics on a compact optical fiber.

"For me the passion comes from discovering new things," says Grenier. "As researchers we push boundaries to discover new frontiers, harness that knowledge and disseminate it through papers and conferences, and that's really the motivation for me." Recently, developments of Grenier's research were presented at the 2012 Photonics North Conference and received the best oral presentation award.

A dedicated student, Grenier is also the founding President of the University of Toronto student chapter of the International Society for Optics and Photonics (SPIE), and is actively involved in various educational outreach activities. "I'm thrilled to be in a position to guide research students at a time when there is such a huge thrust in this field," says Grenier. "Optics and photonics will have a major role to play in the future, and will impact everything from communications, to biomedical advancements and green technologies. For anyone starting out in this area of study, there is great potential."

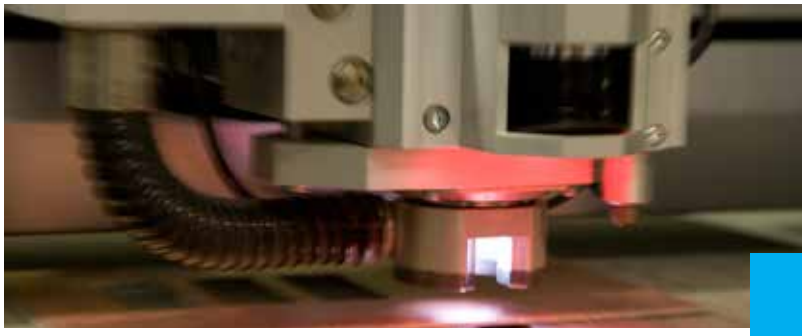
In addition to his group's connections with international research groups and industry partners, networking locally with other researchers on-campus through initiatives organized by the Institute of Optical

Science is also a key focus for Grenier. “The institute brings together all of the U of T researchers working on optics and photonics, and organizes extensive opportunities for us to interact together,” says Grenier. “I find that really rewarding because not only do we know what we’re working on and what our immediate colleagues are doing but there’s a bigger picture here at U of T and the institute facilitates collaboration.”

Another partnership Grenier’s group has successfully developed is one with St. Michael’s Hospital. “The researchers and doctors at St. Michael’s bring a strong knowledge base in biomedical research and we bring a strong knowledge base in laser fabrication and optical devices,” says Grenier. “It’s in this kind of collaboration where we get really interesting and novel expansion of the frontiers and boundaries. When you put the expertise of two great research areas together, that’s where you see the boundaries just balloon out. It’s very exciting to be a part of that.”

116

Number of ECE graduate degrees granted in 2011-12.

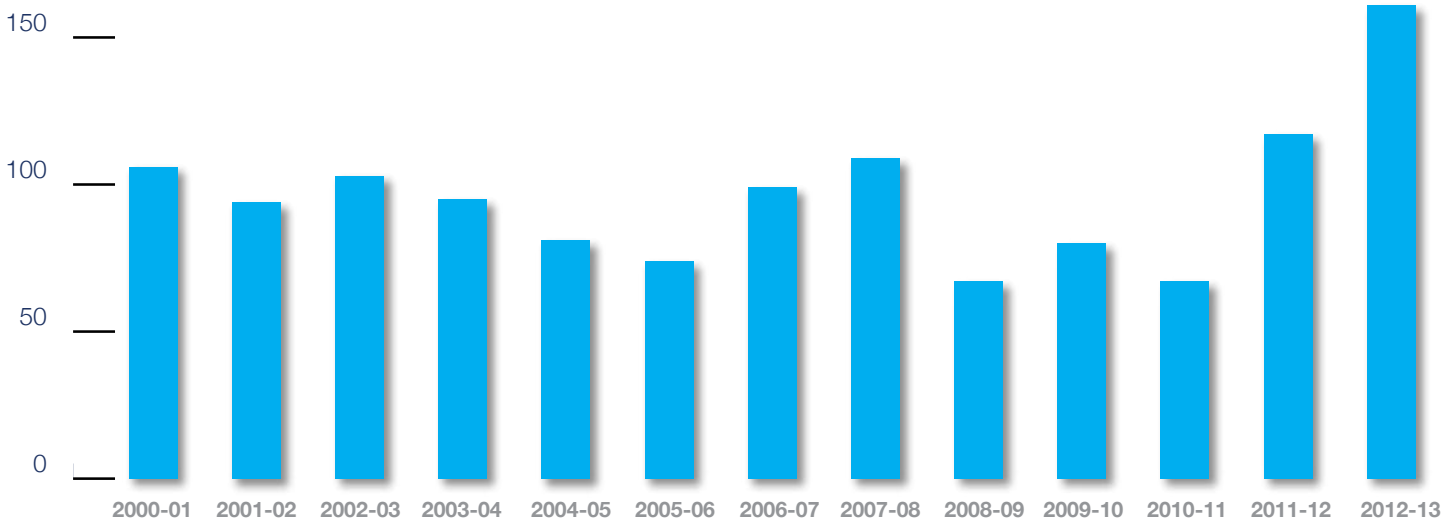


The NSERC Collaborative Research and Training Experience

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.

Since 2009, our Faculty has been awarded over $8 million from NSERC to fund five such programs.

MEng Enrolment, 2000 to 2013



How To Harvest the Sun With Photovoltaics Research

AUDREY **KERTESZ** MASc Student | Systems Control

While it was the sheer mathematical beauty and ubiquity of control theory that first captured the University of Toronto System Control Group's graduate student Audrey Kertesz, what continues to fuel her passion is the ongoing pursuit of applications that will transform her visions into reality.

In 2010, Kertesz was the recipient of the André Hamer Post Graduate Award from the Natural Sciences and Engineering Research Council of Canada (NSERC), from which funding has enabled her innovative research.

"In control theory people inhabit one of two worlds," says Kertesz. "Either you are interested in solving a mathematical problem that has been abstracted away from application, or you have a practical engineering problem to which you're looking to apply those general theories. I found out very quickly that I wanted to work on a practical problem, bridging the gap between the theoretical and engineering worlds," says Kertesz.

One such problem lies in the field of photovoltaics — cells, or panels that convert the sunlight directly into electricity. Here, Kertesz has focused the thrust of her research on the performance optimization of urban-based solar installations by designing better controllers. "An increased demand for sustainable energy resources has led to rapid growth in the area of photovoltaics," says Kertesz. "However, the power generated by a solar cell is highly sensitive to the cell's operating current. The operating point yielding the highest output power, or maximum power point, is dependent on both temperature and lighting conditions. And so, while we have solar panels that work efficiently in rural settings where they sit unobstructed from the sun, they are less efficient in urban settings where they are often hindered by partial shading from trees or buildings. Without the right power electronics and control infrastructure, they suffer a substantial reduction in output power."

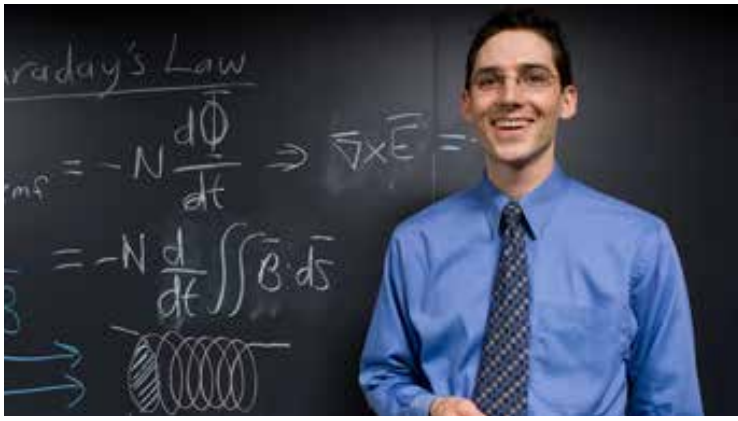
To solve this problem, Kertesz is working to improve an alternative to the traditional control of solar cells, referred to as distributed maximum power point tracking. Conventionally, photovoltaic modules share a common current, rendering them unable to operate exactly at their respective maximum power points under uneven lighting conditions. With distributed maximum power point tracking, local controllers perform maximum power point tracking individually for each module, optimizing the total output of the system. “There are some unique challenges that I am addressing in my research, however by devising a control strategy that provably stabilizes the system under a broad range of operating conditions, maximum power output can be guaranteed,” says Kertesz. “It’s an enticing solution to the problem of series-connected photovoltaic modules.”

433

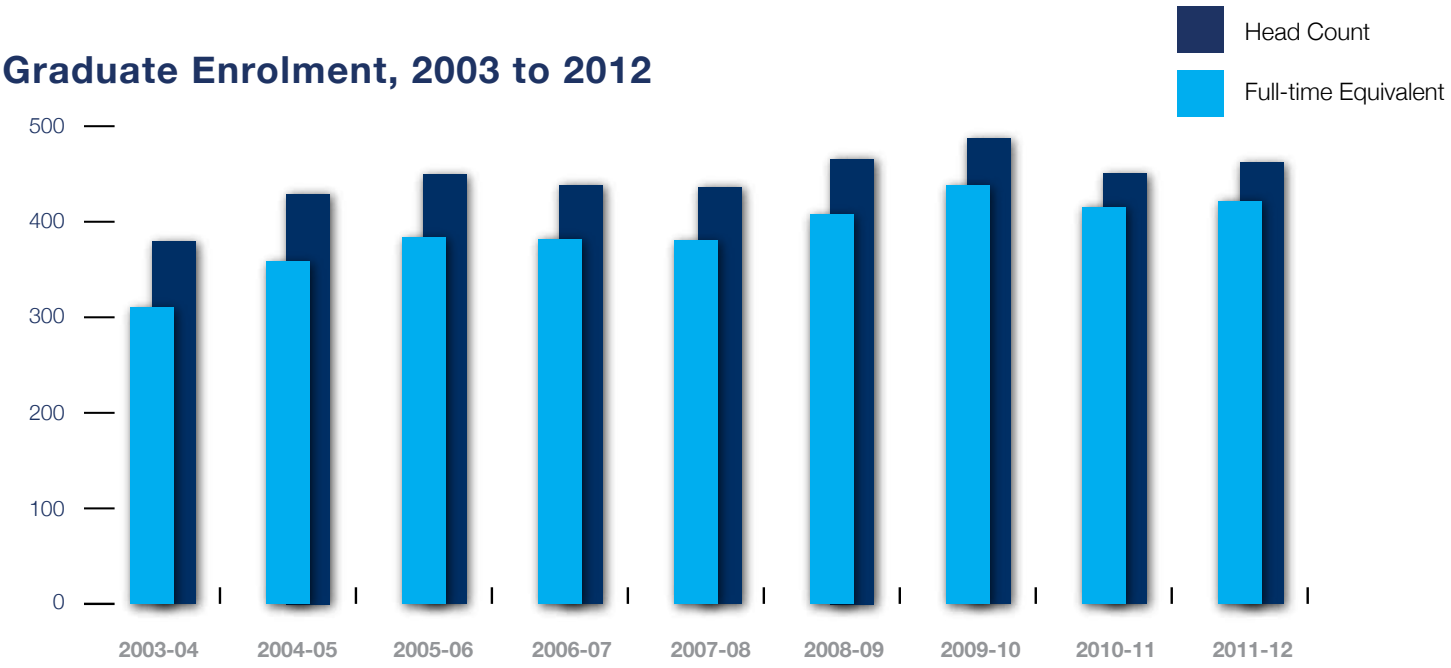
Invention disclosures produced by U of T’s ECE department over the last three decades.

Teaching Excellence

Dr. Micah Stickel is the recipient of three departmental teaching awards and was honoured with the Faculty’s Early Career Teaching Award in April 2012. He is known as an innovator in the use of technology in his lectures. He is currently pursuing research in implementing an inverted classroom model in a large-scale, second-year course in ECE. Dr. Stickel also serves as the Faculty’s Chair, First Year.



Graduate Enrolment, 2003 to 2012



Innovative Technology Lends an Ear to Silenced Voices

ERIC **WAN** MASc Student | Biomedical Engineering

For children with little or no motor control or facial expressions, communicating a simple yes or no can be an insurmountable challenge, however through the remarkable work of a team of extraordinary researchers at the University of Toronto's Institute of Biomaterials & Biomedical Engineering, viable interaction solutions for disabled children are not only possible, they're probable.

One such researcher, Eric Wan, is a graduate student in Electrical and Computer Engineering under the supervision of Dr. Tom Chau. Wan's focus is on designing new ways to improve the quality of life for children with severe disabilities through innovative technology. Most notably, Wan assisted in the development of Dr. Chau's Virtual Musical Instrument, a software program that enables persons with physical disabilities to play musical instruments with as little movement as the blink of an eye. In 2010, Wan received the Centennial Thesis Award for his work on a wheelchair powered by a vocal cord vibration sensor, enabling the user to cause movement through variant humming sounds. "I've been interested in computer programming since I was eight years old," says Wan. "However, when I was 18, my studies were interrupted when I became paralyzed from the neck down from transverse myelitis — a rare, adverse reaction to the measles vaccine. During the months and years that followed I thought a lot about how I could do things without the use of my arms and legs," says Wan. Three years after becoming paralyzed, Wan continued his studies in computer engineering at the University of Toronto where in 2010 he graduated with a Bachelor of Applied Science — eleven years after he started. He is currently working on his Master of Applied Science degree.

"In 2005, I was introduced to Dr. Chau by one of my respiratory therapists," says Wan. "Dr. Chau invited me to assist him with some of his pediatric engineering research projects, and that was when I realized that my skills could be applied to actually help people with disabilities," says Wan.

In the simplest terms, Wan's current research project is the first of its kind using what is called otoacoustic emissions instrumentation that is traditionally used to assess the health of the inner ear, to detect whether a person is focusing attention on certain types of sounds. "I had heard about this technology and thought perhaps it could be used as a communication tool for non-verbal children," says Wan. Called Transient Evoked Otoacoustic Emissions recordings (TEOAE), Wan's research is a first step toward the development of a non-invasive, auditory body-machine interface. It will determine whether cochlear (a portion of the inner ear) response can trigger a switch when the patient focuses on a particular sound, making it possible for severely disabled children who have never been able to communicate, to finally have a voice.

"Children with severe disabilities are in great need of a way to control their environment and to communicate with others," says Wan. "We have to think of alternative ways for them to do that using innovative technology."

13th

U of T's ECE department ranks 13th internationally according to QS World University Ranking 2011.

Early Career Award

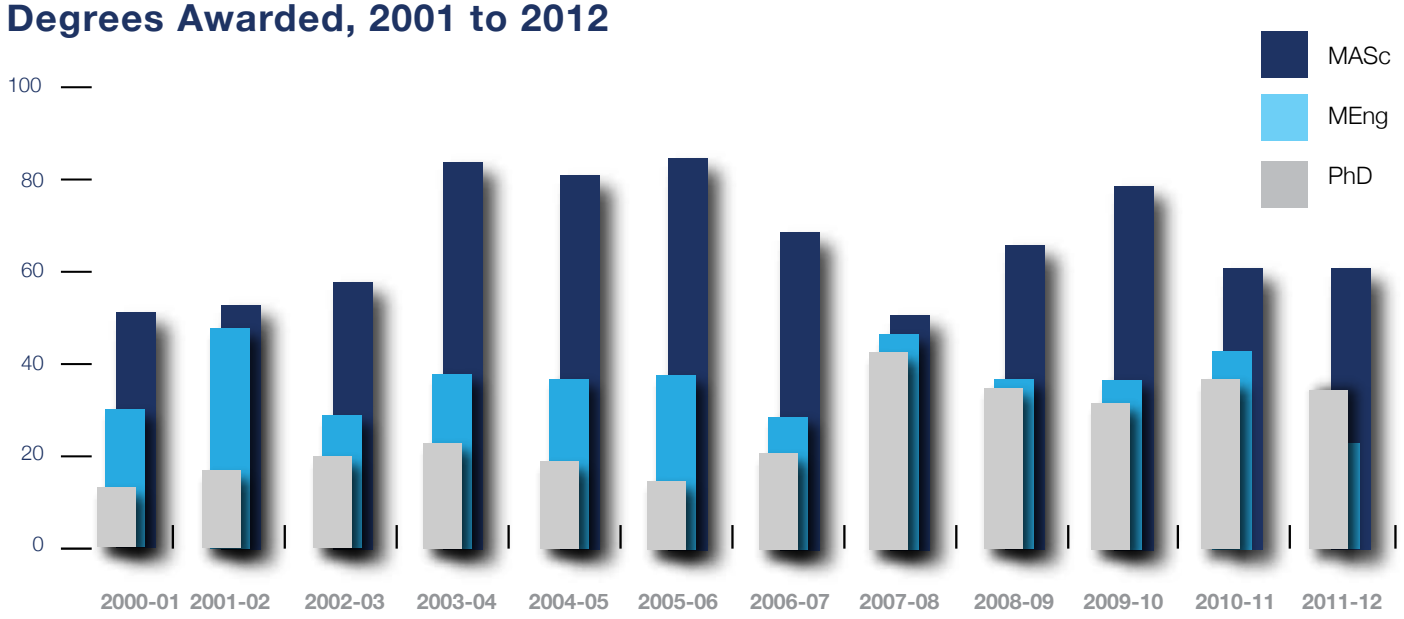
ECE graduate Somen Mondal received the Engineering Alumni Association's Early Career Award in November, 2012.

Mondal was recognized for his success as an entrepreneur in the world of business. Today, N4 Systems is a multi-million-dollar software-as-a-service enterprise that focuses on environmental health and safety with more than 250 global clients, including Cirque Du Soleil, Rio Tinto and GE.

As the CEO and co-founder of N4, Mondal has been responsible for the company's corporate vision, strategy, business growth and customer satisfaction. N4 was listed as a Company-to-Watch by the Deloitte Fast 50 for its innovation, unique market niche and long-term potential. In 2010, the company was ranked 31st in the Profit Hot 50.

Mondal recently earned the title of Ontario Ernst & Young Entrepreneur of the Year in the Emerging Entrepreneur category.

Degrees Awarded, 2001 to 2012



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 U of T Engineering 16th in North America. The Faculty has maintained its position as Canada's top engineering school and one of the very best in the world.

At the Edward S. Rogers Sr. Department of Electrical & Computer Engineering, we are particularly proud of our ability to identify areas of strategic importance to global industry and society, and to pull together major efforts to address these important problems. Initiatives include:

- 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, reliability, and sustainability of electricity services. This initiative leverages U of T Engineering's strengths in energy systems, systems control, algorithms, optimization, security, communications, networking, electronics and photonics;

- Emphasis on the technological, economic and social dimensions of security and privacy in the mobile ecosystem and the emerging cloud. The past year has witnessed U of T's launch of the Southern Ontario Smart Computing Innovation Platform (SOSCIP) in collaboration with Western University and IBM. The University is converging on a future vision of computing and what it can do to enhance all aspects of life. U of T Engineering also offers this project its strengths in computer architectures and enabling technologies in electronics;

- 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 more than 60 industry leaders worldwide to 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.

The Allure of Control Systems Research — Bewitching and Bewildering

EDWARD J. **DAVISON** PROFESSOR EMERITUS | Systems Control

The fundamental challenges inherent in controlling systems that occur in the world include a wide range of diverse areas with varying levels of complexity, spanning from traffic light control to world peace. Such challenges have tantalized Professor Edward J. Davison over his entire career, and inspired him to help create one of the world's foremost centres of control research at the University of Toronto. Control science research is concerned with finding solutions to behavioral problems in dynamic systems, to achieve a desired result.

"I have a passion for trying to solve problems in control science because the results obtained are applicable to almost all aspects of society, from the control of space-craft to the control of social systems," says Davison. "The beauty of this kind of research is that all one needs is a pencil and paper. So I'm always working; it's really become a part of who I am."

After completing a PhD at Cambridge, Davison went to Berkeley, the world centre for control systems in the 1960s. He quickly realized that he wanted to create such a centre in Canada. He returned home to Toronto with a view to making the University of Toronto world-renowned for its control science expertise.

A recent major success for Davison and his team was the development of decentralized control of large-scale systems. "The need for such systems often arises in modern industrial society," says Davison. "For example in traffic light control, to ensure traffic flow of the overall city is optimized, only local information available at each of the traffic light intersections is used." Davison's design approaches have been adopted worldwide and applied in a number of integral societal infrastructure areas such as chemical process control, large flexible space structures, and electrical power systems.

Taking place over a period of twenty-five years, Davison's "eureka" moment came after a series of gradual wins. "In our research, to solve the ultimate problem, you have to solve many intermediate problems — you have to lay the foundation," says Davison. "The motivation to this kind of study is that, unlike physics, where one is trying to understand something, in control automation, one is trying to change the behaviour of something. This doesn't happen overnight."

In the area of control systems research, many long-term unsolved problems exist, some of which are of utmost importance to humankind. One such issue concerns energy. "In this case if we can solve the problem of fusion control, and the main reason we can't is because of a control problem, then all of our energy issues would disappear. There would be no nasty by-products and we would have unlimited energy, as long as we exist."

But solutions as grand as this are elusive, and can take 25 or 50 years to reach — which is the fascination for control systems researchers such as Davison. "Every time I find a solution to a problem, there appear five new problems that are yet more exciting. We might fail nine times out of ten, but when we succeed that once, it's like touching the hand of God."

40

Spin off companies sparked by ECE members since 1950

2011 • Bionym Inc. • PRISED Solar Inc. **2010** • ChipCare Corporation • Engineered Privacy Inc. • Filaser Inc. • RenWave **2009** • Arda Power Inc. • Dreamcube Technologies Inc. (formerly UiRemote) • FOTA Technologies • InVisage Technologies Inc. • KMKP Engineering • Shape Collage Inc. **2008** • Arch Power Inc. • Incise Photonics Inc. • Peraso Technologies Inc. • Simple Systems Inc. • Snowbush Microelectronics **2007** • Inometrix Inc. • Metabacus • Modiface Inc. • OMESH Networks • Vennsa Technologies Inc. • Viewgenie Inc. **2005** • Evistech Inc. **2003** • ArchES Computing Systems Corp. **2001** • Zoomo Software Inc. **2000** • Motion Playground Inc. **1999** • Accelight Networks Inc. • Soma Networks **1998** • Right Track CAD Corp. **1996** • OANDA Corp. **1995** • Arise Technologies **1994** • Trantek Power **1993** • SmartSpeaker Corp. **1992** • Condata Technologies Ltd. • Gao Research & Consulting Ltd. **1985** • Katosizer Industries Ltd. **1980** • Almax Ltd. **1968** • Electrical Engineering Consolidated Ltd. **1951** • Sinclair Technologies Inc.

Research Excellence

In 2012, the American Association for the Advancement of Science (AAAS) awarded the distinction of Fellow to Professor Alberto Leon-Garcia for distinguished contributions to the design, management and operation of communication networks and the creation of innovative educational programs in network engineering. Professor Leon-Garcia is also a U of T Distinguished Professor and the Scientific Director of the NSERC Strategic Network for Smart Applications on Virtual Infrastructure (SAVI).

Publications Per ECE Researcher, 2001 to 2011

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Researchers	55	59	64	63	63	64	71	75	76	75	75
Publications	354	437	493	403	486	513	541	529	510	520	533
Publications per Researcher	6.4	7.4	7.7	6.4	7.7	8.0	7.6	7.1	6.7	6.9	7.1

The Power and Powering of Computers

NATALIE **ENRIGHT JERGER** ASSISTANT PROFESSOR | Computer Engineering

For Professor Natalie Enright Jerger, being able to collaborate with top researchers was the University of Toronto's primary drawing card. "There is such a large and vibrant research program here," says Enright Jerger. "The opportunity to engage with experts across the range of electrical and computer engineering specialties to further my research is very exciting for me."

Currently, Enright Jerger is collaborating with Professor Joyce Poon who is working on optical devices. "Together we're looking at how we can incorporate the devices that she designs into the higher-level architecture and hardware of the computer," she says. "These kinds of collaborations are important as we are reaching a point in my field where we have to start relying on new devices and low-level technology to sustain the computing industry."

As society continues to push the boundaries of computer technology, Enright Jerger and her team of students are challenged to meet the increasing demand for lower-powered computers with higher performance. Their main research area is in the designing of efficient communication fabrics or interconnection networks for next-generation many-core processors.

"One focus area is on how to provide better hardware that is more tailored to the cache coherence protocol, or determining how data is shared between processors," she says. "We look at how certain control information is exchanged. So when we design the on-chip network with certain properties of the coherence protocol in mind, we're able to see fairly large advantages, such as energy savings and performance improvement. Here at the University of Toronto, we've been one of the first groups to exploit this, and we've discovered some pretty exciting opportunities. I'm really looking forward to seeing where we go with this in the coming years."

Although computer architecture has matured as a field, Enright Jerger says there is still significant work to be done in this area. "It's a dynamic and evolving field. Computers bring so much

to society. From the Internet which provides social networks and education tools, to simulating the human brain in neuroscience research, the computer has become an integral part of our world. The driving force for my research involves meeting technology challenges and application demands that will fuel future growth. That makes this an exciting field to work in."

60

Industry leaders around the world who partner with ECE researchers.

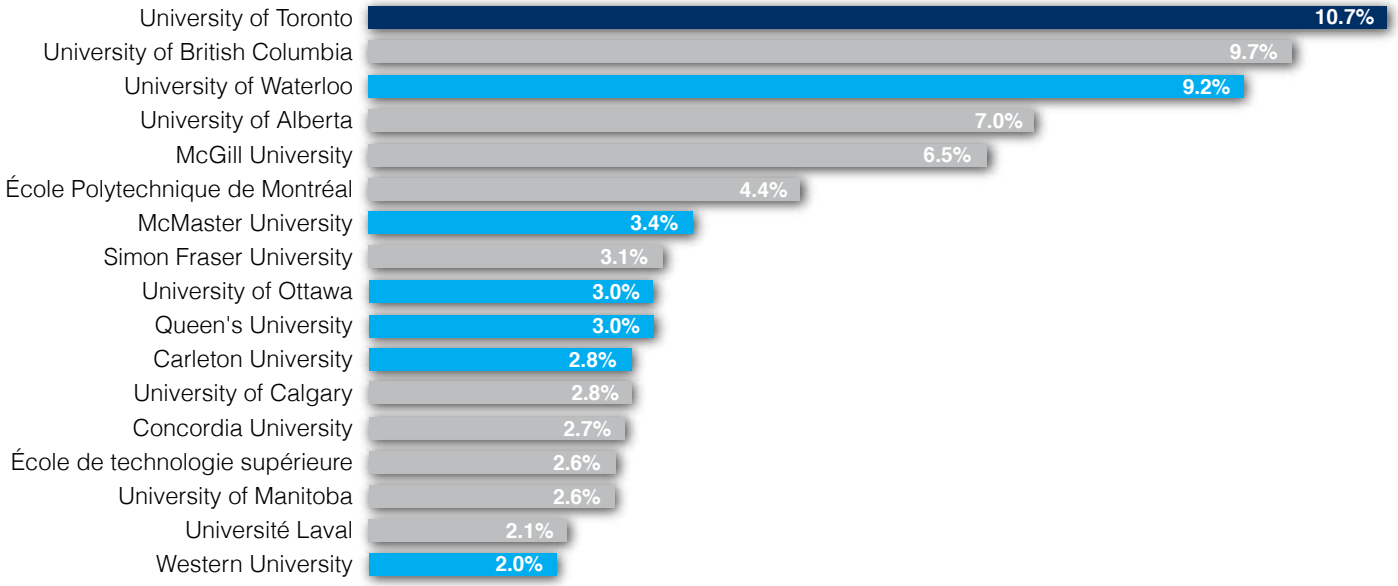
3 Major Awards Received in 2011-2012

Professor Frank Kschischang
Recipient of the 2012 Canadian Award for Telecommunications Research

Professor Brendan Frey
Co-winner of the John C. Polanyi Award

Professor Joyce Poon
Named one of *Technology Review*'s Top 35 Under 35

NSERC Funding for Electrical and Electronics Engineering at Leading Canadian Universities, 2011



Internet Networks — The Next Generation

JORG **LIEBEHERR** PROFESSOR | Communications

While the Internet is indisputably one the greatest engineering feats of our time, for Professor Jorg Liebeherr, there is much work to be done to realize its full potential.

"The Internet has changed the way we communicate and do business, created wealth and reduced social and geographic barriers," says Liebeherr. "Yet, to access the Internet most of us depend on equipment and services of network providers.This creates the view of the Internet as a remote shared resource, quite similar to mainframe computing in the 1960s. Clearly we can design better technologies that are more supportive and adaptive to mobility of data transport," he says.

The goal of Liebeherr's research is to harvest the potential of self-organizing networks. Self-organizing networks comprise an alternative approach to building large computer networks. In contrast to centrally planned and managed network infrastructures, self-organizing networks are formed and operated in a fully distributed manner, and do not rely on centralized mechanisms for network formation, management or operation. As a result, self-organizing networks can be built faster and cheaper than conventional networks. Furthermore, they are better suited to adapt to changes of network topology, traffic mix and service requirements; and are also inherently fault-tolerant. They often exist only for a limited time to perform a particular task or provide connectivity to a group of devices. Their topology can be highly dynamic, as nodes may enter or leave the network at any time.

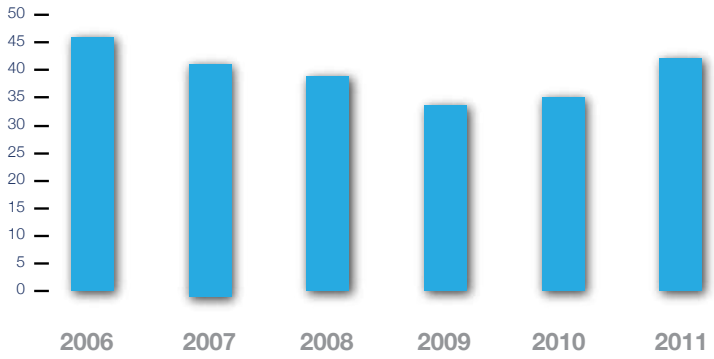
"The way we exchange data is often counter-intuitive," says Liebeherr. "For example, when two mobile devices right next to each other exchange a document, the data is often sent tens or hundreds of kilometers away into the core of the Internet, and then all the way back again before it is received. Modern devices are capable of discovering one another and sharing data on the spot. My research seeks to fully exploit this capability."

Self-organization can be deployed on top of an existing network infrastructure as is the case of Internet peer-to-peer networks, or they can build their own network infrastructure as in the case of mobile ad-hoc networks. Since they can adapt to the availability of resources and usage patterns, self-organizing networks can be more resource and power efficient. As nodes can decide themselves how to connect and communicate, self-organizing networks are able to ensure privacy and security more easily than infrastructure networks.

"Self-organizing networks can be used to build community networks, that is networks run by and for private citizens," says Liebeherr. "In recent years we've witnessed governments whose regimes are threatened shut down the Internet. With self-organized networks, they would not be able to do this. As the Internet played a huge role in the advancement of society, the conversion of our networks can do so as well on many levels."

However, Liebeherr says that we are still a ways away from the reality of self-organizing networks. "There are a lot of questions still unanswered," says Liebeherr. "Right now my role is to conceive technology and develop prototype solutions. Ultimately, since a self-organizing approach can lead to more resource and power efficient networks, these kinds of networks will prevail."

ECE Invention Disclosures, 2006 to 2011

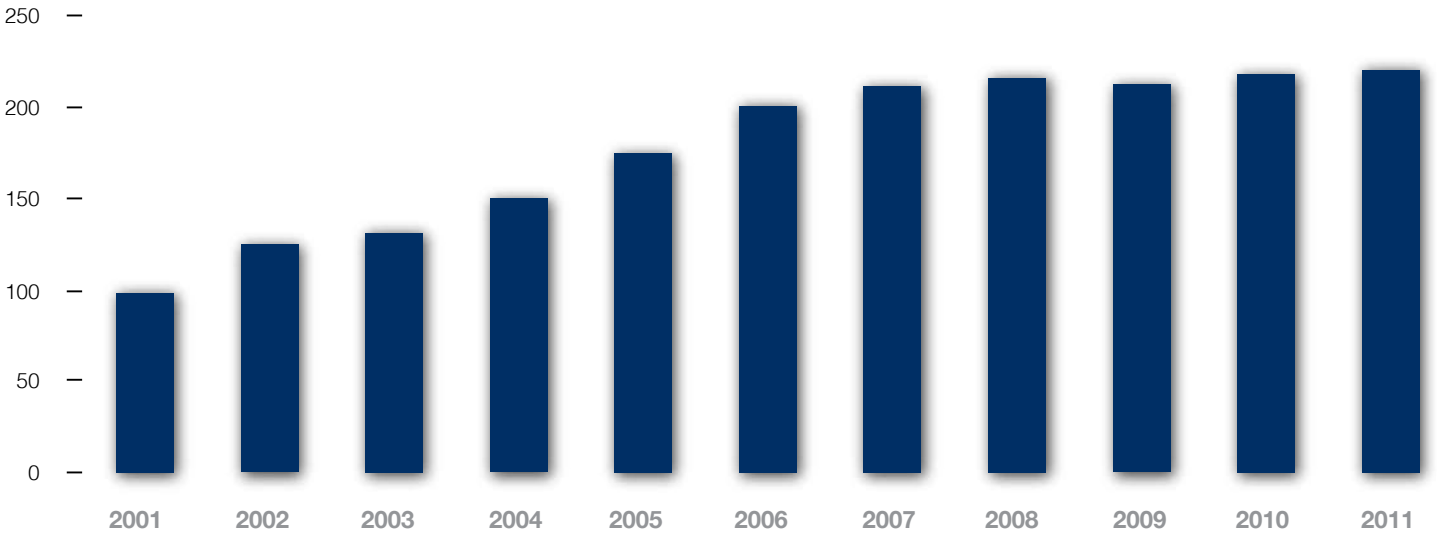


The University's Invention Policy requires inventors to completely disclose their inventions. In most cases, rights to their inventions are then jointly owned by the University and the inventor.

#1

Engineering continues to be the source of nearly half the inventions generated annually at U of T, with ECE responsible for the highest number.

PhD Enrolment, 2001 to 2011



Big Solutions in Little Packages

ROMAN **GENOV** ASSOCIATE PROFESSOR | Electronics

Imagine an implantable microchip the size of a pea that can interface with the brain to treat neurological disorders and detect vital signs of the human body. That's the primary focus of Professor Roman Genov's research at the Intelligent Sensory Microsystems Laboratory.

"I've always been interested in how the engineering and medicine disciplines complement one another, and in the vast opportunities for the advancement of healthcare that ensue from cross-disciplinary research," says Genov, whose extensive work on microchips that interface with the human brain has been widely recognized internationally.

Genov and his research team have developed a low-power, inexpensive microchip that is capable of monitoring electrical activities of neurons at hundreds of locations in the brain at once. In fact, they are among the top research groups in the world in terms of electrical characteristics and number of recording channels on a microchip. "The technology has evolved greatly over the past few years. Now, we have microchips that are highly versatile in not only monitoring but also analyzing electrical activity of the brain," he says.

Such microchips can be implanted to treat certain neurological disorders such as intractable epilepsy in cases where pharmacological agents are not effective. "We are working closely with medical doctors to come up with solutions where a microchip identifies an upcoming seizure and delivers a small electrical charge to the brain in order to prevent or abort the seizure," says Genov. "This is very exciting research because, as it stands now, there are no effective treatment options available for such patients."

Another thrust of Professor Genov's research focuses on developing disposable biosensory microchips for in-field medical diagnostics.

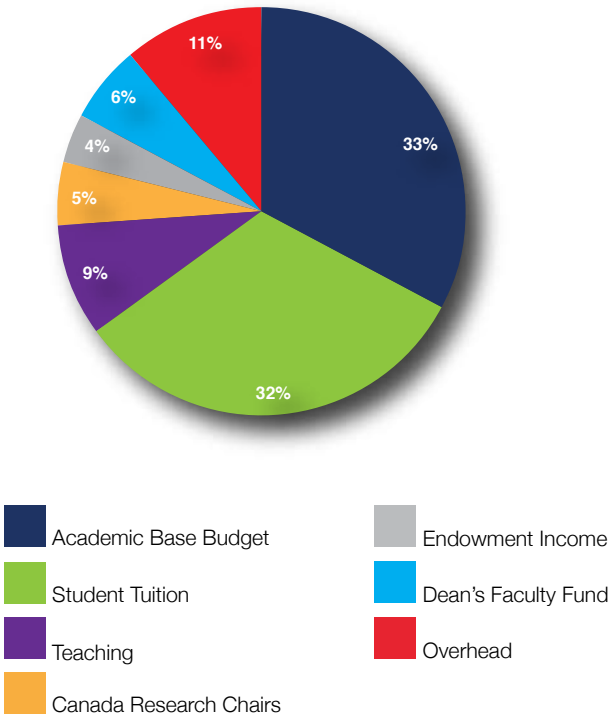
"We have enabled and fine-tuned sensing capabilities of conventional microchip fabrication technologies for quick, in-field analysis of vital signs of the human body," says Genov. "In one such example, a patient's DNA analysis can be performed right on the surface of a

single-use microchip. This enables us to extract important medical diagnostic information at a low cost, quickly and directly on-site, which is often critically important to the patient or doctor."

"What I see happening in the next five years is that more and more gaps like this will close as integrated circuit designers come up with new solutions using electronic microchips to solve current problems in healthcare."

Having joined the faculty at the University of Toronto over ten years ago, Genov says he was attracted to the institution because of the widely acknowledged presence of cross-disciplinary, world-class research. "This is such a significant advantage because it enables collaboration among multiple disciplines, such as engineering and medicine," says Genov. "The potential for new discoveries is immense."

ECE Revenue 2011-2012: $27 million



3
U of T Inventors of the Year

Professor J. Stewart Aitchison
(along with James Dou)

Professor Aleksandar Prodic

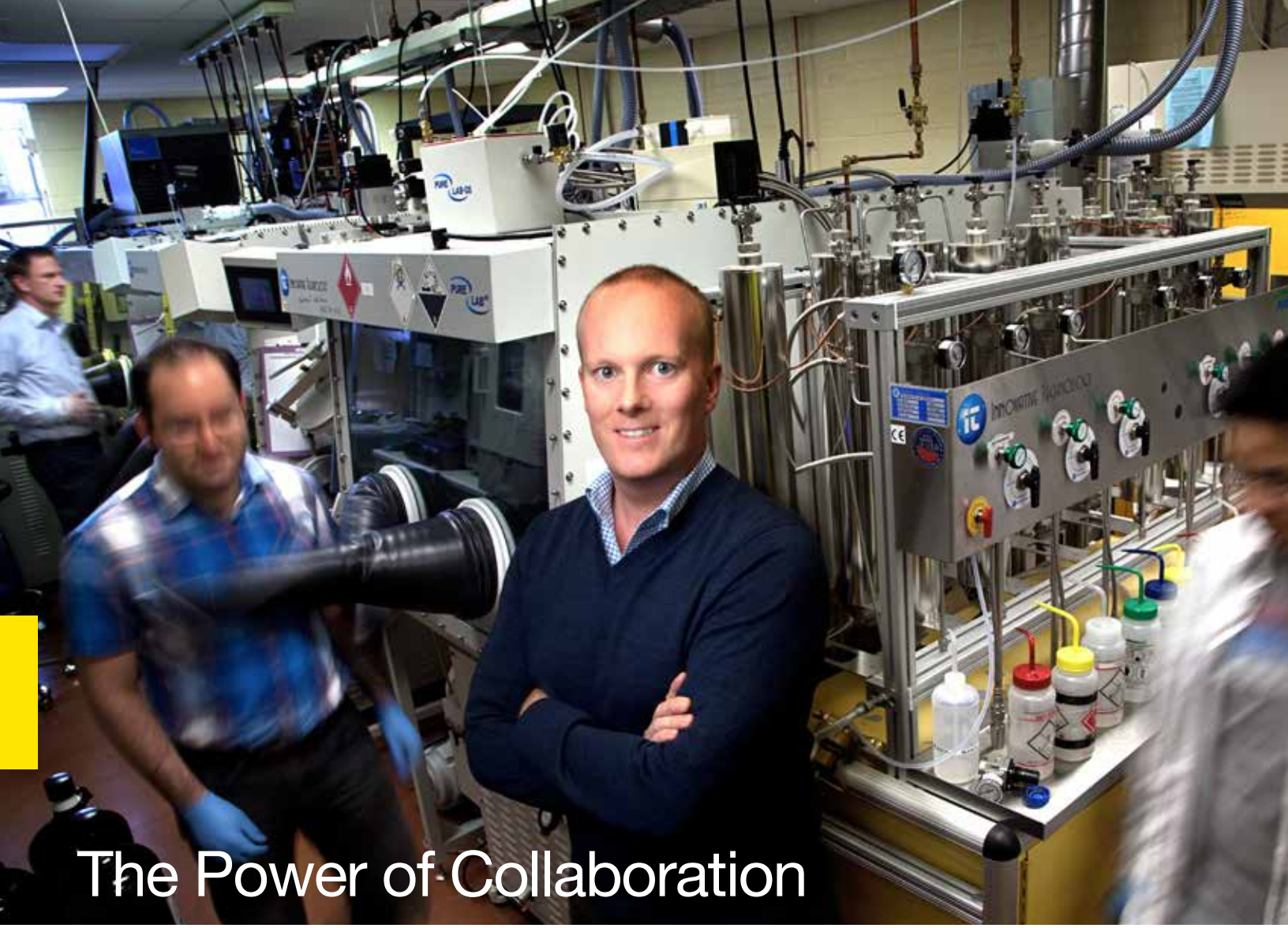
Professor Dimitrios Hatzinakos

#1

The Faculty of Applied Science and Engineering ranks first in Canada for the number of engineering publications, 2006-2010, according to Thomson Reuters

ECE Research Funding, from 2005 to 2011

	2005	2006	2007	2008	2009	2010	2011
Federal	$ 7,807,414	$ 10,397,002	$ 8,705,671	$ 8,440,564	$ 7,966,298	$ 8,756,585	$ 9,294,841
Provincial	$ 3,753,222	$ 5,479,296	$ 3,703,586	$ 3,955,389	$ 4,862,786	$ 3,985,865	$ 2,913,797
Industry	$ 2,280,661	$ 2,266,096	$ 3,363,559	$ 2,940,516	$ 2,789,325	$ 1,471,958	$ 2,575,974
Other	$ 663,252	$ 575,955	$ 957,306	$ 863,281	$ 2,780,615	$ 2,735,435	$ 2,847,164
Total	**$ 14,504,549**	**$ 18,718,349**	**$ 16,730,122**	**$ 16,199,750**	**$ 18,399,024**	**$ 16,912,843**	**$ 17,631,776**



The Power of Collaboration

TED **SARGENT** PROFESSOR AND VICE-DEAN, RESEARCH | Photonics

Great things happen when engaged people inspire and challenge one another to achieve a shared vision. Such is the case for the talented, multidisciplinary group of researchers led by Professor Ted Sargent. They collectively unite chemistry, physics and engineering to develop high impact applications in energy, health and sensing.

"We are continuously learning from each other," says Sargent. "The intelligence of the group and the necessary knowledge to do the work resides within the collective, rather than within any single individual. That's what motivates us and makes our research group so much fun to be a part of."

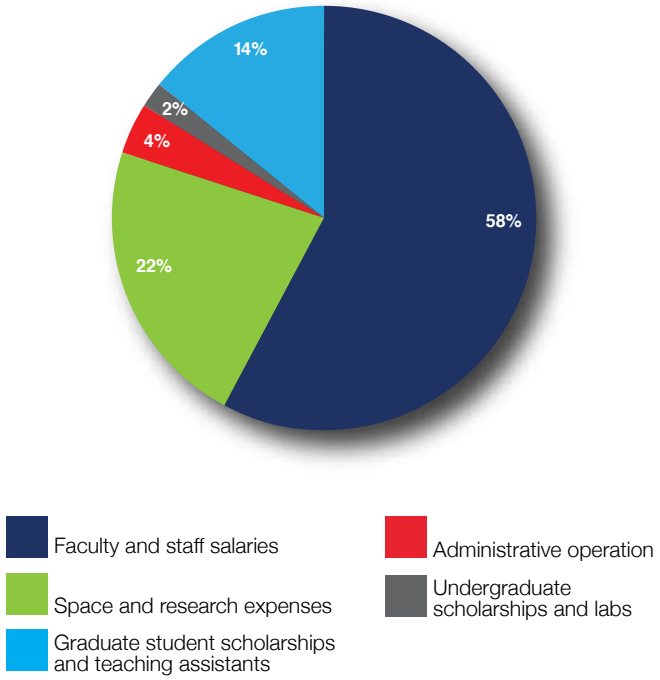
Currently, the group devotes the core of its time to research in two main areas: photovoltaics and nanobiosensors. In the area of photovoltaics, or solar cells, the group's focus is on developing efficient and inexpensive energy conversion technologies. "The sun's energy is a vast resource that well exceeds annual global consumption demands," says Sargent. "The problem we face is that harvesting it is expensive and energy-consuming. Our group is working to change that by enhancing device performance, stability and understanding." In 2005 the group reported the first paint-on solar cell to harvest the sun's abundant infrared rays, and in subsequent years increased the power conversion efficiency of the device several thousand fold. In 2012 they reported the first photovoltaic device of this type to reach 7% solar power conversion efficiency.

The second area of concentration for the group is biosensing for personalized medicine. Nanowires, nanotubes, nanoparticles and quantum dots, developed using advances in nanotechnology, have unleashed a new generation of ultrasensitive and versatile applications in point of care diagnostics, medical screening and treatment planning. Nanomaterials engineered to have particular functions have the potential to revolutionize healthcare through the ability to build low-cost diagnostic devices with large panels of biomarkers and with unprecendented sensitivity and specificity. "In collaboration with the Faculty of Pharmacy and the Faculty of Medicine, we are prototyping innovative devices used for selective and sensitive

readout of nucleic acid sequences and protein biomarkers," says Sargent. "Such devices employing carefully engineered sensing elements are envisioned to diagnose different cancers and bacterial infections at the molecular level in a matter of minutes. Our mission is to find new and innovative approaches to manipulate our sensors at the nanoscale, to design more effective molecular probes and to develop new signal transduction strategies." The work led to the spinoff of Xagenic, the Toronto-based point-of-care molecular diagnostics company.

Comprised of research associates, post-doctoral fellows, graduate students and technical specialists from North America and worldwide, the group's team members are not only multidisciplinary, they're multi-cultural, representing almost every continent on the globe. "Having people that are not only brilliant but superbly trained and with diverse backgrounds brings an unparalleled depth and breadth to the team," says Sargent. "It's one of the ingredients that makes U of T such a spectacular environment in which to carry out research. Because of the University's stellar global reputation for excellence, and because Toronto is such a great city to live in, we are able to recruit truly amazing researchers from around the world. First and foremost, this is about people."

ECE Projected Expenses 2011-2012



10,500+

U of T ECE alumni worldwide.

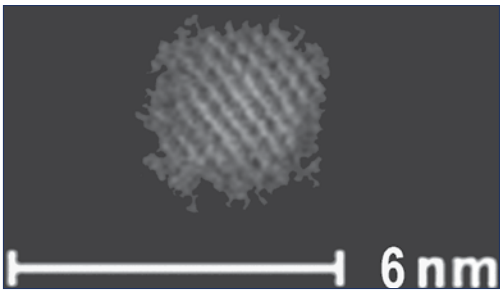
#1

U of T's ECE Department ranks number one in Canada according to the Higher Education Evaluation and Accreditation Council of Taiwan (HEEACT).

2012 Steacie Prize

Electrical and Computer Engineering Professor Edward (Ted) Sargent is the winner of the 2012 Steacie Prize, awarded each year to one person 40 years of age or less who has made notable contributions to research in Canada.

Professor Sargent has been named one of the 'Scientific American 50', one of 'Canada's Top 40 Under 40' and one of the world's 100 top young innovators by MIT Technology Review. He is a Fellow of the American Association for the Advancement of Science and the Institute of Electrical and Electronics Engineers.



A transmission electron micrograph (TEM) of a 3-nanometer-diameter quantum dot, a semiconductor particle tuned to absorb light from across the sun's broad visible and infrared spectrum. The undulations are lattice fringes corresponding to individual planes of atoms in the crystalline nanoparticle.

Corporate Partners

ABB AB
AMD INC.
AEG POWER SOLUTIONS INC.
ALCATEL CANADA INC.
ALTERA CORPORATION
ARISE TECHNOLOGIES CORPORATION
ASAHI KASEI MICROSYSTEMS CO. LTD.
BCUL - RESEARCH FUNDING
BELL CANADA
BLINQ NETWORKS INC.
BROADCOM CORPORATION
CARINTHIAN TECH RESEARCH INSTITUTE
CELESTICA
CICLON SEMICONDUCTOR DEVICE CORP
CISCO SYSTEMS
DIGITAL PREDICTIVE SYSTEMS INC.
ECAMION INCORPORATED
ELCAN OPTICAL TECHNOLOGIES
ELECTRO SCIENTIFIC INDUSTRIES
EXAR CORP.
FIBER OPTIC SYSTEMS TECHNOLOGY INC.
FIRAN TECHNOLOGY GROUP CORP.
FUJI ELECTRIC CO., LTD.
FUJITSU LABORATORIES LTD.
GE
GENNUM CORPORATION
GM CANADA
GO LIGHTING TECHNOLOGIES INC.
H2GREEN ENERGY CORPORATION
HEWLETT-PACKARD COMPANY
HONEYWELL ASCA, INC.
IBM
IBM CANADA LTD.
INOMETRIX INC.
INTEL CORPORATION
INVISAGE TECHNOLOGIES (CANADA) INC
IPPLEX HOLDINGS CORPORATION
IVG FIBER LTD.
KINECTRICS INC.
KT MICRO INC.
LG ELECTRONICS
LOCKHEED MARTIN CANADA
MAGNA E-CAR SYSTEMS
MARK IV INDUSTRIES CORP.
MARS INNOVATION
MATTSON TECHNOLOGY CANADA
MAXIM INTEGRATED PRODUCTS, INC.
MDA
MIRCOM TECHNOLOGIES
MITSUBISHI ELECTRIC RESEARCH LAB.
MORGAN SOLAR
NATIONAL SEMICONDUCTOR
NORTHROP GRUMMAN ISS
NVIDIA CORPORATION
NXP SEMICONDUCTORS NETHERLANDS B.V.
ONTARIO LOTTERY AND GAMING CORP
ONTARIO POWER AUTHORITY
PANASONIC SEMICONDUCTOR SINGAPORE
PERASO TECHNOLOGIES INC.
QUALCOMM CANADA INC.
QUALCOMM INC.
QUANSER INC.
RAMBUS INC.
RAYTHEON CANADA LIMITED
REDLINE COMMUNICATIONS INC.
RESEARCH IN MOTION LTD.
ROBERT BOSCH CORPORATION
SEMICONDUCTOR RESEARCH CORPORATION
SENDYNE CORP.
SIEMENS
SILICON MITUS INC
SIPEX CORPORATION
SIRADEL INC.
SOLANA NETWORKS
SONY CORPORATION
TAIWAN SEMICONDUCTOR MANUFACTURING
TELUS MOBILITY
THALES RAIL SIGNALLING SOLUTIONS
TORONTO ELECTRIC LTD.
TOSHIBA CORPORATION
TOTAL AMERICAN SERVICES INC.
UBM TECHINSIGHTS
VIXS SYSTEMS INC.
XILINX INC.
XOGEN TECHNOLOGIES INC.
ZENTRUM MIKROELEKTRONIK DRESDEN AG

PEY Participants

A THINKING APE , BC & MICROSOFT IN USA
ABB LTD -SWITZERLAND
AECON CONSTRUCTION AND MATERIALS LTD.
AFFINITY SYSTEMS LTD.
ALTERA CORPORATION - SAN JOSE, CA, USA
ALTERA CORPORATION - TORONTO TECHNOLOGY CENTRE
AMD (ADVANCED MICRO DEVICES, INC.)
AMD (ADVANCED MICRO DEVICES, INC.)- USA
ANALOG DEVICES INC.
AVIYATECHNOLOGIES INC.
BANK OF AMERICA MERRILL LYNCH
BANK OF MONTREAL
BAYLIS MEDICAL
BELL CANADA
BELL MOBILITY
BLUECAT NETWORKS
BOMBARDIER AEROSPACE
BRIGHAM AND WOMEN'S HOSPITAL - USA
BROADCOM (US)
CANADA HEALTH INFOWAY
CASEWARE INTERNATIONAL INC.
CAST SOFTWARE INC.
CELESTICA INC.
CIBC
CITY OF TORONTO
DELOITTE
DEMONWARE - B. C
ECAMION
ENVISION MOBILE (FORMERLY VIZIO MOBILE INC.)
EPSON
ERICSSON CANADA INC.
EVENTMOBI
EXECUTIVE HEALTH CENTRE & UNIVERSITY HEALTH NETWORK
FIXMO
GE CANADA
GENERAL MOTORS OF CANADA LTD.
GENNUM (SEMTECH)
GENNUM CORPORATION (SNOWBUSH IP)
HATCH MOTT MACDONALD
HOLCIM, CANADA (INC).
HUSKY ENERGY - CALGARY
HYDRO ONE
IBI GROUP
IBM CANADA LTD.
IMPERIAL OIL - ALBERTA
INDIGO BOOKS & MUSIC
INTEGRAN TECHNOLOGIES INC.
INTERAXON INC.
KIJIJI CANADA
L-3 WESCAM
MANULIFE FINANCIAL
MARIN SOFTWARE - USA
MARVELL TECHNOLOGY GROUP - USA
MCW CONSULTANTS LTD.
MESSIER-DOWTY INC.
METROLINX
MICROSEMI CORPORATION (FORMERLY ACTEL CORP) - USA
MICROSOFT CANADA CO.
MINISTRY OF CHILDREN AND YOUTH SERVICES
MODIFACE
MOLD-MASTERS LTD.
MYPLANET
NATIONAL INSTRUMENTS
NATIONAL RESEARCH COUNCIL CANADA (NRC)
NEXJ SYSTEMS INC.
NORDEX - GERMANY
NVIDIA U.S.A.
OMNIVEX CORPORATION
ONTARIO POWER GENERATION (OPG)
ONTARIO TEACHERS' PENSION PLAN
ORBIS ACCESS -
BERMUDA
PRINCESS MARGARET HOSPITAL
PSION INC.
QUALCOMM CANADA
QUICKPLAY MEDIA
RBC CAPITAL MARKETS
RED HAT CANADA LTD.
REDKNEE INC.
REGIONAL MUNICIPALITY OF YORK
RESEARCH IN MOTION (RIM)
RL SOLUTIONS
SANOFI PASTEUR
SCOTIA CAPITAL
SUNCOR ENERGY - ALBERTA

Community

SUNNYBROOK HEALTH SCIENCE CENTRE & COLIBRI TECHNOLOGIES
SYMANTEC CANADA LTD., DELRINA GROUP
TEKNION FURNITURE SYSTEMS
TEMASEK LABORATORIES@NTU - SINGAPORE
THALES RAIL SIGNALLING SOLUTIONS
THE HOSPITAL FOR SICK CHILDREN
THE INDEPENDENT ELECTRICITY SYSTEM OPERATOR (IESO)
THE REGIONAL MUNICIPALITY OF YORK
TORONTO HYDRO
TORONTO TRANSIT COMMISSION (TTC)
TRANS CANADA - CALGARY
TRAPEZE & RL SOLUTIONS
TRAPEZE GROUP
TYCO ELECTRONICS
UNILEVER CANADA
UNIVERSITY HEALTH NETWORK (UHN)
UPSTREAM WORKS SOFTWARE
V SEMICONDUCTOR INC.
VALE CANADA LTD.
VENNSA TECHNOLOGIES INC.
VIXS SYSTEMS INC.
WATTPAD
WAVEDNA
XTREME LABS INC.

The Edward S. Rogers Sr. Department of Electrical & Computer Engineering (ECE) at the University of Toronto is fortunate to have valuable, long-standing partnerships with visionary corporations, foundations, alumni and friends that support the advancement of research and teaching in the country's largest ECE department. We invite collaborations with both individuals and industry to help make our research relevant, and to create avenues for significant economic and social impact in Canada and throughout the world.

Our industry partnerships are multi-faceted and include over 60 industry funders and collaborators. Corporations such as Altera and IBM provide valuable opportunities for our students through co-op programs such as the Professional Experience Year (PEY), and support the educational and research missions of the department through research grants and philanthropic support. Individual donations from alumni and friends ensure that engineering scholars can focus their time and efforts on developing new technological breakthroughs, rather than worrying about financial constraints.

There are many different ways to support ECE projects and initiatives. Skule Society is a special community of alumni and friends who demonstrate leadership with annual gifts of $1,000 or more to the department. The creation of endowed chairs and professorships, graduate fellowships and undergraduate scholarships are also important elements to U of T Engineering's $200 million component of Boundless: The Campaign for the University of Toronto.

Our individual and corporate partnerships are of vital importance to us and enable today's scholars and tomorrow's engineering leaders to make ground breaking discoveries and advance knowledge and discovery in every area of electrical and computer engineering. Ongoing engagement, support and collaboration ensures ECE's ability to maintain its leadership position among the world's authorities on electrical and computer engineering, and to build a global society of boundless innovation, creativity and economic development.

For further information on how you can support The Edward S. Rogers Sr. Department of Electrical & Computer Engineering (ECE), please contact Joanna Forbes at: joannaf@ecf.utoronto.ca.

Innovative and Entrepreneurial Thinking: Creating a Culture

Arshia **TABRIZI** Technology Lawyer and ECE Alumnus

Arshia Tabrizi is a champion of innovation and entrepreneurship, a computer engineer, a technology lawyer, a small-business owner, an educator, a start-up pioneer, an author, and a poet. He is a Renaissance man with a maverick streak who's been instrumental in fostering a culture of entrepreneurial spirit within the Faculty of Applied Science & Engineering at the University of Toronto for over ten years.

An alumnus of the computer engineering program, Tabrizi was involved in establishing and developing the first entrepreneurship components for the Faculty, and in 2007 was recognized for his contribution with an Arbor Award from the University of Toronto.

Since then, he has been a tireless advisor to the Faculty in his quest to assist the University with various entrepreneurship initiatives, such as the planned Centre for Engineering Innovation & Entrepreneurship, designed to inspire active learning and accelerate innovation; The Entrepreneurship Hatchery, an incubator that encourages undergraduate engineering students to share their ideas and turn them into successful business models; and BizSkule, a networking organization for building alumni involvement with students and academics.

"What drives me, what I'm passionate about, is working with entrepreneurs — whether they are students or my clients — as a strategic partner," says Tabrizi. "I view myself as part of the team, not simply as a service provider. To help them think in an entrepreneurial fashion, to look at real-world application for research and to build viable companies. To help them succeed."

His keen interest in start-up companies and venture capitalism led Tabrizi to relocate to Silicon Valley during the dramatic dot-com era of the late 1990s where he launched his law career with the renowned law firm Wilson, Sonsini, Goodrich & Rosati. "Having learned the ropes, I came back to Toronto with the vision to open my own firm specializing in start-ups and technology because everyone was getting out of it, and that left a niche for me," says Tabrizi. "I was going against the grain but I knew the market would turn around

eventually, and it has. The difference today is the degree of maturity in the Canadian start-up ecosystem, and because I've been in the industry since the beginning, I find that people seek my advice not only as a lawyer, but as someone who has seen the ebbs and flows of the industry," says Tabrizi. "I offer a unique perspective from someone who's worked exclusively in the start-up industry for over a decade."

The Tabrizi Law Office was founded in 2002 to focus on providing all-inclusive, one-stop legal services to early-stage and fast-growth technology and knowledge-based companies in Canada; as well as to large Canadian and multi-national companies, with their specialized technology and licensing law requirements. As a former software engineer, Tabrizi brings a unique perspective to his clients.

Most recently, Tabrizi identified another niche in the market, and pioneered his own social enterprise new media start-up. It's an interactive platform called Vidoyen (www.vidoyen.com). "I've always viewed the Internet as a platform to share thoughts, but there is a disconnect in terms of how people filter out reliable information from unreliable information," says Tabrizi. "I wanted to create a space where critical thinkers and engaged academics could have a well-informed exchange with the concerned public on topics of importance," says Tabrizi.

While his multi-faceted career promises to keep life interesting, Tabrizi says his work at ECE is very close to his heart. "I'm passionate about nurturing engineering entrepreneurship, and committed to educating our students about the value of being entrepreneurial," says Tabrizi. "To that end, I'm very pleased to be working with the Faculty on the numerous initiatives we're putting in place to develop tomorrow's engineering leaders. The Centre for Engineering Innovation & Entrepreneurship, for example, promises to be an internationally recognized hub of learning and innovation. I'm really excited about being a part of that and watching it come to fruition over the next few years."

Corporate Collaborations

Q&A with Stephen Perelgut, University Relations Manager at IBM

Why does IBM work with ECE at the University of Toronto?

We have a number of reasons for wanting to work with the University of Toronto. First of all, it allows us to recruit well-educated engineers and computer scientists for our own workforce; this is also a benefit to ECE's students, many of whom do work placements at IBM while they're in school, and then may join us as full-time employees. We contribute to the classroom and the student learning environment by providing the University with IBM software — mostly without charge or sometimes at a significant discount. We also sell technology to all sorts of departments within U of T — whether it's software for research in ECE and other engineering disciplines, or hardware and services for the University's central financial system. Finally, by collaborating with professors and research students on various projects of interest to IBM, we can expand the reach of IBM's already sizable investment in basic and applied research.

What are some of the research thrusts that IBM is currently supporting in ECE?

There are several exciting projects ongoing, so I'll just mention a few:

- Agile computing for hardware – this is the next generation of computers. We're working with Professors Tarek Abdelrahman, Paul Chow, Greg Steffan, Jonathan Rose and Vaughn Betz, all of ECE.
- Along with Professor Ted Sargent, we're investigating the possibility of solar power for data centres.
- Professor Joyce Poon's optical computer research is an area that IBM is funding.
- IBM is a major industry partner in the NSERC Strategic Network for Smart Applications on Virtual Infrastructures (SAVI) led by Professor Alberto Leon-Garcia.

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, including Computer Hardware

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

Energy

Energy Resources: Production, Exploration, Processing, Distribution and Use

Energy Storage and Conversion

Energy Efficiency

Alternative Energy Resources

Electrical Energy

Life Sciences

Advancement of Knowledge

Biomedical Engineering

Human Health

Life Sciences

Life Sciences, including Biotechnology

Medical Equipment and Apparatus

Quick-Search by Colour-Coded Listing

Communications

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

Computers

• Computer Communications • Computer Software/Hardware

Information Technology

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

Information Technology

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

Energy

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

Life Sciences

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

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 number 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 extract automatically 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 classifying 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 — **Compiler Support for GPU Programming**

www.eecg.utoronto.ca/~tsa

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 definition, 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 — **Dynamic Acceleration of Soft Processors**

www.eecg.utoronto.ca/~tsa

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 — **Adaptive Signal Processing for Wireless Communications and Radar Systems**

www.comm.utoronto.ca/~rsadve

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 — **Nano-photonics for Optical Signal Processing and Sensing**

photonics.light.utoronto.ca/aitchison

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).

LEAD RESEARCHER | RESEARCH TITLE | COLOUR KEY

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 — **Automated Self-management in Cloud Environments**

www.eecg.toronto.edu/~amza

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 centre 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 — **System Support for Parallel and Distributed Software Transactional Memory**

www.eecg.toronto.edu/~amza

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 — **A Self-profiling Adaptive Processor–High-level Hardware Synthesis**

www.eecg.toronto.edu/~janders

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 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
www.eecg.toronto.edu/~janders

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

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 subsequent experiments carried out in our laboratory. 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.

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

Simulation of RF Tag Interrogator Units Underneath Urban Rail Trains

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.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Bardakjian, Berj — **Bioengineering of the Brain**

heart.ibme.utoronto.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, and perhaps even more importantly, how can we best programmably interconnect the huge number of function blocks in modern FPGAs? We are investigating how the circuitry of FPGA-programmable interconnect should be modified to take best advantage of the latest (22 nm) and below process technologies. We are simultaneously investigating a radical change to FPGA on-chip communication in which we augment conventional FPGA programmable interconnect with packet-switched networks on chip. This fundamentally raises the level of abstraction of communication on the chip, but requires new CAD tools, which we are also developing, to automate this new and different design flow.

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. In particular, we are looking at how to make highly scalable placement and routing algorithms that can handle the latest chips, which contain billions of transistors, in a reasonable run time.

Finally, we are also investigating new areas in which FPGAs can accelerate computation. A key application in this area we are currently researching is the modeling of photodynamic cancer therapy. By simulating the paths of millions of photons in complex human tissue, we seek to determine the best arrangement of fibre optic probes to destroy a tumour (and minimize the exposure of healthy tissue) by activating a photosensitive catalyst only in a local area of the patient's body.

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 systems 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 — **Digital Signal Processing for Ultra-high-speed Communication**

www.isl.utoronto.ca

This project strives to integrate robust and reconfigurable digital signal processing (DSP) into our highest speed communication links. Doing so will necessitate significant advances in analog circuits as well as DSP: the power of the circuits must be lowered, in some cases by two orders of magnitude, and signal processing algorithms are required to automatically calibrate and adapt the blocks to the conditions of real-world communication links. We develop integrated circuit prototypes of our solutions, demonstrating their potential impact on real-world applications.

Chan Carusone, Anthony — **Energy-efficient I/O for Supercomputing**

www.isl.utoronto.ca

Supercomputing infrastructure has reached an industrial scale. The video, search, and cloud computing services upon which our modern economy relies are delivered from warehouse-sized facilities housing thousands of individual servers. The energy consumption of these facilities is enormous, both in economic and environmental terms. It is therefore very frustrating that these distributed supercomputers are designed to be most energy efficient when operating under peak load, when in fact most of the time these facilities operate at 10-50% of their peak utilization in order to ensure robust service provisioning. Under these normal-use conditions, they operate at 15-65% of their peak energy efficiency.

Our research strives to improve the energy efficiency of warehouse-scale computers under all normal-use conditions. Specifically, the interconnections within these distributed computing environments are targeted. Without progress on the digital input/output (I/O) circuits at either end of these interconnects, their share of overall server power will increase to over 50% in the next decade. We develop I/O integrated circuits and subsystems that are capable of near-zero energy consumption when idle, sub-nanosecond wakeup times, and the ability to intelligently and autonomously scale power consumption over a decade or more of bandwidth, from a few Gb/s per lane up to 20-50 Gb/s per lane. Leveraging our lab's past work on burst-mode clock and data recovery circuits and low-power injection-locked oscillators, we utilize nanoscale CMOS technologies to create integrated circuit prototypes of these subsystems. Considering a 220 TWh annual energy budget for supercomputers worldwide, and the importance of Canada's ICT sector, we are very excited about the impact our work will have.

Chan Carusone, Anthony — **Highly-integrated Optical Transceivers**

www.isl.utoronto.ca

Optical fibre is already the dominant communication medium for high data rates over long distances. However, there is increasing interest in the use of optical fibre for communication over shorter distances. For example, in rack-mounted computing and storage environments the cost of operating the equipment over its lifetime now exceeds its initial purchase cost, so optical fibre has become attractive for rack-to-rack and within-rack communication because its thin diameter and light weight permit better airflow (hence, reduced cooling costs) and easier maintenance than copper cables. Fibre's immunity to electromagnetic interference is attractive for automotive applications. Moreover, fibres can be routed in very tight bundles with much less crosstalk than copper wires, making it a very scalable medium. Even in consumer applications demanding multi-Gb/s bandwidth, optical cables are attracting increasing interest because of their light weight, flexibility, and thin diameter. In order to exploit the fundamental advantages of optical communication in these areas, our research stre to develop highly-integrated transceivers with much lower cost, higher packing density, and lower power consumption than is currently available.

Chan Carusone, Anthony — **Integrated Circuits and Systems**

tony.chan.carusone@isl.utoronto.ca

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.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Chow, Paul
www.eecg.toronto.edu/~pc

Programming Models and Architectures for Reconfigurable and Heterogeneous Computing Systems

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.

Much of the research is driven by applications. One aspect is to work with users of high-performance computing facilities and help them to improve performance through better algorithms and the use of accelerators implemented with FPGAs and/or GPUs. A current project is a collaboration with a neuroscientist simulating the brain to better understand and treat brain disorders.

Davison, Edward
www.control.utoronto.ca/people/profs/ted/ted.html

Control of Large Scale Decentralized Systems

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.

In particular, the following problem areas which immediately arise from large scale systems are current areas of research: decentralized control, intelligent control, fault-tolerant control,and the control of unknown systems. A direct application of this research is presently being applied to the control of large flexible space structures, the control of earthquake resistive building structures, the control of electric power systems with particular focus on micro-grid systems, and the control of spinal cord injury patients.

Dawson, Francis
www.ele.utoronto.ca/~dawson

Improving Energy Efficiency of Energy Conversion Processes

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. Funders: NSERC, Honeywell Aerospace, Xogen Technologies, Mattson Inc., Ontario Centre of Excellence.

Eleftheriades, George
www.waves.utoronto.ca/prof/gelefth/main.html

Artificial Materials (Metamaterials) from Microwave to Optical Frequencies

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 experimental work as well as fundamental theory.

Enright Jerger, Natalie
www.eecg.toronto.edu/~enright

Interconnection Networks for Heterogenous Multi-core Systems

In recent years, embedded and mobile devices have proliferated within society; with each generation, these devices enable new applications including navigation, digital photography and multimedia. With the scaling of transistor features sizes, the number of components that can be integrated onto a single chip continues to grow allowing of increased functionality. Modern chips may contain several processing cores, graphics processors, memory controllers, I/O interfaces, multimedia accelerators and numerous other specialized functional units. Each of these components within a device requires that data be communicated between it and other parts of the system. To facilitate this communication,

various on-chip communication structures have been proposed and utilized. Driven by higher requirements for concurrent bandwidth and lower latency, interconnect fabrics in practical system-on-chip (SoC) devices have evolved from a bus architecture to an on-chip network. This project explores the needs of SoC communication which differ dramatically from general purpose devices; we are developing novel architectures to meet the power and real-time latency and bandwidth constraints of these systems.

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 **Control Theory and Applications**

sites.google.com/site/brucefranciscontact

1. Distributed robotics theory: We study the mathematical theory of robot formations. The robots are typically modeled as unicycles with only onboard sensors and no leaders. The objective is to design local motion strategies so that a team of robots performs a coordinated task, such as forming a circle. (with Professor Mireille Broucke, Professor Manfredi Maggiore, and Professor Luca Scardovi)

2. Applied robotics: Starting in 2007, we conducted an application in collaboration with the 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. (with Professor Tim Barfoot)

3. Infinite lattices of dynamical systems: In studying the formation of a very large number of vehicles, one approach is instead to model an infinite number of vehicles The question then arises as to what mathematical framework to take so that the latter model correctly describes the behaviour of the former. This leads to the subject of infinite chains or lattices of dynamical systems. (with Professor Avraham Feintuch)

4. Control of switched-mode systems in power electronics: Laptops, cell phones, and many other devices use switched-mode power supplies (SMPSs) to regulate a voltage. SMPSs are based on pulse-width modulation for control actuation and as such are nonlinear and time varying. The simplest regulator, known as a buck converter, consists of a MOSFET switch, a lossless LC filter, a battery, and the load. A recent generalization has a single inductor but two output voltages to be regulated; this is called a single-inductor, dual output (SIDO) converter. The controller is then multivariable: two voltage inputs, two duty cycles as outputs. (with Professor Olivier Trescases)

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

LEAD RESEARCHER | RESEARCH TITLE | COLOUR KEY

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**

sites.google.com/site/brucefranciscontact

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.

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**

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), 56,600 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.

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 scat-

LEAD RESEARCHER | RESEARCH TITLE | COLOUR KEY

tering 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 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 S. — **A Universal Trace Sensing Platform for Nanoparticles and Biological Samples in Solution and Gas Forms**

photonics.light.utoronto.ca/helmy/research

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 S. — **High Power Diode Lasers**

photonics.light.utoronto.ca/helmy/research

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.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Helmy, Amr S. — **High Power Electrically Injected Laser Chips in the Infra Red and THz**

photonics.light.utoronto.ca/helmy/research

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

Helmy, Amr S. — **Infrared and THz Semiconductor Laser Chips**

Bragg reflection waveguide lasers are essentially one-dimensional photonic bandgap structures that are doped in a p-i-n profile, 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 mode.

Bragg reflection waveguide lasers have the potential to enable the realization of high power single mode lasers and amplifiers with larger mode volumes, high gain coefficient and strong mode discrimination. Moreover, this class of novel lasers also shown the potential in applications related to nonlinear frequency conversion, monolithically integrated optoelectronic integrated circuits.

We have demonstrated the first edge-emitting BRW laser-diode with low threshold current and high characteristic temperature. This group's research focuses on using this class of lasers to develop high performance single-mode lasers, monolithically electrically injected optical parametric oscillators. These chip-based sources can provide continuous coverage of spectral regions, which are not accessible by other technologies including quantum cascade lasers. Examples of niche applications served by this unique platform include sources for environmental and biomedical sensing elements in the 1-4 μm window and chip-based THz spectroscopy sources.

Helmy, Amr S. — **Nanophotonic Devices and Networks**

photonics.light.utoronto.ca/helmy/nanophotonics

Our work in the field of nanophotonics focuses on the design of functional devices based on plasmonic slot waveguides (PSWs). With sub-wavelength footprint, versatile functionality, and low parasitics, PSW is a promising platform for creating high-speed optoelectronic devices with low power consumption and can potentially help alleviate the latency and power dissipation bottlenecks in current VLSI technology. Specifically, our research addresses four components of PSW device design: excitation mechanism, functionality, modeling, and loss.

For efficient PSW excitation, we have developed a broadband, non-resonant excitation mechanism by interfacing conventional dielectric waveguides and PSWs in a direct, orthogonal junction to achieve phase matching. By minimizing the momentum mismatch between the two waveguides, efficient energy transfer across a large spectrum can be obtained instantaneously at the junction interface. These devices exhibit record broadband performance and occupy the smallest footprint possible, both of which are ideal for temperature-insensitive hybrid optoelectronic applications.

To create PSW devices suitable for on-chip integration, our research explores reconfigurable PSW networks, which consist of 2D networks of intersecting PSWs. Utilizing the ability of bound surface waves to propagate over sharp bends, the simultaneous power distribution and interference within a network of PSW junctions can enable the design of multi-input multi-output optical devices with diverse functionalities.

In order to reduce the computational cost associated with designing PSW devices through numerical techniques, our research also involves creating analytical models for PSW mesh structures. By approximating PSWs as microwave transmission lines, a scattering matrix model based on characteristic waveguide impedance has been formulated to model the dispersion of localized plasmonic waves within mesh structures. The transmission responses of the mesh are encapsulated into generic closed-form expressions that can handle arbitrary combinations of junctions without requiring numerically-extracted parameters. Thus, the model serves as a scalable, generalized framework that can be adapted to model specific mesh configurations as well as perform device design, optimization, and sensitivity analysis.

Helmy, Amr S. — **Parametric Photonic Intergated Circuits for All Optical Signal Processing and Quantum Optics Using Second-order Nonlinearities**

photonics.light.utoronto.ca/helmy/research

Parametric processes based on second-order optical nonlinearities in III-V semiconductors are receiving attention for the development of novel photonic devices such as integrated self-pump optical parametric oscillators (OPOs). The efficiency of parametric processes chiefly relies 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 then be realized in an integrated platform to favour some emerging disciplines such as quantum optical coherence tomography and generation of photon-pairs 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 S.

Photonic Integrated Circuits for Ultrafast All Optical Signal Processing

Parametric processes based on second-order optical nonlinearities in III-V semiconductors are an ideal platform for the development of novel parametric devices for all optical signal processing. The efficiency of parametric processes chiefly relies on the phase-matching technique 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 demonstrated an exact phase-matching technique using Bragg reflection waveguides (BRW) in the AlxGa1-xAs material system. Current research focuses on improving the conversion efficiency of the nonlinear processes by investigating advanced transverse waveguide geometries as well as extending the technique to other second order nonlinear processes including sum- and difference-frequency generation that benefit other domains of all optical signal processing in photonic integrated circuits.

Bragg reflection waveguides are also 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. This tuning can be achieved through the lithographic process used to define the waveguides. It can also be achieved 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 tuneable characteristics.

Helmy, Amr S.

Quantum Photonic Devices and Circuits

Photons, the particles of light, play a pivotal role in the emerging area of quantum information science, such as optical quantum computing and quantum cryptography. However, these futuristic technologies only exist in specialized labs and practical commercial systems are not available to date. One of the reasons these technologies have not moved into practical settings is that they need to be implemented using bulky components that are not portable and are sensitive to vibrations. Current technologies required to produce the building blocks of quantum systems does not allow for high level of integration of these components. Those include devices for the generation, manipulation and detection of paired photons that are entangled. These entangled photons are an essential building block for quantum systems as required by quantum mechanics. For example, the main stream technique to produce entangled photon pairs is to use a strong laser beam to hit a nonlinear crystal. With a probability of 10^-10, a photon in the laser can be converted into a pair of entangled photons. Such a system is extremely in-efficient and very energy consuming. Besides, the whole system, including the laser, nonlinear crystal, mirrors and lens, etc., takes a big space on an optics table. The optical setup requires delicate construction and is sensitive to external environment.

Thanks to breakthroughs of our group, fully integrated, portable, and robust entangled photon sources have been made possible using the mainstream semiconductor technology. We successfully demonstrated the generation of entangled photons from a semiconductor chip. This chip is specially engineered which, not only increases the photon generation efficiency from the bulk crystal counterparts, but also makes the integration with other optical components possible. Our technique could lead to the world's first fully integrated, room-temperature entangled photon source in the foreseeable future. Meanwhile, our group has been working on engineering the generated photon properties on the same platform. Ultimately, our techniques will allow the entire photon generation and manipulation processes on the same chip, which could be a big step towards a practical, commercial quantum computer and other quantum information processing systems.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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

Sensing Liquid-phase Nano- and Bio-materials in Optofluidics using Raman Spectroscopy

Conducting Raman spectroscopy in hollow core photonic crystal fibres (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 fibre'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. Nano-optics 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 nano-optic 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 nano-optics 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
photonics.light.utoronto.ca/laserphotonics/

Intelligent Beam Control for Ultrashort Laser Manufacturing of Photonic and Biomedical Microsystems

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 fibre assemblies, smart medical catheters, optical sensors, and other high value photonic systems for our Canadian partners.

Hum, Sean
www.waves.utoronto.ca/prof/svhum/research.html

Reconfigurable Antennas for MIMO and Compact Handsets

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

Reconfigurable Aperture Antennas

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

Ultra-wideband Antenna Arrays

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.

Iravani, Reza
www.ece.utoronto.ca/~iravani

Real-time Simulation, Control, and Protection of Integrated AC-DC Power Systems

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.

Iizuka, Keigo
www.keigo-iizuka.com

Omni-focus Video Camera

Our major achievements during the recent past were the invention of two novel types of distance mapping video cameras. The first invention, called the Axi-Vision Camera, is a distance mapping camera that is based on the combined principles of time of flight and modulated light illumination. Television programs produced by using the Axi-Vision Camera have been broadcast from NHK, Japan.

In a contest sponsored annually by *Optics & Photonics News* of the Optical Society of America, the paper on the Axi-Vision Camera was selected as one the most significant scientific accomplishments described in a refereed journal in 2002. The Axi-Vision Camera was commercialized by NHK Enterprises, Japan, and the first unit was sold at $400,000. We received the 2003 Fujio Frontier Award in recognition of our leading edge research and development of the Axi-Vision Camera.

The second invention, called the Divcam (short for Divergence Ratio Axi-Vision Camera), is a distance mapping camera that utilizes the universal decay rate of the illuminating light with distance. The Divcam is light weight, compact, portable, and reliable, has a fast response and

LEAD RESEARCHER | RESEARCH TITLE | COLOUR KEY

is low cost (a US Patent was filed on the Divcam and later extended to (PCT) Patent Corporation Treaty, an International Patent).

The omni-focus camera which needs the information of distance was invented as a natural extension of the Divcam. The invention of the Omni-focus video camera was reported by various news organizations and magazines including US Fox News Network. Some news media even stated that the Omni-focus video camera will revolutionize the world camera industry.

Recently, the Omni-focus video camera was applied for obtaining a super deep 3D iage. The article "Super deep 3D images from a 3D omnifocus video camera" was highlighted. The image appeared on the cover page of the February, 2012 issue of the Applied Optics.

Jacobsen, Hans-Arno — **Middleware Systems**

www.msrg.org

This research aims to ease the development of scalable, reliable, and secure distributed enterprise applications. In pursuit of these objectives, the researcher engages in basic research on event processing, publish/subscribe, service-orientation, aspect-orientation, and green middleware. In research and development engagements with various companies, the researcher 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.

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.

Joy, Mike — **Current Density and Conductivity Imaging with MRI**

www.currentdensityimaging.org/

This is a very active research area. Every decade a new medical imaging technology appears or matures. The most recent of these is magnetic resonance imaging (MRI). We are investigating the use of magnetic resonance imaging for tissue characterization. The goal here is to physically characterize not just the shape of an organ or neoplasm but also the tissues within it.

We are also studying electric current density imaging with potential application in electrical safety, therapeutic electrical stimulation, management of electrical burns, impedance tomography, and solution of the inverse problem of the measurement of bioelectric sources.

Our analytical tools include Fourier transforms, singular value decomposition, and phase unwrapping. We use magnetic resonance imagers to image electric current. We have access to a clinical 1.5 T magnetic resonance imager.

Our research is closely related to impedance tomography (the electrical measurement of tissue conductivity) and biomagnetic encephalography (the measurement of the biomagnetic fields produced by neural currents). The patient group benefiting from our research has not yet been identified.

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 — **Micro-power 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. Research on micro-power sources focuses on the development of continuous vibrational piezoelectric energy harvesters using (1) ambient vibrational sources and (2) tritium-occluded-in-silicon beta-emitting source. In the latter case, integration of the beta source enables an autonomous vibrational energy generator. These vibrational energy harvesters are based on aluminum nitride piezoelectric material. Research on sensors focuses on the the development of aluminum nitride-ultrananocrystalline diamond platform to synthesize surface acoustic wave nano-transducers operating at GHz frequencies. Recent research has demonstrated resonant frequencies and Svelocities exceeding 10 GHz and 10000 m/s, respectively.

Kherani, Nazir — **NICE Composite Materials**

www.ecf.utoronto.ca/~kherani

Nano-Integrated Carbon-Enveloped (NICE) composites are being developed (1) as smart coatings for energy conservation in buildings' applications, and (2) 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 to 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 process applications.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Khisti, Ashish

Low Delay Communication Systems for Streaming Media

We investigate theoretical foundations and practical architectures of communication and compression techniques optimized for low-latency applications such as conferencing and cloud computing. It turns out that traditional methods that separate compression and error-correction into different modules are far from optimal when end-to-end latency is considered. Furthermore the instantaneous dynamics of the communication channel play a fundamental role in the ultimate performance limits of low latency systems. Therefore both the theoretical approaches and resulting architectures for low latency communication systems are radically different from traditional approaches to reliable communication systems. The proposed project tackles this challenge in collaboration with Hewlett Packard Laboratories.

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

Advanced Coding and Signal Processing in Fibre-optic Communication Systems

www.comm.utoronto.ca/frank

Fibre-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 fibre 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.

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 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.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Kundur, Deepa
www.comm.utoronto.ca/~dkundur/

Cyber-physical Security of the Smart Grid

The smart grid represents a marriage of information technology with the electricity network. While the increased reliance on cyber infrastructure enables greater reliability, efficiency and capacity of power delivery, this dependence also creates a host of insidious weaknesses. The scale and complexity of the smart grid, along with its increased connectivity and automation, make the task of cyber-physical protection particularly challenging. Smart grid security constitutes a daunting effort for asset owners because of resources limitations. Important questions arise when identifying priorities for design and protection: Which cyber components, if compromised, can lead to significant power delivery disruption? What kinds of grid topologies are inherently robust to classes of cyber attack? Is the additional information available through advanced cyber infrastructure worth the increased security risk?

To address these challenges, this research program pioneers the development of a modeling and analysis methodology for cyber-physical smart grid systems by harnessing the power of dynamical systems frameworks. Through integration of mathematical tools from the fields of nonlinear dynamical systems, graph theory and game theory, we aim to address timely and important cyber-physical security problems influenced by the needs of electric power utilities.

The work will provide timely design insights and instruments essential for developing more reliable, secure and safe smart grids. Solutions for securing the smart grid are just emerging and the proposed research provides a necessary framework to better assess, re-develop and prioritize them. Moreover, this research helps to reinforce the synergy among communication, computation, economic and electricity networks fostering an important interdisciplinary view of the emerging smart grid. The ability to build secure and safe smart grid systems will provide commercial and environmental benefits by facilitating widespread adoption of smart grid infrastructure revolutionizing the electricity marketplace and reducing our society's ecological footprint.

Kwong, Raymond
www.control.utoronto.ca/~kwong

3D Conformal Thermal Therapy of Soft Tissues for the Treatment of Localized Cancer using MRI-controlled Ultrasound Therapy

MRI-guided ultrasound therapy is a powerful method for cancer treatment in which ultrasound energy, guided by magnetic resonance imaging, is used to coagulate a target region of tumour. This kind of treatment has been developed as a non-invasive alternative to conventional therapies such as surgery and radiation, which often lead to long recovery times with high complication rates. Successful application of this technology for treatment of localized cancer depends critically on the ability to deliver ultrasound energy to a targeted region of the affected organ, while avoiding thermal damage to surrounding structures. This requires accurate control over spatial and temporal deposition of energy to regulate the temperature. The goal of this research is to develop advanced control strategies to enhance the treatment effectiveness of the ultrasound therapy system.

Kwong, Raymond
www.control.utoronto.ca/people/profs/kwong

Dependability and Security in Control and Multimedia Systems

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.

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.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Leon-Garcia, Alberto — **Application Platforms and Smart Infrastructure**

www.met.utoronto.ca/alg/alg.htm

We are developing systems for the control and management of resources in power utility grids, transportation systems, and cities. These systems leverage the collection of state information using a vast array of sensors. We use a service-oriented approach to resource management that extends methodologies from cloud computing, and we extend and apply graph theoretic models for the flow of demand in these resource networks. We are assessing the effectiveness of current supercomputing system in the control and management of future smart infrastructures.

Leon-Garcia, Alberto — **Autonomic Service Architecture**

alberto.leongarcia@utoronto.ca

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 — **Connected Vehicles and Smart Transportation**

www.vani.utoronto.ca

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 system 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 — **Design of Converged Communications and Computing Infrastructure**

www.met.utoronto.ca/alg/alg.htm

We consider the design of optical networks that can provide connectivity for future datacentres that can interconnect several million servers. At this scale, power consumption and space for Ethernet cabling become severe challenges. We are designing optical switching fabrics that combine WDM and burst switching to provide extremely high capacities with high spatial compactness and low power consumption.

Leon-Garcia, Alberto — **Green Networking**

www.met.utoronto.ca/alg/alg.htm

In this project we are developing resource management techniques for the operation of computer networks that are energy efficient and that have low carbon emissions. We use graph theoretic methods to synthesize flow and capacity assignment as well as topology designs that are conducive to green networking.

Leon-Garcia, Alberto — **Green Telco Cloud**

In this project we are investigating the migration of the telecom service provider infrastructure into a green cloud computing infrastructure. We model and experimentally assess the performance of existing and future services using cloud computing. We focus in particular on services that depend on wireless access networks.

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

alberto.leongarcia@utoronto.ca

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 datacentres 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.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Leon-Garcia, Alberto — **Optical Networks for Ultrascale Datacentres**

alberto.leongarcia@utoronto.ca

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.

Levi, Ofer — **Optical Bio-sensors and Biomedical Imaging Systems**

biophotonics.utoronto.ca

Our research interests include developing bio-medical imaging systems and optical bio-sensors based on semiconductor devices and nanostructures, 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 bio-medical diagnostics, cancer studies and neurobiology.

Li, Baochun — **Agile Cloud Computing via Multi-level Performance Inference**

iqua.ece.toronto.edu

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 — **Magellan: Charting Large-scale Commercial Peer-to-peer Streaming Systems**

iqua.ece.toronto.edu

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 — **Nuclei: Many-core Network Coding on the GPU**

iqua.ece.toronto.edu

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 — **Broadband Multimedia Communication in the Mobile Environment**

www.comm.utoronto.ca/~liang

Multimedia content is the single most influential factor driving the need for increased mobile network capacity and device capability. The proliferation of cloud-based content distribution services and video social networking applications will severely stress the existing mobile systems. The inherent heterogeneity of both wireless access technologies and mobile devices also enables rich and ubiquitous multimedia services, but it also significantly complicates system design. We are interested in investigations into system optimization, resource management, and algorithm design to create innovative technologies for multimedia communication in the mobile environment. Promoting a synergistic approach, we work at the interface between mobile access, broadband communication, and distributed-system technologies.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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.

Lie, David
www.eecg.toronto.edu/~lie

Computer Systems Security

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 giving 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
www.comm.utoronto.ca/~jorg

Network Architectures and Services for a Mobile World

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.

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

High Speed Quantum Random Number Generator

Quantoss is a high-speed quantum random number generator (QRNG) prototype, which is a joint effort of Mars Innovation and Department of Electrical and Computer Engineering & Department of Physics, University of Toronto. It generates truly random numbers from the quantum phase noise of a laser. For more information about the technology, please refer to the scientific publications: B. Qi, et al. *Opt. Letters*, 35, 312-314, (2010); F. Xu, et al. *Opt. Express*, 20, 12366-12377, (2012).

We plan to develop the prototype further to make it compact and low cost. We also plan to develop the software for the classical post-processing. Funders: NSERC, CIFAR, Canada Research Chair Program, MaRS Innovation.

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

Measurement Device Independent Quantum Key Distribution

Quantum cryptographic systems are, in principle, unconditionally secure. In practice, quantum hacking has emerged as a key challenge to their security. To foil quantum hacking, we have recently proposed an entirely new approach — measurement-device-independent quantum key distribution (MDI-QKD) — that can "short-circuit" all detector security loopholes. In other words, the system will be automatically immune to all detector side channel attacks. This is remarkable because it means that commercial QKD detection systems would no longer require any special security certifications and, in fact, they can even be manufactured by a malicious eavesdropper, Eve.

We will build a prototype MDI-QKD system and demonstrate its robustness against detector side channel attacks. We will also develop the theory of MDI-QKD and take into full account various imperfections in real-life devices. Our work will allow us to use our enemy Eve in quantum cryptography.

Lo, Hoi-Kwong — Quantum Cryptography: from Theory to Practice

www.comm.utoronto.ca/~hklo/index.html

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 — Advanced Motion Control in Robotic Systems

www.control.utoronto.ca/~maggiore

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 — Development and Control of an Autonomous Co-axial Helicopter

www.control.utoronto.ca/~maggiore

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.

Maggiore, Manfredi — Formation Control of Nanosatellites

www.scg.utoronto.ca/~maggiore

NASA and the European Space Agency have proposed the deployment of nanosatellite clusters to create a platform for scientific observation of the universe. The idea is to launch nanosatellites in orbit, with each satellite carrying a mirror, and to assemble the cluster in a rigid formation. The result would be a large orbiting telescope with unprecedented resolution and range. One of the key challenges in deploying such a telescope is the development of formation control algorithms. The electric actuators used to propel nanosatellites (electric thrusters) produce very low thrust with low resolution. These two factors, combined with tight specifications on the accuracy of the control task, make the formation control problem very hard. This research, in collaboration with Prof. Chris Damaren at UTIAS, aims at developing a formation control methodology that takes into account the characteristics of electric thrusters and solves the formation control problem with the required accuracy.

Maggiore, Manfredi — Virtual Constraints: A New Paradigm for the Control of Motion

www.scg.utoronto.ca/~maggiore

The traditional approach to making robots perform complex motions relies on a hierarchical decomposition of the control task: motion planning at the high level and reference tracking at the low level. This approach has proven to be inadequate in complex motion control problems such as locomotion in multi-legged robots or flight in bird-like robots. This research aims at developing a new paradigm for motion control. This paradigm is based on the concept of virtual constraint, a constraint on the states of a control system that does not physically exist, but can be enforced via feedback control. This idea has been used in the literature to induce stable walking in biped robots, and we believe it can be used to emulate the flight of birds and insects, the swimming of fish and, more generally, to induce complex behaviours in robots.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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/

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 are 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 achieves 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 does the wearable face-recognizer put virtual nametags on people, etc., the mediated vision 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.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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/.

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

Engineering the Electric and Magnetic Dispersive Responses of Artificial Media

Many 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 as 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

Performance of computers is expected to reach its fundamental limits in terms of speed, bandwidth, power consumption, and electromagnetic interference. Partially, the 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,

digital photography, etc. 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 favour 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? and (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 behaviour that can be used to anticipate and optimize for future program demands.

Moshovos, Andreas
www.eecg.toronto.edu

FPGA-friendly Processor Architectures for Irregular Applications

Our assertion is that, as embedded applications evolve, some of them will exhibit irregular behaviour. We have demonstrated that conventional soft processors are inefficient for this purpose. We have proposed FPGA-friendly designs for various processor structures. We are looking at conventional processor implementations developed for ASIC implementation, identifying inefficiencies when these are implemented on an FPGA. We are proposing alternate organizations that are instead FPGA-friendly.

Moshovos, Andreas
www.eecg.toronto.edu/~moshovos

Power-aware Cache-based Structure Design

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.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Moshovos, Andreas — **Smartphone and Mobile Platform Architiecture**

www.eecg.toronto.edu/~moshovos

Cellphones are changing the way we interact with each other, access information, do business. Just a few years ago, cellphones offered just voice calling and short text messaging, today cellphone capabilities parallel those of recent, high-end desktop systems while they include several additional capabilities to communicate and interact with the physical world such as embedded cameras, touch, position, and acceleration sensors. New applications are continuously emerging including image based searching, speech recognition, and translation.
All of this is possible because smartphones incorporate significant computation power. However, providing this computation power is a very challenging task as smartphones must operate using limited energy sources, maintain a reasonable manufacturing cost, and a relatively small physical size. A key mechanism for improving smartphone capabilities is computer architecture which studies how to build smartphones given the available manufacturing technologies while taking into consideration the applications that these smartphones will be used. Computer architecture faces continuous challenges for two reasons: (1) the properties of the underlying technology change significantly over time, and (2) so do the applications. This work seeks to understand smartphone applications and to identify the opportunities that exist for improving smartphone architectures leading to next generation smartphones. The primary target of this work is applications that acquire, manipulate, and use images and video in smartphones. Expected benefits include increased compute capability and functionality, novel imaging applications, improved energy efficiency, and reduced cost for smartphone platforms. Funders: NSERC Strategic.

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.

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

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Ng, Wai Tung
www.vrg.utoronto.ca/~ngwt

Smart Power Integration and Semiconductor Devices

Our research group is focusing on the integration of power devices, smart power integrated circuits, and power management systems. Our group has worked extensive in the development of CMOS compatible HV fabrication processes for automotive and consumer applications in the 40-100V range. We also have on-going collaborative projects with our industrial research partners to develop discrete and integrated power MOSFETs, silicon and SiGe based BiCMOS fabrication processes for smart power ICs and wireless applications, respectively.

In recent years, we have focused in the design and implementation of VLSI power management circuits. This includes the demonstration of integrated soft-switching topology with predictive dead-time control and a practical DVS (Dynamic Voltage Scaling) system in 2004. We are also working on the integrated DC-DC converters with digital control. One of our aims is to prove that digital controller is a viable approach for portable power management. We were able to demonstrate an integrated DC-DC converter with dynamically adjustable power transistor size for power conversion efficiency optimization at ISPSD'06 for the first time. In 2010, we will be introducing a superjunction power FINFET at IEDM 2010. This is an exciting work toward enabling the next generation FINFET CMOS fabrication technology to be compatible for the implementation of smart power ICs.

Power management is currently an intensely pursued field. Our group is focused on the integration of the controller with power output stages. We currently have activities in all-digital on-chip temperature sensors for thermal management applications, gate driver circuits with dynamically adjustable driving strength to suppress EMI and improve efficiency, dead-time control circuits, as well as integrated class-D power amplifiers.

Pavel, Lacra

Decentralized Optimization and Game Theory

We are working on decentralized dynamic optimization from mathematical problem formulation to algorithm design. The optimizing agents could be nodes in a network, channels in a link or network, even autonomous robots in a group formation. We consider either a game theoretical framework or an optimization framework. In a game theoretical framework, agents or players are endowed with an individual cost function to be optimized and the aim is to achieve a Nash equilibrium, whereby no player has an incentive to deviate from its action. In an optimization framework our work, considers a number of agents that cooperate to estimate the minimum of the sum of their locally known cost functions. These agents are to dynamically adjust their actions, in response to their individual cost and the analogous decisions made by neighboring agents (nodes), a consensus-based idea.

Pavel, Lacra
www.control.utoronto.ca/~pavel/LP_research2.htm

Dynamic Optical Network Control and Self-optimization

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)
www.dsp.utoronto.ca

Affective Signal Processing: Unraveling the Mystery of Emotions

Emotion plays an important role in our daily activity and greatly influences many areas, such as learning, decision making and interaction with others. Our decision and course of actions are adapted to the emotion cues we receive while interacting with others. This allows the exchange of information to be much more effective and smooth. To integrate the emotional states of a user into a human-mobile interface will provide a user-centric experience that enables the interaction to be more intuitive, flexible and efficient. We are proposing an affective signal processing system that enables real-time analysis, tagging, and inference of cognitive-affective mental states from facial video and EEG recordings. This framework combines vision-based processing of the face (e.g., a frown or smile) with EEG predictions of mental-states (e.g., interest and confusion) to interpret the meaning underlying EEG and facial signals over time.

Plataniotis, Konstantinos N. (Kostas)
www.dsp.utoronto.ca

Privacy Enhancing Face Recognition

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.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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.

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 modeling for optical modulators.

Poon, Joyce — **Active Plasmonics**

www.ecf.utoronto.ca/~poon

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.

Poon, Joyce — **Integrated Photonics for Communications and Computing**

www.photon.utoronto.ca

We invent, design, fabricate, and measure integrated photonic devices and circuits, such as transmitters, switches, and receivers, for communications and computing. Our unique strength is the breadth of technologies we access. We partner with a rich variety of collaborators in industry, academia, and institutes around the world to use the most sophisticated electronic-photonic integration platforms. Our photonic devices and circuits are implemented in the following material systems and platforms: (1) Silicon-on-insulator (SOI); (2) Indium phosphide on SOI; (3) Silicon nitride on SOI; 4. Indium phosphide; 5. Correlated electron materials (vanadium dioxide).

Our goal is to demonstrate integrated photonic-electronic devices and circuits that are ultra- low-power, high-speed, and compact for communications at > 1 terabit per second using as few wavelengths as possible.

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 applications consuming power from a fraction of watt to several kilowatt 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.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Qian, Li — **Fibre-optic Sensing**

www.ecf.utoronto.ca/~qianli

We utilize photonics technology to create instrumentation for fibre-optic sensing and metrology. Our frequency-shifted interferometry technique has been demonstrated to have a variety of applications, such as dispersion measurement, fibre 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. The virtual-reference interferometry (VRI), a technology developed by one of our graduate students, has been commercialized and resulted in a success start-up company.

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 fibre-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 implement them using existing fibre-optic technologies. These include a specialized optical homodyne detector for quantum key distribution, a fibre-based entangled photo pair source, and fibre-based quantum key distribution systems.

Rose, Jonathan — **Acceleration of Protein Co-evolution Detection for Determining Interactions in Software and on FPGAs**

www.eecg.toronto.edu/~jayar

The MatrixMatchMaker algorithm was recently introduced to detect co-evolution between proteins using pairs of phylogenetic distance matrices, and has numerous advantages over existing methods of co-evolution detection. Co-evolution detection is a method for determining which proteins interact. We have developed a revised algorithm which recasts the co-evolution 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 — **Architecture of Field-programmable Gate Arrays**

www.eecg.toronto.edu/~jayar/research/architecture.html

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 architectures which 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 — **Computer-aided Design for FPGAs**

www.eecg.toronto.edu/~jayar/research/CAD.html

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 — **Computer Vision Acceleration with FPGAs on Mobile Devices**

www.eecg.toronto.edu/~jayar

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 — **Creative Applications for Mobile Devices**

www.eecg.utoronto.ca/~jayar/ece1778/

Mobile smartphones have given rise to an explosion in creativity over the past few years. There have been exciting, inspiring and incredibly useful software apps in the areas of medicine, music, psychology, senior support, banking, cooking, global health, exploring, travel, shopping, games and many more fields. These applications have only just scratched the surface of the potential of mobile devices. As our understanding of how mobile technology can be used, many new possibilities will occur to each of us. As new hardware sensors and other capabilities are added to the phones, ever-more clever ways of helping humans will be created.

The purpose of this research/graduate course is to build a collaborative environment of creativity for new applications of mobile devices. Graduate students from all disciplines at the University of Toronto are invited to take the course for credit. This course will be taught January - April, 2013. It is primarily a project-based course in which the goal was to produce a working app by the end of course. Projects will be done in groups of 2 or 3. Students with computer programming skills will be matched with those from non-programming backgrounds to do projects in the latter students' disciplines.

Rose, Jonathan — **Overlay Architectures for FPGAs**

www.eecg.toronto.edu/~yiannac/VESPA

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, thedifficulty of learning the programming model implied in typical digital systems design. This broad research project is engaged in several methodsof 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 — **A Biochip for Gene-based Disease Detection**

light.utoronto.ca

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.

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.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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 electromagnetic engineering. 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 complex media and meta-materials, plasmonics, electromagnetic compatibility/interference (EMI/EMC) problems and modeling under uncertainty.

In particular, emphasis is given on indoor and urban propagation studies to improve the fidelity of current wireless planning tools with the aid of full electromagnetic analysis. Such analysis can be employed to assess the impact of multiple miniature antenna systems, embedded in portable devices, on the overall capacity of a link based on those. Stochastic methods are developed to capture the impact of uncertainty in channel features, such as wall properties and antenna parameters and orientation. Research is also conducted on innovative ray-tracing techniques for large-scale propagation modeling, accelerated by Graphics Processor Units.

Scardovi, Luca — **Analysis and Control of Complex Interconnected Systems**

www.scg.utoronto.ca/~scardovi/

It is well recognized that the role of control proved to be an essential ingredient in almost every engineering system ranging from power and automotive systems to space missions and that feedback is a key element in many natural phenomena ranging from molecular pathways in living organisms to ecological systems. Recent years witnessed an increasing interest in systems that are composed of (possibly many) interconnected units. As a whole, those systems often exhibit one or more features that cannot be predicted from the properties of the individual parts. These properties (called emergent behaviour) are not an attribute of any single entity: they are irreducible and are generated by their interconnection. Emergent behaviour can lead to surprising and useful phenomena such as memory, intelligence and self organization in cells but can also lead to disastrous consequences. Examples include the spread of infectious diseases, neuronal synchronization disorders in the brain, collective motion in bacteria and locust swarms. It is therefore of great interest to understand the principles behind the emergence of such properties and investigate solutions to control them. The control and systems-theory paradigm is natural in this context but unfortunately "off the shelf" techniques are not always appropriate for such complex systems. In the present research effort, we propose to overcome these limitations by developing new principles and methodologies that go beyond classical stability and regulation theory. Future applications range from the domain of biological networks to the domain of complex man-made systems and include closed loop control of neuronal synchronization, analysis and control of synthetic biological circuits and coordination in autonomous sensing networks amongst others.

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. This includes circuit designs for the transmitter (such as the design of MUX, equalization, and driver), and the receiver (such as adaptive equalization and clock and data recovery).

At speeds beyond 1Gb/s, even a few inches of a PCB trace acts like a transmission line and as such exhibits frequency-dependent attenuation, signal reflection, crosstalk, and timing jitter. The goal of circuit design in this area is to compensate for the channel attenuation, reduce signal reflections, and reduce cross-talk and timing jitter so as to reduce the bit error rate (BER) of the communication link while using less than a few mW per Gb/s operation.

In the past few years, we have been able to contribute to this research through the design of ADC-based receivers that allow for extensive signal equalization in the digital domain. Our latest work in this area will be presented at ISSCC 2013 where we present a 10Gb/s blind baud-rate receiver using an ADC front end. In the past few years, we have also contributed to the design of a non-data-aided equalization techniques and to burst-mode CDRs.

Moving forward, there are still many challenges in the area of high-speed signaling as there is more demand for signaling speeds of 28Gb/s and beyond. These data rates impose a very stringent requirements on the channel equalization as well as on power budget for these links. We strive to address these challenges in the near future.

Smith, Peter W. E. — Ultrafast Photonics

www.ecf.utoronto.ca/~upl

My teaching and research interests have centred 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.

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 modern multicore processors easier to program. In particular, we are investigating support for optimistic parallelism and transactional memory, with a current focus on parallelizing CAD applications.

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.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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.

Tate, Joseph (Zeb) — **Phasor Measurement Unit Data Characterization and Compression**

www.ele.utoronto.ca/~zeb

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 behaviour 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 and 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 and 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 and 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 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

LEAD RESEARCHER | RESEARCH TITLE | COLOUR KEY

using a hybrid storage system comprised of a smaller Li-ion battery and a 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 is 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
www.ele.utoronto.ca/~ot

Power Converters for High-efficiency LED Lighting

Electric lighting accounts for approximately 11% of the worlds 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.

Triverio, Piero
www.waves.utoronto.ca/triverio

Electromagnetic Transients in Power Distribution Networks

We develop numerical models and algorithms to predict electromagnetic transients in power distribution networks. Lightning, faults, and switching activity can induce fast transients on the network, potentially compromising its stability and safety. As network complexity increases, because of the penetration of renewable sources and distributed generation, predicting these phenomena becomes more and more challenging. Our contributions provide a fast way to investigate broadband transients in large power networks made by overhead, underground, and subsea cables.

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

Triverio, Piero
www.waves.utoronto.ca/triverio

Modeling and Simulation of Complex Systems

Numerical techniques for the simulation of complex systems are nowadays a strategic asset in many scientific and industrial projects. Computational complexity is often a big issue, however. Our group develops techniques to generate compact models for highly-complex components, based on system identification and model order reduction concepts. Models can be extracted from high-fidelity simulations or experimental results, and enable a fast simulation of large-scale systems. This approach has been applied to the design of high-speed circuitry and to the thermal simulation of 3D integrated circuits with liquid cooling.

Triverio, Piero
www.waves.utoronto.ca/triverio

Signal Integrity and Electromagnetic Compatibility Engineering

Signal integrity and electromagnetic compatibility issues, like crosstalk and interference coupling, are a major concern in the design of a wide range of electronic systems. My group develops efficient numerical techniques to predict and address these issues during electronic design. An early prediction of these phenomena is nowadays strategic to achieve high performance, reliability, and minimize costly prototyping. Our developments are applicable to the design of high-speed boards, integrated circuits, and cabling systems for the transportation sector.

Truong, Kevin
apel.ibbme.utoronto.ca

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
apel.ibbme.utoronto.ca

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

LEAD RESEARCHER | RESEARCH TITLE | COLOUR KEY

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 the 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 — **Wireless Communications in Vehicular Environment**

www.comm.utoronto.ca/~valaee

In 2000, an estimated 6,394,000 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.

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 centres 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 on the community.

Venetsanopoulos, Anastasios — **Digital Signal/Image Processing; Digital Communications; Biometrics; Biomedicine**

www.dsp.toronto.edu/

In digital signal/image processing our work is contributing to both fundamental and applied areas. New digital filters, such as linear, non-linear. multidimensional and multi-spectral, have been introduced of fixed and adaptive natures.These filters have been applied to geophysics, imaging, financial data and biomedicine, including radiology, tomography, mammography and MRI.

In the area of telecommunications, we have dealt with the problems of sonar transmission through fading dispersive random channels and image compression, focussing on techniques called perceptually lossless techniques. Biometrics and multimedia have been also explored.

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 — **2-D Crystal Electronic Devices**

www.eecg.toronto.edu/~sorinv

This exploratory research focuses on the simulation, design and fabication of novel nanoscale 2-D crystal and metal nanowire transistors. The ultimate goal is the physical implementation of sub-10nm transistors.

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 clock will be employed to recover the clock and data information and to recondition the signal before transmission. An 80-Gb/s equalizer capable of equalizing over 30 dB of cable loss has been demonstrated.

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

Large swing DACs for 200 Gb/s optical transmitters with QAM and OFDM modulation

www.eecg.toronto.edu/~sorinv

As internet traffic continues to increase exponentially due to the explosion of mobile multimedia devices, there is renewed demand for electronic circuits and optoelectronic systems that can operate at serial data rates in excess of 50 Gb/s. Current OOK and QPSK-modulated optical transmitters are limited to 50-Gb/s bit streams due to optical filter and optical fibre limitations. This is one of the reasons for the widespread adoption of QPSK modulation in the 110-Gb/s standard. Rather than transmitting and receiving a single 110-Gb/s NRZ bit stream, 4 NRZ bit streams, each at 28 Gb/s, are employed to modulate two orthogonally-polarized optical carriers in-phase and in-quadrature. The next generation of optical fibre standards will inevitably imply the deployment of both higher-level modulation schemes such as 16-QAM and OFDM, and of higher serial bit streams at and beyond 112 Gb/s.

Optical modulators typically require 3-5V electronic signal swing for proper operation. The large voltage swing and the very broadband operation from DC to over 55 GHz are beyond the best performance reported for digital-to-analog converters in nanoscale CMOS and SiGe BiCMOS technologies. One option would be to use a low-voltage swing DAC followed by a very large voltage-swing, large gain, broadband linear amplifier fabricated in III-V technology. This is an expensive multi-chip solution. Additionally, because of the large resolution (8-10 bit) required, it is almost imperative that the DAC directly drive the optical modulator to avoid signal distortion.

This proposal seeks to research and develop large swing (>3V differential), multi-bit (6-10 bit) BiCMOS55nm and 32-nm CMOS DAC topologies for 16-QAM, 64-QAM and OFDM optical transmitters. One such SiGe BICMOS DAC, developed in our group and operating at 50 GS/sec with 6Vpp differential swing was presented at IEEE IMS in 2012 and won the best student paper award.

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 0.5Tb/s 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 integrated systems that have already been demonstrated in the lab are (1) 120GHz and 150GHz high resolution position sensors with above IC and in-package antennas fabricated in a SiGe BiCMOS process and which work over 2-5m, (2) 160GHz radio transceiver array with on-die antennas operating as a 4Gb/s radio and as a Doppler radar, (3) a 165GHz passive imaging receiver with sub 0.3 K temperature resolution and consuming 82 mW, and (4) 200-300GHz low-noise signal sources and amplifiers.

Alphabetical Listing by Lead Researcher

LEAD RESEARCHER	RESEARCH TITLE	COLOUR KEY

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. Currently I engage in three active project areas: (1) Theoretical studies of sensory information processing. We are developing a physics-based model of the process by which the sensory system transmits information from periphery to the brain. The goal of this project is to elucidate the underlying physical laws that govern the process of sensation; (2) Biomedical signal processing. We work with a team of doctors and surgeons to use signal processing and data mining techniques to better understand and diagnose neurological disorders like schizophrenia or major depressive disorder. We are also engaged in invasive brain studies for rehabilitation applications; (3) Acoustic and speech processing. We focus here on problems related to speech and hearing loss, and the tools that we can develop to aid those with communication disorders.

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 program aims to use novel cooperative transmission techniques to enhance capacity, coverage, and reliability of wireless cellular networks. The goal is to develop novel coordinated signal processing, resource allocation, and network optimization techniques based on information theory in the design and analysis of interference management and mitigation methods for future wireless networks. Interference mitigation is expected to become a crucial task in wireless system design as future networks become more densely deployed, frequencies more aggressively reused, and the network topologies increasingly heterogeneous. My research program focuses on two network architectures in particular: the Network MIMO architecture where base-stations cooperate in transmitting and receiving signals, and the heterogeneous architecture where remote radio units are deployed within the cellular structure to enhance coverage. This research program aims to advance the state-of-the-art in the theoretical capacity analysis of wireless networks and to impact the design philosophy, standards development, and forward evolution path of future-generation wireless networks.

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.

The Edward S. Rogers Sr. Department of Electrical & Computer Engineering
University of Toronto
10 King's College Road
Toronto, Ontario, Canada
M5S 3G4

Telephone: 416-978-1801

www.ece.utoronto.ca

General Inquiries: susan.grant@utoronto.ca

Design: Laurie LaBelle
www.icon-art.ca

Photography:
Robert Waymen
Engineering Strategic Communications
Robert Teteruck
Jason KB Photography