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April 5, 2013

To: Members of the Canadian academic computer science research community

Dear colleagues:

Set up in March 2011, NSERC's Computer Science (CS) Liaison Committee (LC) aims to expand and strengthen interactions between NSERC staff and the Canadian academic CS research community. In this role, the Committee members continue to interact with members of the Canadian CS research community regarding the program and funding needs of CS researchers and the ways in which CS research can best support Canadian discovery and innovation.

As you know, the Committee commissioned an independent and comprehensive assessment of the current state of the Canadian CS research landscape, with the strong support of the Canadian Association of Computer Science (CACS). The assessment was carried out by the Observatoire des sciences et des technologies (OST). To complement this study, the Committee developed a questionnaire for our community to provide input on various matters of common relevance. The Committee received extensive and invaluable responses to this questionnaire. The community's strong participation demonstrates its high interest for this endeavour. The Committee sincerely thanks the community for its active involvement; in particular, it commends the heads and chairs of CS departments and schools in Canadian universities for the enabling role they played in this important process.

The Committee reviewed and discussed the report it received from the OST, as well as the community's responses to the questionnaire. Subsequently, it prepared an analysis report that presents the current strengths of CS research in Canada, the challenges it faces, and recommendations for actions that would, in our opinion, address the challenges and enable our community to further strengthen its pivotal role in Canada's economy as well as strengthen its leadership in several key fronts on the international stage.

It is the Committee's pleasure to provide you with its analysis report, which you will find enclosed. The report includes, as appendices, the OST assessment report and the summary of the community's responses to the Committee's questionnaire. The report is also available on the Web site that has just been established by the Committee; it can be accessed at www.cs-nserc.ca.

Members of the Committee will be participating in the May meeting of the Canadian Association of Computer Science (CACS), where they will meet with heads and chairs of CS departments and schools in Canadian universities. We encourage the CS research community to provide any comments and input about the assessment and analysis carried out by the Committee to their heads and chairs in order for the latter to convey them to us in that meeting. Members of the Committee will also be attending a few conferences in the coming months to meet directly with the community and discuss our report and the next steps.

The members of the community are also encouraged to e-mail comments directly to us, at sack@scs.carleton.ca.

We thank you again very much for your active participation in this important endeavour. Our objective is to work together with you to further strengthen our research field and ensure that it continues its crucial contributions in making Canada a leader on the international stage, scientifically and economically.

Sincerely,

Jörg-Rüdiger Sack,
on behalf of the NSERC Computer Science Liaison Committee

encl.

Computer Science Research in Canada:
Strengths, Challenges and Recommendations

Prepared by the NSERC Computer Science Liaison Committee

Jörg-Rüdiger Sack (Chair) – Carleton University
Michael Bauer – University of Western Ontario
Anne Condon – University of British Columbia
Gregory Dudek – McGill University
Marc Frappier – Université de Sherbrooke

Executive Summary

Canadian computer science (CS) research is strong, thriving and growing. It is critically important to the long-term economic health and prosperity of Canadians. This report, prepared by the NSERC Computer Science Liaison Committee (LC), summarizes the strengths of CS research in Canada and the challenges that it is facing and makes recommendations for addressing these challenges. These strengths, challenges and recommendations are summarized below.

Strengths

1. Canadian academic CS research is healthy and vibrant and has had an impressive record of value and impact to date.
2. CS is critical for Canada's economic innovation and prosperity.
3. CS highly qualified personnel (HQP) are highly educated; they are in high demand and critical for Canada's economy and its growth.

Challenges

1. Although NSERC has many excellent programs, some programs of NSERC and other Canadian funding agencies are not well matched to the needs of the CS community.
2. It is increasingly difficult for Canadian universities to meet the growing market demand for Information and Communications Technologies (ICT) HQP, and to attract the best students to graduate programs in CS.
3. Canada's financial investments in academic CS research are falling behind those of other countries that have invested significantly in this field.

Recommendations

1. The rate of discovery-driven, curiosity-driven CS research must be accelerated. There must be a stable means of funding this research, and it is essential to sustain and expand support of HQP training at all levels.
2. It is critical to have funding for CS hardware and software infrastructure and for the technical staff needed to support it.
3. More effective ways of supporting academic CS-industry partnerships are needed.
4. Increased support for international collaborations can help to advance CS research in Canada and attract CS HQP to this country.
5. More tri-Council and Canada Foundation for Innovation (CFI) funding for interdisciplinary research is critical for this highly interdisciplinary field.
6. With the support of its stakeholders and partners, including NSERC, the Computer Science community must become better organized.

1. Introduction and Context

Computer Science is an exciting, growing discipline with a proven track record of research excellence, production of HQP, and significant contributions to the Canadian economy. CS has tremendous potential to address many of today's global challenges and will remain of critical importance for the foreseeable future. The Canadian CS community appreciates the support that it has received from the government thus far, including that from the Natural Sciences and Engineering Research Council of Canada (NSERC). As stated in *Mobilizing Science and Technology to Canada's Advantage*, ICT and the digital economy are priorities for the federal government, and the investments that Canada has made in digital media research, for example, have been important. Government and industry support has helped to create a strong CS research community and ICT sector.

This report was prepared by the NSERC Computer Science Liaison Committee to inform all stakeholders, including the CS community and NSERC, about the status, impact and direction of CS research in Canada. First, this report presents the strengths of Canadian CS research and the challenges that this field now faces. It then concludes with six key recommendations that can help to ensure that Canadian CS research not only continues to thrive and play its pivotal role in Canada's economy, but also strengthens its presence and assumes leadership in several key fronts on the international stage.

Report and data sources. This report was prepared on the basis of an extensive professional report [1] that the NSERC Computer Science Liaison Committee and the Canadian Association of Computer Science (CACS) commissioned from the *Observatoire des sciences et des technologies* (OST), an organization affiliated with the Université du Québec à Montréal and dedicated to the measurement of science, technology and innovation. OST prepared its report in collaboration with Science-Metrix, an independent research-evaluation firm specializing in the assessment of science and technology organizations and activities. In addition to the data from OST, our report also utilizes data from other reliable sources, including Industry Canada, NSERC, Statistics Canada, and the Information and Communications Technology Council of Canada (ICTC).

The OST study presents the relative strengths of Canadian CS in the world in terms of scientific research production (measured by bibliometric data), inventive activity (measured through patent data), investment in R&D (measured by research and development data from the OECD [2] and from the NSERC grants database), and HQP training and workforce composition (measured by Canadian university enrolment data and OECD data on ICT skills and employment [3]).

This report also includes some of the key responses to a survey that the NSERC Computer Science Liaison Committee conducted within the academic CS research community. The Committee sent the survey questionnaire to all CS university departments and schools in Canada in Summer 2012. In Fall 2012, the Committee received and compiled the responses, wrote the survey report [4], and circulated it to the Canadian academic CS community, with a request to submit any additional comments to the Committee.

It is important to note that the Government of Canada and its departments and agencies (including NSERC) routinely use the term "ICT" to describe computer-related technologies and research. ICT has CS at its heart, but also includes a few other closely related areas. ICT data provide the best approximation of CS data (CS is the major component of ICT). When available, CS-specific data were used in this report.

It should also be noted that CS researchers use conference papers as a primary means of disseminating their research findings, but that compared with journal articles, conference papers are not so well covered in bibliometric databases such as Scopus[1] and Web of Science[2]. OST chose Scopus as the source for its study, because Scopus provides better conference coverage than Web of Science. For many purposes, such as comparative international statistics, the coverage in Scopus is sufficient, because the exclusion of some titles affects CS in all countries equally. Moreover, research has shown that the differences between these bibliometric databases do not substantially alter the nature and conclusions of the data [5].

2. Strengths, Opportunities and Challenges

This section summarizes the three most significant strengths (S1-S3) of the CS research community in Canada and the three most important challenges (C1-C3) that it faces now and in the near future, as evidenced by our data sources.

Strengths and Opportunities

Canadian academic CS research is strong internationally and plays a key role in fostering Canada's ICT sector, making critical contributions to Canada's economic prosperity through its scientific innovation and its continuous training of much sought-after, highly qualified CS personnel.

S1. Canadian academic CS research is healthy and vibrant and has had an impressive record of value and impact to date

[1] Scopus is the world's largest abstract and citation database of peer-reviewed literature with smart tools that track, analyze and visualize research. It includes over 20,500 titles from 5,000 publishers worldwide and contains 49 million records, 78% with abstracts. 5.3 million entries are conference papers [23].

[2] Web of Science ® provides researchers, administrators, faculty, and students with quick, powerful access to the world's leading citation databases. Authoritative, multidisciplinary content covers over 12,000 of the highest impact journals worldwide, including Open Access journals and over 150,000 conference proceedings [24].

Academic CS research in Canada is highly competitive internationally, in terms of quality, impact and volume [1]. In terms of scientific impact, as measured by citation rates relative to other countries, Canada shares the 2nd rank with the United Kingdom. In terms of absolute number of publications, Canada ranks 7th, with close to 50,000 ICT publications between 2003 and 2010.

More specifically, on the basis of annual number of publications, average of relative citations [1, p. 3], and specialization index [1, p. 3], Canada ranks among the top 10 countries in each of the eight ICT subfields; its rankings range from 3rd in Medical Informatics to 10th in Artificial Intelligence and Image Processing [1]. In terms of scientific impact, as measured by average of relative citations, Canada's rankings range from 2nd to 8th, depending on the subfield considered [1].

When each country's number of publications is normalized for its population size, Canada ranks 1st (see Figure 1 (a)), and when this number is normalized for GDP, Canada ranks 3rd overall, and 1st within the G8 countries (see Figure 1 (b)).

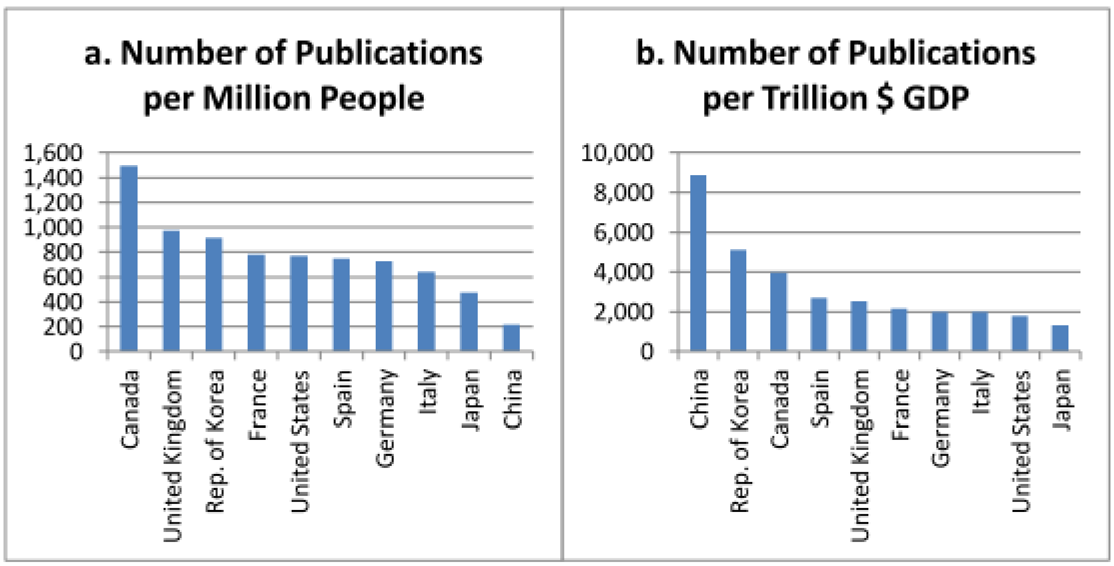


Figure 1: (a) Ranking of countries by number of CS publications per million population; (b) Ranking of countries by number of CS publications per $1 trillion GDP

The recent report by the Council of Canadian Academies on the state of science and technology in Canada [6] pointed to ICT as one of six fields in which Canada excels, based on citation rates and on how ICT was ranked in a comprehensive survey of international experts. Of course, as mentioned earlier in this report, ICT is broader than CS alone, but the CCA report also highlighted the successes of significant Canadian investments in CS research. One prominent example is the Graphics, Animation and New Media (GRAND) Network of Centres of Excellence (NCE) that brings together researchers in CS, the visual and performing arts and the social sciences.

Data from respondents in the NSERC Computer Science Liaison Committee survey [4] suggest that one significant mechanism through which CS research achieves its economic impact consists of spin-off firms, which commercialize ideas that emerge from curiosity-driven, discovery-funded research. One prominent example is OpenText. In 2012, this firm had revenues of $1.2 billion, spent $169 million on R&D, and had 4,574 employees. Although it took "only" eight years from OpenText's project start-up to its first viable commercial product, when all of the underlying, NSERC-funded research effort is counted, the actual time span was over 15 years. There are many other Canadian firms whose products have roots in academic CS research. Table 1 lists a number of examples that were identified in our survey of Canadian computer scientists. These examples show how high-quality, curiosity-driven research can result in socio-economic innovation; innovation itself is ***not*** the primary driver. This point is also a key message of the report *Continuing Innovation in Information Technology* by the National Research Council of the National Academies of the United States [7].

Alias; Side Effects Software	Animation and special effects software; Alias is now called Autodesk.
Autostitch; Cloudburst Research	Fully automated panorama reconstruction
Brightside Technologies	Electronic display technologies
BumpTop	Virtual desktop environment
CognoVision	Audience measurement and retail intelligence solutions
Convergent.io	Storage and networking support for software-defined data centres
Exotic Matter	Dynamic software for visual effects and 3D animation
Independent Robotics	Autonomous and remotely operated devices for land and water
Maplesoft	High-performance software tools for engineering, science and mathematics
Namkis	An application that enables businesses to obtain user-generated content
NeuroPlanningNavigator	Interactive 3D visualization tool for neurosurgical planning
Optemo	Online shopping
Point Grey Research	Embedded camera systems, multi-camera arrays
RapidMind	Support for multicore architecture programmers, acquired by Intel
Sysomos	Social media monitoring and analytics tools
Tasktop Technologies	Support for software and digital work management
Zite	A personalized iPaD magazine enabled by machine-learning algorithms, recently acquired by CNN

Table 1: Selected Canadian companies that spun off from computer science academic research

Also notable is that ICT accounts for 34% of all R&D investment in Canada [8]. Patent indicators show that inventive activity in ICT and efforts to protect intellectual property in ICT are currently accelerating throughout the world. Despite this growing global competition, Canadian inventors' share of world ICT patents has increased. The share of world ICT patents granted by the United States Patent and Trademark Office (USPTO) to Canadian inventors grew from 1.9% in the 2003-2006 time period to 2.3% in the 2007-2010 period. While the fraction of ICT patents assigned to entities outside of Canada has increased, the fraction assigned to (and presumably generated at) Canadian universities and other Canadian post-secondary institutions has grown by 170% [1]. As measured by USPTO patents, the share of Canadian assignees decreased over the period studied, but as measured by triadic patents (those filed in Japan, Europe, and the United States, which captures the inventions with the highest commercial potential), it increased [1].

S2. CS is critical for Canada's economic innovation and prosperity

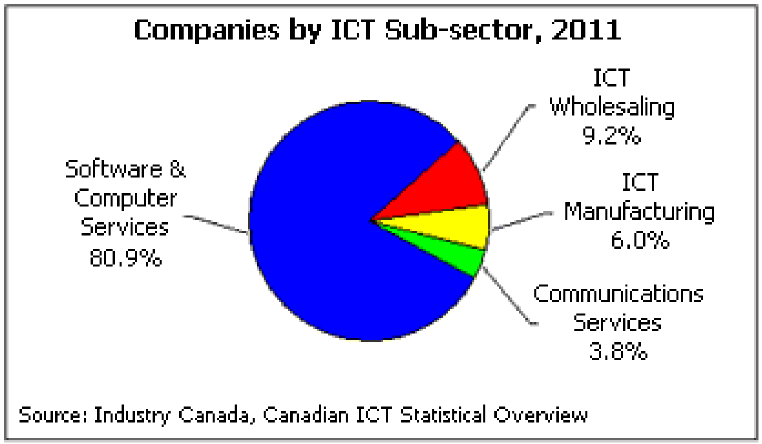
Advances in computing have enabled fundamental contributions to science and society. From computational biology to digital humanities and cognitive science, from social networking to independent living and green homes, computer science is a highly interdisciplinary field that continues to play a critical role in almost every other research area and almost every facet of our lives, and that will continue to do so for decades to come. Computer science has had a huge economic impact both directly, through the ICT sector itself, and indirectly, through other sectors. Computational analysis of "big data" provides a significant economic advantage for companies that are equipped and ready to embrace such opportunities [9].

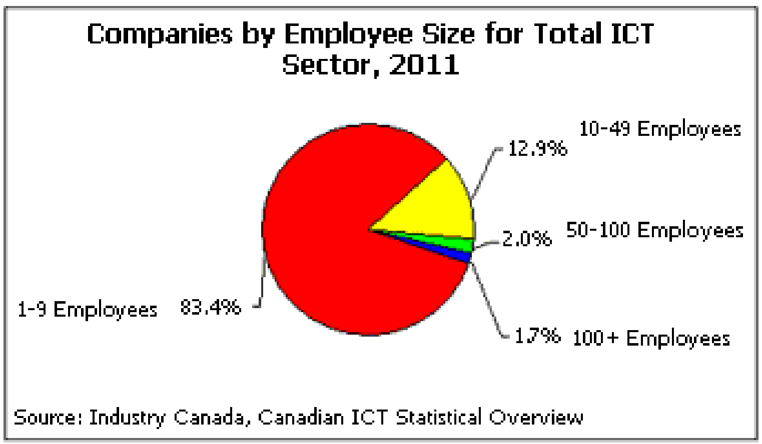
In 2011, the Canadian ICT sector was a key driver of national economic growth. Sector GDP grew by 3% from 2010 to 2011, after having grown by 2.6% from 2009 to 2010. Since 2001, the ICT sector has grown an average of more than 4% annually — almost twice as fast as the overall economy's average annual growth rate of over 2% [10]. Since 2002, the ICT sector has accounted for 8.9% of Canadian GDP growth, and ICT services industries have driven this sector by generating 70% of its growth. Overall, ICT now accounts for 4.9% of Canada's GDP [8]. In 2011, revenues in the ICT sector increased by 5.1%, for a total of $168 billion.

According to Industry Canada [8]:

- The ICT sector comprises about 33,500 companies, of which 80.9% are in the software and computer services industries and 9.2% in the wholesaling industries.

- The number of large companies in the Canadian ICT sector is relatively small. In 2011, there were only about 100 companies with more than 500 employees, compared with over 27,900 companies with fewer than 10 employees. The latter group accounted for 83% of all the companies in the sector.



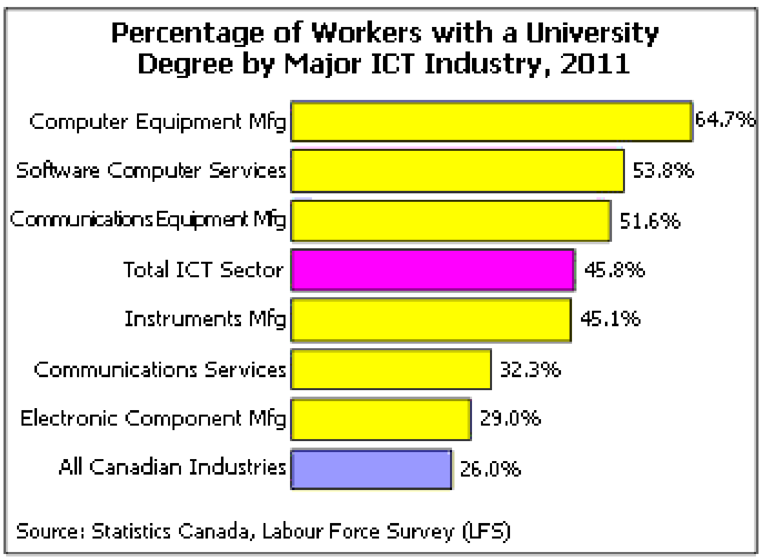


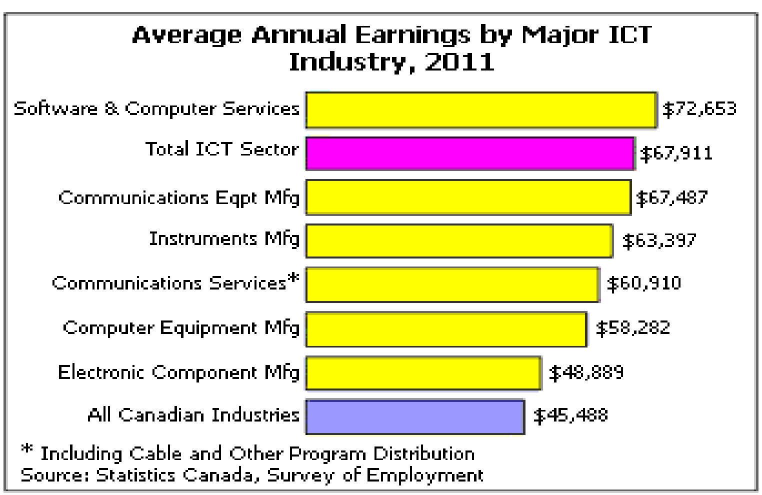
Geographically, although Canada does have some larger technology clusters, many of the 33,500 ICT companies are distributed widely throughout the populated part of the country.

The ICT sector has consistently enjoyed high employment and strong labour demand and been less affected by economic downturns than the rest of Canada's economy [8, 12]. As of August 2012, the unemployment rate in core ICT occupations stood at just 2.7% [11]. Every province benefits from a strong ICT sector: the distribution of the ICT workforce roughly follows the distribution of the Canadian population across the provinces. As Prime Minister Harper recently noted in an interview with the Canadian American Business Council, access to skilled labour is the single most difficult issue for the Canadian economy, and science and engineering and the skilled trades are the two key areas of this labour shortage. ICT lies at the intersection of these two areas.

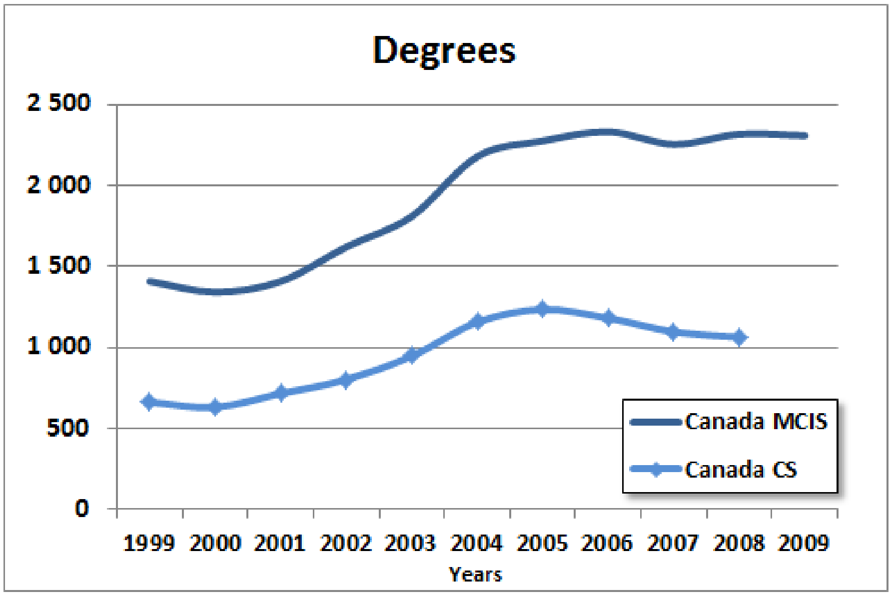
S3. CS highly qualified personnel (HQP) are highly educated, in high demand and critical for Canada's economy and its growth

According to Industry Canada [8], the ICT sector is characterized by a highly educated workforce. As of 2011, 45.8% of workers in this sector had university degrees, compared with a national average of 26.0%. The proportion of university-educated personnel is 64.7% in computer equipment manufacturing and 53.8% in software and computer services. ICT employees are also well compensated, reflecting their high skill levels and their value to the industry. As of 2011, employees in the ICT sector earned an average of $67,911 — 49% more than the average of $45,488 for workers economy-wide. The highest earners in this sector work in the software and computer services industries.





Canadian CS researchers have made significant contributions to producing this highly skilled, university-educated workforce, as illustrated in the figure below, which shows graduate degrees awarded in MCIS (mathematics, computer and information sciences) and CS from 1999 to 2009 [1].



According to Labour Force Survey data, “between 2005 and 2010, persons with post-graduate qualifications accounted for more than a fifth (22.8%) of the increase in ICT employment. Though not restricted to the Producer Industries, the need for highly qualified professionals is more pronounced in these industries. This has implications for industry and government support for post-graduate studies and for immigration policy. **Both industry strategy and public policy need to align to the reality that the ICT sector in Canada increasingly is being anchored in highly specialized technical skills.**” [13]. This increased demand for post-graduate qualifications in ICT will continue for the foreseeable future, which underscores its critical importance. It is both a strength of the field and a challenge, as we discuss in the next section.

Challenges

Although the academic CS research community has demonstrated its strengths and leadership, it still faces a number of challenges. If this community can meet these challenges, it will become even more competitive globally and make even more effective contributions to Canada’s leadership in innovation and its economic wealth.

C1. Although NSERC has many excellent programs, some programs of NSERC and other Canadian funding agencies are not well matched to the needs of the CS community

Research Partnership Programs

As stated before, ICT is one of Canada's strongest economic sectors, growing faster than the economy overall. ICT is also the best performer in R&D, accounting for 34% of all private-sector R&D expenditure in Canada [8]. Given these numbers, one would expect academic CS researchers to participate heavily in NSERC's Research Partnership Programs (RPPs), which are meant to foster collaboration between academia and industry. But the figures show that this expectation is not being met. The NSERC Discovery Grants (DG) Program can be used as a benchmark to compare participation in all NSERC programs, because DG is NSERC's single largest program and covers all disciplines. Table 2, based on publicly available NSERC data, shows that during the period 2003 to 2010, CS researchers received 9.6% of NSERC's total DG funding, but only 6.3% of all Strategic Project Grants funding, 6.6% of all Collaborative Research and Development Grants funding, and 4.6% of all Industrial Research Chair funding [1].

NSERC Program	CS Share	DG Benchmark
Discovery Grants	9.6%	100
Strategic Grantss	6.3%	66
Collaborative Research and Development Grants	6.6%	69
Industrial Research Chairs	4.6%	48

Table 2: NSERC key programs and share of funding received by CS researchers

Thus Table 2 shows that CS researchers obtain a smaller share of the total funding from the main RPPs than from the DG Program. This situation is especially surprising, because some other disciplines that obtain DG funding have very few potential industry partners and hence very few opportunities to participate in RPPs, while the Strategic Grants Program targets areas that include ICT. Given that these other disciplines can less easily participate in RPPs, and that ICT is the largest industrial R&D spending sector in Canada, one would expect the CS share of RPPs to exceed, or at least equal, the CS share of DGs. This situation certainly calls for further investigation. We offer some potential explanations below, but they should be validated through a more in-depth analysis.

The first hypothesis is that the RPPs do not fit the structure of the Canadian CS industry. The ICT sector contains a very high proportion of small and medium-sized enterprises (SMEs), which may not have the human or financial resources to engage with these programs. For instance, the CRD program requires financial participation from the industry partner, but SMEs are typically short on cash. Moreover, CS companies have a very short product cycle: their innovations must be commercialized within a period ranging from a few months to a year or two at most. But academic projects typically rely on graduate students to develop software, and master's students may take up to two years before producing something commercially exploitable, while Ph.D. students make take up to three or four years. This is far too long for most SMEs in the ICT sector. Moreover, academic CS research is often high-risk, addressing radically new ideas that require venture capital for their commercialization; it may be hard to accommodate such requirements in the current RPPs.

The second hypothesis is that spin-off companies are a more effective means of flowing innovation from academic CS researchers to industry. New ideas originating from academic CS research may not find an industry partner for various reasons (lack of funding, lack of expertise, incompatible business missions and markets), so academia generates its own spin-off firms to commercialize its ideas. But because RPP rules quite rightly prohibit academic researchers from being their own industry partners, a large number of potential partnerships are excluded from these programs. Nevertheless, the list of successful spin-offs from academic CS research (Table 1) shows this mechanism's strong economic potential.

The third hypothesis is that it is hard for CS academics to find companies whose R&D needs match their academic research interests and that have the resources to engage in research partnerships. Companies are looking for researchers who are interested in their firms' specific problems, which are often short-term, because of short product cycles. Academic researchers may be torn between short-term industrial impact and long-term research impact, which may not be mutually compatible if the application focus is too narrow or immediate. Matching may be easier in other disciplines that rely on expensive infrastructure that is available only in university laboratories and is typically acquired through large CFI grants. In such cases, companies have no option but to work with academia, in order to access this sophisticated infrastructure.

Another issue is that Canadian start-ups that commercialize academic research innovations often get bought out by international firms, so that future returns on the RPP investment go to foreign firms that often maintain little or no connection with the academics who did the original research.

NSERC has recently produced an analysis of ICT researchers' participation in its Research Partnerships Programs [27]. In this analysis, NSERC classified grants as ICT on the basis of the application area codes that the researchers had supplied when submitting their grant applications. Unfortunately, these codes cannot be used to determine which of these grants were obtained by CS researchers, because the same codes are used by researchers in other ICT disciplines as well. The NSERC Computer Science Liaison Committee therefore had OST classify RPP grants as CS according to a different criterion: the DG committee of the principal investigator, as determined by cross-referencing the RPP grant database with the DG database. Thus the results in Table 2 are based on a more fine-grained classification than those given in [27] for ICT.

Encouraging results are shown in [27] for the participation of software companies in the Engage Grants, whose short duration (six months) and low overhead seem more suitable for software companies.

Infrastructure Programs

In the past, NSERC's Research Tools and Instruments (RTI) Grants Program has been an essential means of funding equipment for CS research. Unfortunately, this program has recently been scaled down. Current CFI programs have not been designed for this purpose: their scale is too large, they are tied to each applicant's university's strategic plan, and they may require matching funds from various sources, including industry. CS researchers have received only a very small percentage of the CFI's budget since its inception: 1.7% [1]. Instrumentation for world-class fundamental CS research cannot be funded on the back of an NSERC Discovery Grant. We realize that, in times of financial pressure, NSERC must make difficult decisions, and we appreciate that the RTI program has not been terminated. But we would like to point out that the CS community sees this program as highly relevant and regards the support that it provides as essential for meeting the equipment needs of CS researchers.

In addition to equipment, CS research infrastructure also includes software tools. These tools must be developed and maintained over a number of years. Often these tools are developed by graduate students while they are working on their degrees. When these students graduate, CS researchers are left with no resources to maintain these tools and to train the next generation of students in how to work with them. Valuable ideas and investments are wasted because of a lack of sustained funding for technical staff to support such tools. NSERC CS Discovery Grants are typically too small to support technical staff for such purposes. There is no program to pay for technical staff to support such software tools and for the ongoing operation and maintenance of software laboratories. Other countries have funding mechanisms for this purpose (Germany, for example, has fully funded long-term positions attached to CS professorships, and the responsibilities of these positions include operating and maintaining software laboratories). As a result, Canadian CS research is not as competitive as it could be internationally in large-scale software R&D.

C2. It is increasingly difficult for Canadian universities to meet the growing market demand for Information and Communications Technologies (ICT) HQP, and to attract the best students to graduate programs in CS

Although there is a growing labour-market demand for software engineers, computer and information systems managers, network administrators, database analysts and data administrators, Canada is last in the G8 and second-to-last in the OECD for the number of undergraduate and graduate degrees awarded in computer science per 100,000 population [1]. The unmet demand for technical talent is further exacerbated by the targetting of Canadian undergraduates by U.S companies and U.S. graduate programs. This competition for talent makes it difficult to attract and retain the strongest students to do their graduate work in Canada. This difficulty is cause for concern, because people with postgraduate qualifications accounted for more than one-fifth (22.8%) of the total increase in ICT employment in Canada from 2005 to 2010.

Similarly, as the field has matured and the depth of knowledge required has increased, postdoctoral fellowships have become increasingly important, both to support top-flight CS research and to enable graduate students to progress to faculty positions. But in Canada, funding levels per CS researcher have not increased to recognize this emerging need, and CS postdoctoral funding success rates in the NSERC Postdoctoral Fellowships Program have dropped from one in five in 2008 to less than one in ten in 2011 [14]. In contrast, in the U.S., the number of postdoctoral fellows in CS has risen dramatically, and there have been concerted initiatives to fund them (http://cra.org/govaffairs/blog/tag/postdocs/).

Canadian CS faculty are not receiving enough research funding to produce the number of graduate and postgraduate HQP needed to meet Canadian industry's needs. Furthermore, international talent is harder to attract, because Canadian tuition fees are higher than those of other countries, and many Canadian institutions do not offer international students any fee waivers to compensate. At the same time, NSERC graduate scholarships (PGS/CGS) are aimed exclusively at Canadians, even though the Canadian government states that Canada must attract talent from abroad. For example, in report *International Education: A Key Driver of Canada's Future Prosperity* [15], Foreign Affairs and International Trade Canada states as follows:

> Seventy-five percent of Canada's workforce growth now comes from immigration. It is expected to reach 100 percent by the end of the decade. International recruitment strategies targeting both the quantity and quality of talent are needed to address Canada's future shortfalls in the human capital necessary for building a world-class knowledge economy. International students provide an excellent source of highly qualified and skilled persons to meet our current and future labour market needs, although Canada faces strong global competition with industrialized countries to attract the same pool of young international talent.
>
> International students choosing to remain in Canada after their studies constitute a desirable source of qualified immigrants who are capable of integrating well into Canadian economy and society. Those who return to their home country will become allies with Canada by fostering successful commercial and political relations, given their understanding of Canadian values and society.

Shortages of HQP in ICT are forecasted until at least 2016 [13]. Enrolments in CS programs have recovered somewhat but are still insufficient to keep up with industry demand. Attracting foreign students into graduate programs increases the pool of trainees and is thus an important way of increasing both the supply and the quality of HQP in ICT. Foreign students account for 26% of all Master's students and 35% of all doctoral students in CS and mathematics in Canada [16].

HQP are required by a very large number of ICT companies, many of them SMEs, which are distributed widely across Canada. Access to locally/regionally produced talent is especially vital for SMEs. CS may differ in this respect from some other disciplines. If so, that would have implications for approaches to funding CS.

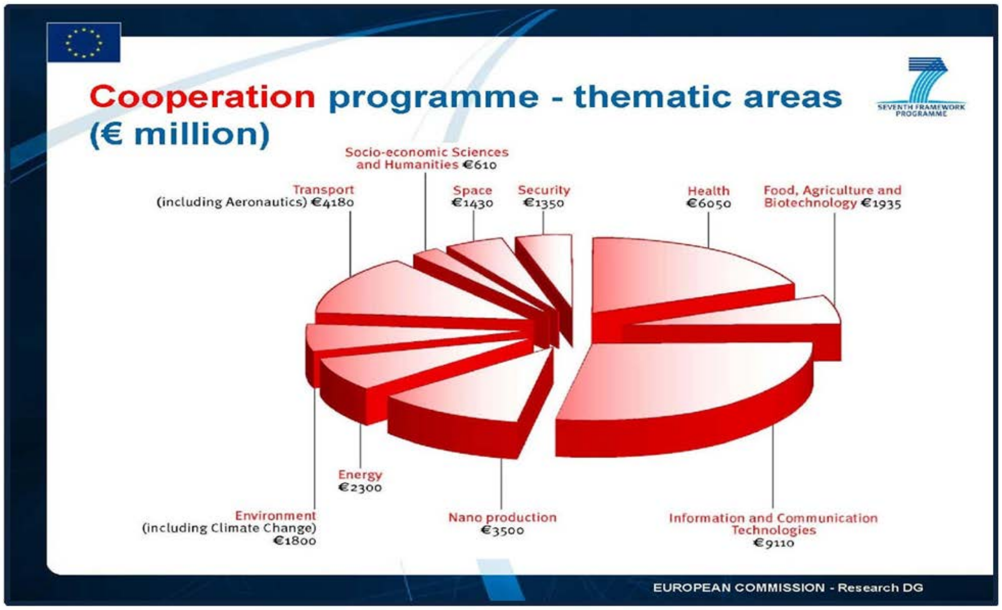
HQP production in CS is affected not only by the total amount of funding provided to researchers, but also by their DG success rate. Because NSERC DG amounts are not very high, the vast majority of DG funding is used to support graduate students. Holding an NSERC grant is also a prerequisite for accessing other funds, such as university co-funding for graduate students, and for supervising students who hold Mitacs grants or NSERC Undergraduate Student Research Awards. Thus holding an NSERC DG effectively amplifies a researcher's ability to support additional students. Reducing the DG success rate among CS researchers would therefore reduce Canada's capacity to produce HQP in a sector that is of great importance to the economy and has been identified as such by the Government of Canada. If the goal is to maximize support for HQP in CS, then reducing the DG success rate in this field would not be a wise solution to the challenge of overall low grant sizes.

C3. 3. Canada's financial investments in academic CS research are falling behind those of other countries that have invested significantly in this field

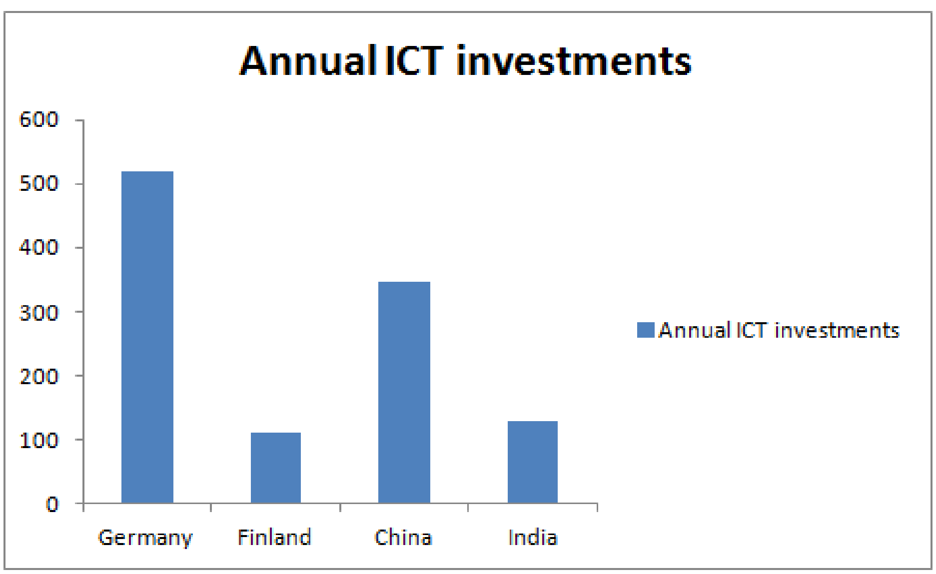
Competition for researchers and research results, development and talent in the ICT field is now global. The global ICT market itself totalled US$3.6 trillion in 2012 and is forecast to grow by 3.4% annually from 2011 to 2016 [17]. ICT also contributes to economic growth indirectly, by enhancing worker and organizational productivity — so much so that ICT has accounted for more than half of all U.S. productivity growth over the past 15 years [18]. As described in [19], other countries have ramped up their funding to support academic CS research, but Canada has not followed this trend. For example, the U.S. has recently created the Networking and Information Technology Research and Development Program (http://www.nitrd.gov/) to support research in targeted areas of CS. The European Union's annual report on the digital economy highlighted the benefits of ICT investments: "'ICT drives 50 per cent of E.U. growth', was one of the conclusion[s] of the recently published annual progress report [on] i2010, the Commission's five-year strategy to boost the digital economy [20]." One of the three key priorities of this strategy is to strengthen investment in innovation and research in ICT.

The EU has taken a number of actions to address this priority: ICT research in the 7th Framework Programme, European Technology Platforms, Joint Technology Initiatives; innovation; take up of ICT by EU citizens, ICT Policy Support Programme in the Competitiveness and Innovation Programme, ICT Task Force, eSkills, etc. [21]. Europe's

7th Framework Programme alone will increase the EU's annual level of ICT R&D funding by 50% between 2010 and 2013, investing **€** 9.1 billion (total: 2007-2013) in ICT as its largest area of investment [22].



On top of this investment by the EU, Germany will be investing an additional $520 million annually in its ICT 2020 - Research for Innovation Program, and Finland will invest $110 million annually. China's government will provide at least $345 million annually in civilian ICT R&D funding as part of its Medium- and Long-term Plan for Science and Technology Development, and India's government will provide at least $130 million annually as part of India's Eleventh 5-Year Plan, spanning 2007 to 2012.



Such investments by these countries indicate the importance of funding CS research and stimulating the ICT sector. Because the competition for ICT talent has now become global, such investments may draw highly qualified Canadian CS talent and ICT entrepreneurs to other countries. At the same time, these investments may encourage the best students from other countries to stay there, or to work in countries other than Canada, thus reducing Canada's ability to attract some of the best foreign students to this country and its ICT sector.

3. Recommendations

In this section, we present six recommendations for addressing the challenges discussed in the previous section, with the goals of strengthening the Canadian CS research community so that it can enhance its contributions at the forefront of discovery and innovation on the international stage, further assert itself among the leaders in numerous key areas, and help to ensure Canada's economic prosperity. These recommendations outline steps and directions that will require further collaboration among the CS research community, the NSERC Computer Science Liaison Committee, NSERC and other funding agencies and government organizations, and CACS and other groups. In our opinion, these steps and directions are essential to support the success of the CS community in its research endeavours, which are ultimately critical to the success of the Canadian ICT industry, and, indeed, Canadian industry as a whole.

R1. The rate of discovery-driven, curiosity-driven CS research must be accelerated. There must be a stable means of funding this research, and it is essential to sustain and expand support of HQP training at all levels

Challenges 1 and 2 raise concerns not only about ongoing support for curiosity-driven research, but also about increased support to attract and train HQP, particularly graduate students and postdoctoral fellows.

Even though the DG Program is NSERC's largest funding program, it has faced budgetary constraints. As a result, it does not provide sufficient funding levels for the CS discipline. The long-term support provided by the DG Program has been a major help in ensuring stable funding for curiosity-driven research and supporting HQP. One of our key recommendations is to ensure that this program provides stable and adequate — i.e., increased — funding for CS, despite financial difficulties. The LC looks forward to the results of the current evaluation of the DG Program and the preliminary assessment of the impact of the recently established review process for HQP training.

As the CS field has matured, the role of postdoctoral fellows has become increasingly significant, not only because they provide mature personnel for research programs, but also because these very high-end HQP represent an important resource for the society. The amount of money offered for NSERC Postdoctoral Fellowships is not enough to attract top applicants.

As computers have grown from single-core to multi-core and even multi-data-centre systems, and software has grown so that its footprints are now measured in gigabytes instead of kilobytes, so too has the complexity of the supporting research infrastructure for such systems grown. Simply put, modern computer systems have become the most complex artifacts ever created by humanity, and building the knowledge infrastructure to support, analyze and manipulate them has likewise become increasingly demanding. State-of-the-art research enterprises are often based on large-scale software or hardware infrastructure and must be able to hire and retain both technical staff and postdoctoral fellows to provide the critical continuity that allows these systems to flourish. Continuity in these human resources is needed to ensure the ongoing efficiency and usability of such infrastructure. We recommend that, for CS, DG funding be increased or new programs be launched to provide the required support for appropriately skilled personnel.

R2. It is critical to have funding for CS hardware and software infrastructure and for the technical staff needed to support it

Recommendation R2 addresses aspects of all three challenges: the need for funding programs that are more aligned with the needs of CS researchers, the need for increased funding for postdoctoral fellows and graduate students to train more HQP in CS, and the need for broader support of academic and industrial research in CS.

CS researchers need computing infrastructure on various scales, ranging from mobile, handheld devices to desktop-sized multi-core processing systems, to multi-rack heterogeneous clusters. With the scaling down of NSERC's RTI program, funding for such infrastructure is reaching a crisis point. The minimum amounts that CFI programs will support are too large in relation to the cost of computing hardware. The need for CFI applicants to secure matching funds from other sources is another obstacle, because it makes success in obtaining CFI funding depend on factors irrelevant to the excellence of the research (for example, whether there are sufficiently well funded provincial programs to provide the required matching funds). CFI has funded large-scale computational facilities, now operated by Compute Canada and provincial consortia, but such infrastructure is not satisfactory for much CS research. CS researchers cannot, for example, experiment with beta versions of new operating systems or perform fine-grained analyses of computational experiments on such facilities, which can be down for weeks at a time. State-of-the-art research in cloud computing, large software systems, artificial intelligence, robotics, and data sets of unprecedented scale demands sophisticated hardware and software infrastructure that are increasingly difficult to acquire and maintain, given the scaling down of the RTI program. Such infrastructure is too expensive to be funded with a DG, but not expensive enough to meet the CFI requirements.

CS researchers also increasingly require non-computing equipment, particularly in areas involving human-computer interactions (HCI) and mobile devices. Examples of such equipment include tracking systems for graphics or for HCI research on whole-body interaction techniques; large-screen, high-resolution displays; sensors and sensor networks; and custom-built equipment to investigate haptics and other advanced input modalities, often in interdisciplinary settings. Cameras and tracking systems are also needed for research in other CS sub-disciplines, such as software engineering — for example, to understand how software developers use software development tools. Software licences are increasingly expensive. CS researchers often require the flexibility to measure environmental variables, such as the power consumption of a processor or the temperature within an equipment rack.

Finally, as the size and complexity of CS systems has increased over the past three decades, the need has grown more pressing for highly trained technical staff to maintain hardware and software infrastructures and to provide continuity and stability across changes in student personnel. The level of expertise that these technical staff must have is higher than that needed to support computing equipment and maintain software systems in other scientific research programs, and accordingly, salaries are higher. CS research that can potentially have a significant impact on society and business increasingly relies on highly sophisticated hardware and software systems. These systems require highly qualified technical staff to design, implement and maintain them in a continuous fashion that transcends the lifetime of individual master's and Ph.D. theses. Technical staff can greatly enhance CS research in many domains, including large-scale software engineering, networking, computer security, robotics, bioinformatics, and cloud computing.

R3. More effective ways of supporting academic CS-industry partnerships are needed

On the one hand, the discovery-driven CS research programs have been successful in training HQP to pursue academic careers, to meet the needs of industry, and to take a hand in the creation of new companies. Like much other curiosity-driven research, CS research programs often spawn powerful ideas that superficially seem divorced from industry. But many key innovations, and many companies, have been based on computing technologies that resulted directly from basic research and then moved rapidly to commercialization (Google is a notable example). The ease and rapidity with which such transfers occur once ideas reach a suitable level of maturity may well help to explain why CS researchers and the ICT industry take so little advantage of NSERC's existing Research Partnership Programs. The overheads involved in accessing these programs, in terms of logistics, the size of the potential partner organization, the associated commitments, and the necessary timelines may all make it harder to use these programs effectively to exploit CS research or transfer the knowledge that it creates. Such obstacles could be addressed in a variety of ways. For example, to foster more co-operation between academic CS researchers and SMEs, whose human and financial resources are limited, the cash commitment required for a company to participate in a Collaborative Research and Development (CRD) grant could be adjusted according to its size or revenues (smaller companies would match a smaller fraction of the NSERC contribution). The Canadian government could adjust the R&D tax incentives offered to companies so that it would be more attractive for them to collaborate with university partners. Lastly, the strategic priority areas for Strategic Project Grants could be broadened for the area of ICT.

R4. Increased support for international collaborations can help to advance CS research in Canada and attract CS HQP to this country

As shown in [1], the inter-institutional collaboration rate in ICT is somewhat low for all subfields except Medical Informatics, but the international collaboration rate is much higher. In International collaboration, the trend is upwards in all subfields, with Computation Theory and Information Systems in the lead. Hence international collaboration is of particular importance for CS research.

As discussed in connection with Challenge 3, several major geopolitical units (notably the US, the EU, and Japan) have established large-scale collaborative networks for computer-science-related research. Canada would benefit from participating in these research networks and taking the opportunity to attract the top-notch HQP who are trained in them. It would therefore be worthwhile to provide the funding mechanisms and support the efficient infrastructure needed to facilitate this participation, so long as that does not detract from existing funding for the Discovery Grants Program. If funding for the DG Program were higher, then Discovery Grants could support some of these international collaborations. Also, other existing funding programs that allow for some international collaboration need to be modified so that the respective partners' timelines and application/review processes are more closely aligned. Another step in the right direction would be to open NSERC's Research Partnership Programs further, for example, by encouraging new links between university-industry networks and international networks. All of these steps could help to address Challenge 2 as well: attracting high-quality graduate students and post-docs, both domestically and internationally.

The highest-impact research topics increasingly are of global interest and require global resources and a broad knowledge base. Global modeling, for example, requires access to global data and researchers with a variety of skill sets and specialized facilities not all of which are typically available in any one country. In particular, Canada often does not have the capacity, human resources, or equipment to address these challenges alone. Yet Canadian society and the Canadian economy may be affected by these pressing issues, and Canadian researchers could play pivotal roles in addressing them. International research groups can potentially provide cost-effective solutions by using specialized equipment and bringing together talents from different continents. Many countries, including those of the European Union and BRIC (Brazil, Russia, India, China) would welcome Canadian participation in some of their programs and are also open to developing new joint funding opportunities.

Grants are needed to start or foster collaborations between Canadian and foreign researchers and thereby help create opportunities for Canadians to participate in international proposals and projects. Such programs are very cost-effective and in Canada's best interests. They deserve consideration for incremental funding by the Government of Canada, especially now, at a time of economic pressures.

Furthermore, Canadian funding agencies need to actively support interdisciplinary and inter-institutional research projects at the international level. Many respected figures, such as I. V. Samarasekera, President of the University of Alberta, have called for the leaders of major government funding agencies (particularly from North America, Europe, India and China) to define a funding model to support such projects [25]. The Global Research Council [26] is an example of an international organization that could contribute to this model, and Canadian funding agencies should consider taking a more active role in defining it.

R5. More tri-Council and Canada Foundation for Innovation (CFI) funding for interdisciplinary research is critical for this highly interdisciplinary field

Computer science is central to many interdisciplinary research programs and is often in a natural position to lead such endeavours. The opportunities are manifold, in areas such as digital data, digital media, and big data. Big data is a topic of especially high importance, as evidenced by a number of recent international initiatives (see, for example, the 2010 report and the 2012 strategic plan of the U.S. NITRD Program; the NSF Big Data Research Initiative; and the Digging into Data Challenge sponsored by SSHRC, NEH, NSF and Jisc). Networks of Centres of Excellence have been an effective funding mechanism for some interdisciplinary topics, but of a wider scope than CS. Discovery Grants are not well suited to support major new involvements of CS researchers in interdisciplinary initiatives.

Given the cross-cutting nature of some of the fundamental interdisciplinary research thrusts, we recommend the establishment of targeted tri-Council + CFI programs. Where knowledge and innovation are to be advanced in the natural sciences and engineering, NSERC's role will be critical. The Canadian government could regard such initiatives as strategic opportunities for new investments.

R6. With the support of its stakeholders and partners, including NSERC, the Computer Science community must become better organized

To meet the three collective challenges identified in this report will require additional government investment in programs to support and expand computer science research, to support the ICT sector, and to attract domestic and international students. But in addition, the Liaison Committee now calls on Canadian CS researchers from both academia and industry to step up to lead efforts to strengthen research and advanced education in computing and to build a cohesive Canadian CS research community.

Canada already has two national organizations that deal with CS. The first is the Canadian Association of Computer Science (CACS), which consists of chairs and heads of CS departments and schools and is administratively oriented. The second is the Canadian Information Processing Society (CIPS), which is primarily industry-oriented but does provide accreditation services to Canadian academic CS departments.

What Canada needs now, alongside CACS and CIPS, is a national organization representing CS researchers from both academia and industry. This organization should engage CS researchers in communicating the importance of Canadian computing research and innovation, in facilitating ongoing, cross-community discussions on emerging research directions and on the most effective ways for Canada to continue leading on the world stage, in developing a long-range plan for Canadian CS research, and in influencing Canadian CS research policy.

This new organization could serve as a conduit through which the CS/ICT community could interact with NSERC and other government organizations. For example, this new organization could identify major opportunities for CS research by holding workshops that bring together international panels of experts. The organization could use the reports from such workshops to suggest new funding programs, to increase the community's awareness of and participation in policy issues pertaining to the CS/ICT sector.

In addition to Canadian societies for other scientific and engineering disciplines, the Computing Research Association (CRA, www.cra.org) provides a good model for such an organization. The CRA's goal is "to catalyze and empower the U.S. computing research community to pursue audacious, high-impact research."

4. Summary

Canadian academic computer science research is vibrant and thriving, but must meet a number of challenges if it is to maintain its strength, attract more students, train more HQP to meet the demands of the Canadian ICT industry, enhance and increase academic CS collaboration with this industry (especially SMEs), and help Canada address the globalization of the ICT industry and ICT talent. It is critically important to the long-term economic health and prosperity of Canadians that creative, transformative CS research and innovation be aggressively funded. Several recommendations have been made in this report. They are sweeping and require collaboration among the academic CS community, NSERC and other stakeholders to translate them into specific action items, programs and initiatives.

Acknowledgments

The report by the *Observatoire des sciences et des technologies* (OST), which served as the basis for the present analytical report, was made possible by a joint initiative of the Canadian Association of Computer Science/Association d'Informatique Canadienne (CACS) and the NSERC Computer Science Liaison Committee and was funded by CACS. The Committee members wish to thank CACS both for funding the OST report and for providing us with such excellent support in interpreting it. In particular, we are grateful to Dr. Mike MacGregor, who was CACS's interface with the LC, and Dr. Ken Barker, Chair of CACS, for their time and detailed comments. The authors also thank Dr. Evangelos Milios, NSERC CS Group Chair and non-voting member of the LC, for providing valuable information for this report. We are also indebted to the heads of Canadian academic CS departments and to individual members of the Canadian CS research community who answered our survey questionnaire and provided comments on our summary of the responses to this survey.

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Abbreviations used in this document

CACS	Canadian Association of Computer Science
CFI	Canada Foundation for Innovation
CS	Computer Science
HQP	Highly Qualified Personnel
ICT	Information and Communications Technology
ICTC	Information and Communications Technology Council of Canada
LC	NSERC Computer Science Liaison Committee
NCE	Networks of Centres of Excellence
NSERC	Natural Sciences and Engineering Research Council of Canada
OECD	Organisation for Economic Co-operation and Development
OST	Observatoire des sciences et des technologies
USPTO	United States Patent and Trademark Office

Appendix I: Terms of Reference of NSERC Computer Science Liaison Committee

NSERC
CRSNG

NSERC's Computer Science Liaison Committee
Terms of Reference

The Natural Sciences and Engineering Research Council of Canada (NSERC) is establishing a Computer Science Liaison Committee. The purview of the Liaison Committee includes, but is not limited to:

- discussion of opportunities the Canadian computer science research community could seize or build on, and challenges it may face, in its quest to be at the forefront of research at the international level;
- discussion of emerging trends/needs for capacity building, innovative R&D thrusts, and current and potential scientific initiatives within the Canadian computer science research community which might relate to NSERC;
- provision and discussion of suggestions that the Canadian computer science research community may have regarding NSERC's programs;
- discussion of matters that may help to inform the Group Chair about his/her participation in the Committee on Grants and Scholarships (COGS).

Unless otherwise indicated, information that is produced for, and discussed within, the Liaison Committee can be shared with the broader research community.

The Liaison Committee will be composed of an appropriate number of highly regarded members of the Canadian computer science research community, with broad scientific expertise that covers the main sub-disciplines reviewed by NSERC's Computer Science Evaluation Group (EG 1507). The Liaison Committee will include one representative for each of the following overarching areas:

- Computer Applications
- Computer Methodologies
- Computer Systems
- Theoretical Computer Science

The Committee will be chaired by a senior member of the research community with an extensive knowledge of the Canadian and international computer science research environments.

The Chair and members will serve a three-year, non-renewable term. In order to ensure continuity and establish an appropriate rotation pattern in the early years of the Liaison Committee, a few members will be asked to serve for a longer duration. It is important that the members act as conduit of the greater research community and bring matters of common/broad interest to the Committee's attention, as opposed to anecdotal/personal ones.

Moreover, the Liaison Committee's membership will include NSERC's Research Grants' Team Leader and Director overseeing the Computer Science portfolio. Other NSERC staff may participate in the Committee's meetings on occasion. The Liaison Committee will also include NSERC's Computer Science Group Chair as an *ex officio* member. In this capacity, the Group Chair will only be an observer and a resource for the other members.

The Liaison Committee will hold two meetings per year, preferably in advance of COGS' fall and spring meetings. The meetings will be held via teleconference. Face-to-face meetings and additional *ad hoc* meetings could be held, if necessary. The Chair of the Liaison Committee will participate in the annual meeting of the Heads and Chairs of computer science departments, either by teleconference or in person.

Appendix II: Current Members of NSERC Computer Science Liaison Committee

Jörg-Rüdiger Sack, Carleton (*Chair*)

Dr. Sack received an M.C.S. degree (*Diplom*) from the University of Bonn, Germany, in 1979 and a Ph.D. from McGill University, Montreal, in 1984. He has held an NSERC Industrial Research Chair in Applied Parallel Computing and currently holds an HPCVL-Sun Microsystems of Canada Chair in the same discipline. His research interests include algorithms, data structures, distributed and parallel computing, computer graphics, geographic information systems and foremost computational geometry. He is editor-in-chief of the journal *Computational Geometry: Theory and Applications* and the *Journal of Spatial Information Science* and editor of the *Journal of Visualization and Computer Animation*. He served on NSERC's Advisory Committee for University-Industry Grants, Committee on Research Partnerships, and Committee on Grants and Scholarships. He also served as Group Chair for Mathematics, Statistics, and Computing and Information, as well as a committee member on the G8 Research Councils Initiative on Multilateral Research Funding. He is also a member of the Joint Commission for the German government's Excellence Initiative.

 **Michael Bauer, University of Western Ontario**

Dr. Michael Bauer is a Professor of Computer Science at the University of Western Ontario ("Western"). He was Chair of the Computer Science Department at Western from 1991 to 1996 and again from 2002 to 2007. From 1996 to 2001, he served as Western's Associate Vice-President for Information Technology. He has served on NSERC's Computer Science Grant Selection Committee both as a member and as Chair. He was Principal Investigator for the CFI project that initially funded the creation of SHARCNET (www.sharcnet.ca), a multi-university, high-performance computing grid. He is currently the Associate Director for SHARCNET. Professor Bauer's primary specializations are in the fields of distributed systems, high performance computing and applications of parallel computation.

 **Anne Condon, University of British Columbia**

Dr. Anne Condon is a Professor and Head of the Department of Computer Science at the University of British Columbia. Her research is in the areas of computational complexity and algorithms, with a current focus on problems in biomolecular computation and nucleic acid structure prediction. She is an ACM Fellow and a Fellow of the Royal Society of Canada. She held the NSERC/General Motors Canada Chair for Women in Science and Engineering (2004-2009), and received the Computing Research Association's Habermann Award for outstanding contributions aimed at increasing the numbers and successes of women in computing research (2010). She received her Bachelor's degree from University College Cork (Ireland) in 1982 and her Ph.D. from the University of Washington in 1987. She has received Distinguished Alumna Awards both from University College Cork and from the University of Washington's Computer Science Engineering Department and College of Engineering.

 **Gregory Dudek, McGill University**

Dr. Gregory Dudek is a Professor in the School of Computer Science, a member of the McGill Research Centre for Intelligent Machines (CIM), and an associate member of the Department of Electrical Engineering at McGill University. In September 2008, he became Director of the McGill School of Computer Science. He has served on NSERC's Computer Science Grant Selection Committee. He earned his Ph.D. in Computer Science (Computational Vision) from the University of Toronto, his M.Sc. in Computer Science (Systems) from the University of Toronto, and his B.Sc. in Computer Science and Physics from Queen's University.

Marc Frappier, University of Sherbrooke

Dr. Marc Frappier is a Professor of Software Engineering in the Department of Computer Science at the Université de Sherbrooke. He earned his Ph.D. in Computer Science from the University of Ottawa in 1995. His research interests include formal methods for specification, synthesis, and construction of software, as well as access control. He has served on NSERC's Computer Science Grant Selection Committee both as a member and as Chair. Before joining the Université de Sherbrooke, he worked for over five years as a consultant, senior analyst, and project manager for a variety of companies in a variety of industries, including manufacturing (Alcan and Cascades), banking (Royal Bank of Canada, National Bank of Canada, BFD/ÆBIS), pharmaceuticals (Merck Frosst), aerospace (the Canadian Space Agency), and telecommunications (Nortel).

Evangelos Milios, Dalhousie University
***Ex officio*, NSERC, Group Chair for Computer Science**

Dr. Evangelos Milios received a diploma in Electrical Engineering from the NTUA, Athens, Greece, and Master's and Ph.D. degrees in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology. Since July 1998, he has been a member of the Faculty of Computer Science at Dalhousie University in Halifax, Nova Scotia, where he served as Director of the Graduate Program from 1999 to 2002 and has served as Associate Dean - Research since 2008. He is a Senior Member of the IEEE. He has been a member of the ACM Dissertation Award Committee (1990-1992) and of the AAAI/SIGART Doctoral Consortium Committee (1997-2001). He is co-editor-in-chief of the journal *Computational Intelligence*. He served as a member of the NSERC Discovery Grants Evaluation Group for Computer Science from 2008 to 2010 and as Chair of this Group from 2011 to 2013. At Dalhousie, he held a Killam Chair in Computer Science from 2006 to 2011. He has published on the interpretation of visual and range signals for landmark-based navigation and map construction in robotics. He currently works on modelling and mining of content and link structure of networked information spaces, text mining and visual text analytics.

Samir Boughaba (NSERC, *ex officio*)

Dr. Samir Boughaba is the Team Leader, overseeing the Computer Science and Physics portfolio within the Mathematical, Environmental and Physical Sciences Division of NSERC's Research Grants and Scholarships Directorate.

Anne-Marie Thompson (NSERC, *ex officio*)

Anne-Marie Thompson was the Director of NSERC's Mathematical, Environmental and Physical Division within the Research Grants and Scholarships Directorate. Since March 1, 2013, she is the Director of the Energy, Environment and Resources Division of NSERC's Research Partnerships Programs Directorate.

Appendix III: Summary of Responses to NSERC CS Liaison Committee Survey of CS Researchers

The following is a summary of responses provided by the heads and chairs of Computer Science (CS) departments and schools in Canadian universities, in consultation with faculty members, to a set of 10 questions posed by the NSERC CS Liaison Committee (LC). Integrated are also further comments received by individual faculty members in response to the summary.

1. What distinguishes CS research from other science and engineering disciplines, in terms of funding needs and priorities?

Impact: Future job prospects for CS graduates are considered to be higher than for any other science or engineering field. From computational biology to digital humanities to social networking to cognitive science to assisted living to green homes, Computer Science is playing a critical role in almost every discipline, scientific and otherwise. The US, through the Computing Research Association (CRA, a US professional organization that includes many Canadian CS departments as members), as well as through the National Science Foundation (NSF) and the Office of the US President, recognizes the strategic importance of computing to national security-related economic and societal health and is aggressively expanding funding for basic CS research.

Funding for CS research in Canada is falling behind, jeopardizing Canada's ability to produce highly qualified personnel and socio-economic innovation. CS Discovery grants do not provide sufficient support to cover the costs of doing forefront research, while addressing the high and continued demand for HQP production across the country. CS research costs are distinguished from those in other disciplines in the following ways:

Infrastructure: Unlike other engineering or science disciplines, whose researchers *use* computers to support their research, CS researchers *design* new computational technologies. While shared computing clusters are valuable to some CS researchers, much CS research is distinguished by the need for dedicated computing environments so that researchers can perform fine-grained analyses of computational experiments, as well as by the ability to bring the entire cluster down. Moreover, computing hardware, software and software licenses are expensive and different from the infrastructure needs of other disciplines in significant ways. Computing technologies become obsolete rapidly, and accordingly, hardware, algorithms and software must frequently be updated.

HQP: In the past, CS researchers were viewed as comparable with mathematicians in terms of funding needs, but that view is outdated. Today, CS researchers who are developing innovative software systems tools and artifacts, or who analyse large data sets, or design and analyse high-performance algorithms, need highly qualified personnel at all levels: graduate students, postdoctoral fellows and technical staff. Compared with other disciplines, a relatively larger proportion of funding is needed to be able to attract excellent students, since the computer industry jobs offer higher salaries than other industries. Additionally, the skill level, and thus salary level, needed of technical staff and system administrators who play an integral role in CS research is higher than technical and laboratory support personnel in other science disciplines.

Research Dissemination: In CS, conferences are the main archival publication venue. This means that CS faculty and their students must give presentations at and travel to international conferences to remain visible and competitive. This is unique to computer science in that there is no other science or engineering discipline in which conferences have nearly *replaced* journals as the main archival venue. Without increased travel funds, faculty and students are precluded from publishing their research in the highest impact venues. It's not just about visibility and competitiveness; it's about dissemination of results.

Lastly, in contrast with other science disciplines, there are no Canadian institutes that focus on the advancement of Computer Science research.

2. NSERC's mission is to support discovery and innovation in Canada. Can you provide examples in which socio-economic innovation has followed from research funded through NSERC's Discovery Grants or other grants that support long-term, curiosity-driven research?

The following examples illustrate the ways in which CS discovery research (also called curiosity-driven research or basic research) has been effective in transforming creativity into discoveries and socio-economic innovation. We note also that CS graduate programs train HQP who not only start up new companies, but also help to retain and attract other companies to Canada by creating a highly educated labour pool for them.

Many academic CS researchers have commercialized their work through highly successful start-ups (this is just a small sample of mostly recent examples, ordered alphabetically, that emerged in our survey):

- Alias (now Autodesk) and Side Effects Software (animation and special effects)
- Autostitch and Cloudburst Research (fully automated panorama reconstruction)
- Brightside Technologies (electronic display technologies)
- BumpTop (virtual desktop environment)
- CognoVision (audience measurement and retail intelligence solutions)
- Convergent.io (storage and networking support for software-defined datacenters)
- Exotic Matter (dynamics software for visual effects and 3D animation)
- Independent Robotics (autonomous or tele-operated devices for land and water)
- Maplesoft (high-performance software tools for engineering, science, and mathematics; while it took "only" eight years between the project start and first commercialization, effectively the real research effort, funded by NSERC, took over 15 years to get to a viable commercial product)
- Namkis (app that enables businesses to obtain user-generated content)
- NeuroPlanningNavigator (interactive 3D visualization tool for neurosurgical planning)
- OpenText (information management; Canada's largest software company)

- Optemo (online shopping)
- Point Grey Research (embedded camera systems, multi-camera arrays)
- RapidMind (support for multicore architecture programmers, acquired by Intel)
- Sysomos (social media monitoring and analytics tools)
- Tasktop Technologies (support for software and digital work management)
- Zite (a personalized iPaD magazine, recently acquired by CNN)

There are many other examples where ideas and software developed using NSERC CS Discovery grants and related funds have been incorporated into commercial products or have led to patents (again, the following examples were provided in response to our survey, and the list far from exhaustive):

- Work on constraint satisfaction algorithms has been incorporated into ILOG CPLEX, now owned by IBM.
- Graphics algorithms for 2D unfolding of surfaces are used by Dassault systems (one of the biggest European developers of CAD tools).
- Combinatorial auction research results were transferred to two start-up companies (TradingDynamics; Cariocas), the first of which was sold for $1.2 billion, and to the US Federal Communications Commission for their auctions of radio spectrum to cell phone companies.
- Canadians have been co-founders of forefront US-based companies, e.g. Pixar.
- Patents related to breast cancer diagnosis (featured in work with clinical applications, and with substantial commercialization potential).

The following examples of the social impact of discovery research were mentioned in responses to the survey:

- Bioinformatics for health-related research, e.g. participation in the analysis of 1000 Genomes Project data or identification of novel small peptides.
- Gilles Brassard's research on quantum cryptography, which leads to practical applications for secure data transmission.
- The scheduling algorithms developed by researchers in Montreal, for Air Canada and nurses in Quebec.
- Sensor technology that provides an alarm if a senior falls, and another developing a care-flow management system for health services delivery for community-based health programs.
- The Tor project: enables individuals to use the Internet without surveillance (for example, to blog from foreign countries), and the Telex project, which provides to citizens of countries where the Internet is censored a means to circumvent the censorship.

Respondents also offered some valuable perspectives in the context of these examples. First, while examples such as those above demonstrate tangible links between discovery research and socio-economic innovation, it is critical to also keep in mind that innovation depends not only on such direct links, but also indirectly on other research. New discoveries get refined and advanced by the contributions (including many failed attempts) of researchers around the world, ultimately leading to socio-economic innovation. For example, the success of public key cryptography in secure real-world communications is the outcome of many intermediate lines of basic research (integer factorization, NP-completeness, hash functions, etc.) that have been investigated by thousands of people over a long period of time. It is therefore often difficult to document the practical impact of discovery research.

Moreover, the dearth of computer science research labs in Canada makes it particularly difficult to integrate innovative research into the products of Canadian tech companies. Instead, as some of the examples above demonstrate, Canadian start-ups that commercialize a research innovation are often bought out by international firms, leaving much of what was invested to vanish in terms of its connection to Canadian research funding. (In contrast, research labs in the US include Google Research, Microsoft Research, Intel Research, Willow Garage, Honda Research, Xerox PARC, Mitsubishi Electric Research Lab and NEC Research Institute, not to mention all the federal research labs such as Los Alamos, Lawrence Berkeley, NIST, Argonne and Oak Ridge, to name just a few examples).

For these reasons, while we have documented some of the myriad ways in which CS discovery research does lead to socio-economic innovation, we caution that research quality is the most important attribute of discovery research, and impact on socio-economic innovation is secondary. Donald Knuth, a foremost computer scientist, wrote that "if you asked me any year what was the most important thing that happened in computer science that year, I probably would have no answer for the question, but over five years' time the whole field changes. Computer science is a tremendous collaboration of people from all over the world adding little bricks to a massive wall. The individual bricks are what make it work, and not the milestones."

The CRA has recently compiled a report that documents the impact of government funding of Computer Science basic research on the US economy, ranging from the Internet to the core technologies behind companies such as Electronic Arts, Google, Oracle, HP, Cisco and Apple - to name just a few. Clearly, government funding of basic research in Computer Science has had an enormous impact on the US economy as well as its strategic interests. A similar report for Canada would be very valuable in augmenting the *ad hoc* examples provided here.

3. Which NSERC grant programs are your primary sources of funding? What do you consider to be the strengths and weaknesses of these programs for CS researchers?

Discovery Grants (DG) are the main source of funding for researchers in many institutions. As a result, there was extensive input on DG. The new merit-based review process was seen as positive, but its impact on smaller universities was felt by some (but not all) to be negative, leading to concentration of funding to the larger research-intensive universities and pressure to do more applied research.

The DG program's strengths include flexibility in the domain of research pursued, the long funding interval, the fact that strong junior faculty members receive funding, and it being the only program that supports scientific research as opposed to industry-oriented R&D.

The DG program's weaknesses include the following: The minimum grant is not sufficient to support two graduate students, funding amounts are not sufficient to sustain an internationally competitive research program, and lack of predictability in the amount awarded in the new review model leads to great caution in accepting new graduate students. The minimum grant in the new funding model is such that it may cut off researchers at small universities with no or small graduate programs, who could still make significant contributions with a level of funding lower than the minimum grant. If we compare the grant levels now and 40 years ago, and if we consider inflation, we see that the DG value has eroded significantly. As CS becomes more conference-based and less journal-based, there is an increased need for travel funds. DG levels are not sufficient for hiring post-docs and research associates critical for system-building activities. World-class faculty are hard to retain because they feel they cannot sustain their basic research programs on small DGs. Travel is more important for schools with small graduate programs when it comes to facilitating collaborations. There were mixed views on the weight assigned to HQP when evaluating grants and how could disproportionately affect sub-populations of researchers.

CRD grants: The required industry participation can be seen as a strength and a weakness. For some areas of research, it is very hard to find matching funds from industry.

Engage grants: These are very useful in establishing linkages with industry. The short starting timeframe makes it difficult to recruit people. There is a risk of a gap between the end of an Engage project and any follow-on larger grant, which can create uncertainty for trainees and supervisors.

Strategic Project grants: The strengths include the fact that the award of the amount requested, if successful, allows for internationally competitive research activities. It does not require cash from industry. It encourages medium-sized groups to work together. The weakness include the very low success rate, the timing (award notifications come in October, which is too late to recruit students for the current academic year). They are not well suited for creating a new start-up because they emphasize research partnerships.

NCE and Strategic Network grants: These are very effective in establishing and strengthening cross-Canadian collaborations. They are an excellent vehicle to attract outstanding graduate students, and attract and retain top faculty. They often contain programs to support early career researchers, networking and links to industry, and travel for students within the networks. A weakness is the amount of administrative work required.

Research Tools and Instruments grants: The support RTI grants provide for smaller-scale equipment needs is vital and critical for many research programs.

Industrial Research Chairs: The strengths include the focus of research in areas of high industrial relevance, and help in attracting top students with an interest in both fundamental research as well as practical relevance.

Idea-to-Innovation grants: This program is easy to apply to, and the amount of funding, appropriate to move technology from academia to industry. The feeling was expressed that there is a lack of clarity in the evaluation. It appears that hardware technology has a serious advantage over software technology and that the technology for which funding is requested must already be marketable, while the program is intended to take a laboratory prototype to the commercialization stage. Concern was raised about the amount of paperwork involved in I2I grants.

General comments

There are no mechanisms to appropriately fund small teams to do basic research.

Support through DG funding has shrunk, while the funding targeted at partnership programs has increased. The US, through the Computing Research Association (CRA, a US professional organization that includes many Canadian CS departments as members), as well as through the National Science Foundation (NSF) and the Office of the US President, recognizes the strategic importance of computing to national security and economic health. Unfortunately, in Canada, computer science has received no such recognition, and available funding (across all NSERC programs) is insufficient to sustain the research programs of the world-class CS faculty we have in Canada. Our NSERC funding significantly lags that of other science and engineering disciplines.

Stipends offered to graduate students in Canada are far less competitive than stipends offered in top US programs.

4. What are the barriers to more uptake by CS researchers of partnership programs, such as NSERC Strategic Grants, Industrial Research Chairs, or other Industry-Driven Collaborative Research and Development Grants? Also, what are the barriers to participation in these programs by the computing industry?

Barriers for academics

- To satisfy industrial R&D needs, rapid access to students is required. This is considered to be possible only in larger institutions.
- Proximity to industry and area of research greatly affect the ability to tap into partnership programs.
- Timelines and requirements for industrial research may not match those of academic researchers.
- Getting the required multi-year funding commitments from industry, as opposed to short-term funding, is very difficult.
- Looking beyond the IT industry for industrial partners was suggested.
- Researchers fear losing credibility in doing more applied research.
- It is hard to find companies that work in one’s area of interest. Several key players such as Microsoft or Google have a “branch plant” operation where the Canadian branches, if present at all, are relatively small and have a disproportionately small research presence.
- It is hard to convince companies that research is good for them in the long run.

- Some CS branches are facilitative in that they provide tools, usually algorithms (for carefully chosen methods, etc.), which are used by other disciplines. These areas are not on the frontline for industrial collaboration.
- Difficulties in publishing work co-funded by industry may discourage academics.
- There is a general concern that these programs may push researchers into becoming part of the development – rather than research – activity of industry. Some joint research projects are really disguised consulting relationships (where consulting is a legitimate activity, but needs to be distinguished from research).

Barriers for industry

- Complexity of programs, IP issues, lack of awareness.
- Canadian industry has so many kinds of R&D support from the government that collaborations with academia are not always a priority.

Barriers for both academics and industry

- A barrier could be the design of these programs. As a comparison, many US programs (e.g. DARPA) involve government funding flowing to companies, which then sub-contract to university researchers to produce novel research. This (i) incentivizes companies to engage with university partners and (ii) allows companies to pay their own research staff from the funding. In Canada, professors must do "business development" to sell industry partners on a collaborative grant that will provide no direct funding to the company.
- The conflicting goals of the university and industry communities. Most potential industrial partners do not understand the need for long-term basic research, as their horizons are often very short. Many want prototypes and deliverables that can lead to better products in the short term, and that's simply not what faculty and graduate students should be spending their time working on. Too few industrial partners correctly see the university as providing a world-class research department that can explore next-generation technologies/algorithms/prototypes, providing a competitive advantage at an affordable cost to them. Part of this is the culture of Canadian companies in that there's no history of serious corporate R&D since the demise of Bell-Northern Research (an arguable exception would be IBM Canada). Changing this culture takes considerable time.
- It's time-consuming for faculty to explain to a potential industrial partner the nature of their research, and equally time-consuming to extract from the company a concise specification of what they need.
- The biggest barrier remains the lack of industrial R&D in Canada.
- We need more success stories and more PR promoting the value of academic collaborations to industries.
- US-based universities and funders do a much better job of facilitating partnerships. The barrier between the university and industry is much more permeable. Faculty members can take long-term leaves from the university, go to industry, and be confident that they can return. Industry-based researchers have opportunities to take up research faculty positions. Support for people to move across the industry-university line needs to come in many forms, but most important is funding and support by senior university administrators.

- Few resources are available for “match-making” between researchers and enterprises.

5. Roughly what fraction of your current NSERC funding is used to support international collaborations? What features (e.g. award size, purpose of funding, partnership with funding programs in Europe, the United States of America, or Asia) would be useful in a broad-based, NSERC program targeted at international collaborations (i.e. to enhance international collaborations in ways that are difficult or not possible with your current funding sources)?

Fraction used to support international collaborations

Little money is used for international collaboration. At best, we take advantage of a conference trip to visit colleagues and nurture the collaboration via email and/or teleconference (not very effective) – between 0% and 15%.The collaborations are funded mostly by travel expenses and post-doc hosting paid by NSERC DGs. While there is the possibility of starting such collaborations through the application of DG funds, such grants are far too small to be of likely use in this. The CREATE program is clearly not enough and aims only at bigger endeavours.

Ideas for an NSERC program targeted at international collaborations

There are examples of programs, e.g. NSF + CNPq (Brazilian funding agency), where each country funds its own researchers to work on collaborative projects aimed at exchanging students and researchers. One idea would be to have NSERC co-fund exchange programs with the provinces. For instance, Alberta has a solid history of collaboration with Bavaria in Germany, so why not look into a program for exchange and mobility of students/researchers co-funded by Alberta and NSERC on one side and DFG and Bavaria on the other?

There is the potential for leveraging funds from other countries to advance Canadian research. This seems to be done far more in the EU, and it would be nice to see also partnership programs with the BRIC countries. Such programs should be varied and include shorter durations (< 1 year) as well as longer projects.

“Enticement” funds for international students to carry out their last year of PhD research in Canada, something like a “dissertation award” in Canada, could be useful. It would have to be linked to a Canadian professor becoming co-supervisor. Chances are that once the student graduates, he/she would be interested in remaining in Canada first.

Awards of about $10K to invite visiting students or to facilitate bi-directional travel between research centers could be useful, provided there is extremely little administrative overhead and very quick application procedures.

International programs that would fund an international post-doc to come to Canada, that would support our students wishing to spend a year abroad with an international collaborator, and that would provide the travel funds necessary to support international collaboration could be useful.

Support for Canadians to join European collaborative grants, even if at a modest level (e.g. one student working on the joint project and one or two yearly trips), could be useful. Currently there is no real incentive for Canadian researchers to join European projects. A Canadian could submit a proposal to NSERC for research activities and travel that tie in with the European project for "pre-approval." If pre-approved, in case the European project is accepted later on, NSERC would release the promised funds to the Canadian researcher.

An "international supplement" would allow NSERC discovery holders to participate in upcoming international collaborations and increase the visibility of Canadian researchers.

Having a fund targeting research visits to promote international collaborations could be useful. The NATO Science and Technology Collaborative Linkages Awards (a few years ago) had such a fund.

6. How well do NSERC programs work for funding interdisciplinary research projects that involve CS researchers?

Interdisciplinary research is important and common among CS researchers. It was noted that NCEs have been very effective in providing funding for interdisciplinary research. Others stated that the CHRP program can be useful, but only when there is a strong prior collaboration.

However, a perceived challenge for interdisciplinary researchers who apply within the NSERC DG program is that it can be difficult to obtain objective evaluations from NSERC panel reviewers, because collaborative interdisciplinary proposals, e.g. in the biomedical field, look “applied” and “project-like” and can be perceived as second-class. More joint NSERC-SSHRC-CIHR (possibly including CFI) initiatives would address this challenge.

Interdisciplinary research seems to occur more in spite of NSERC programs than because of them. Interdisciplinary research is important, and this is why people are pursuing it. There is little attraction to the area through NSERC programs. Despite efforts made, there still seems to be a sense that much interdisciplinary research is second-class.

The interdisciplinary slant should mean that more would be going to joint NSERC-SSHRC-CIHR-CFI initiatives. Digital media, for example, is a hot area in CS, but it involves people from CS and the humanities in equal parts. Similarly, “Big Data” research spans tri-council (NSERC-SSHRC-CIHR) topics, in particular from CS.

NSF has also introduced important cross-cutting programs, including the National Robotics Initiative (http://www.nsf.gov/pubs/2011/nsf11553/nsf11553.htm) and the Big Data Initiative (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504767), and provides significant funding for its Cyberinfrastructure Framework for 21st Century Science and Engineering program (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504730). In contrast, there are no initiatives, either at NSERC or cross-cutting several funding agencies, that focus on advancing basic research in areas of computer science that are essential for Canadian societal and economic well-being in the information age.

7. As NSERC's Research Tools and Instruments Grants program winds down, with the last competition to be held in 2013, the Canada Foundation for Innovation (CFI) is becoming the primary source of funding for research infrastructure. What are the strengths and weaknesses of the CFI programs for supporting CS research? Do CS researchers have particular infrastructure needs that would be better addressed by variants of the CFI programs or alternative funding mechanisms?[3]

The CFI's existing programs do not suit the needs of typical RTI applicants. Not only are the dollar values at the CFI wrong, but the purposes are often contrary. RTIs largely support curiosity-driven research. This is not possible with the CFI, as there will be no source for the 60% match for such research and at those dollar values. The CFI is also much more strongly tied to a specific set of target domains, which also limits the utility of the program. An alternative mechanism with lighter dollar values and broader applicability is needed.

RTIs are a good vehicle to fund niche non-generic equipment.

The CFI should open up to requests from $20K and up. The CFI does not serve the need for specialized equipment of moderate cost (e.g. robots, cameras).

For the CFI, not only is the application for large equipment, it also has a very complex procedure in the procurement of equipment, in matching and in the reporting mechanism. The CS hardware market is so competitive that it may be difficult for manufacturers to provide the special discounts needed for CFI applications. Also, there is inadequate flexibility in a domain where the specific hardware available on the market (and hence the optimal choices) may change from the preparation of a CFI application to the installation of the equipment.

The scaling back of the RTI program will put more pressure on Compute Canada resources. This has possibly already started with the CFI being unlikely to support departmental clusters in recent years. It is therefore now critical for Compute Canada to continue to be well funded. It won't solve everyone's RTI needs, but on the other hand it would enable considerable research on multiple fronts.

The CFI is the wrong scale (too large) to serve as a proxy for RTIs, and the CFI also requires industrial participation. Basic research in CS requires both major and minor instrumentation. If the only way to secure essential instrumentation is to make one's research compliant with industrial interests, basic CS research in Canada will face a

[3] Question 7 was formulated immediately after the announcement of the winding down of the Research Tools and Instruments (RTI) Grants program. Since then, NSERC has launched a consultation with the communities it serves on the future support of this program in light of reductions in available funding. Your input should take this into account.

major setback. World-class CS basic research instrumentation simply cannot be funded on the back of an NSERC Discovery grant, nor can the staff required to maintain/administer the instrumentation. The RTI program should be resurrected. NSF has an outstanding program (MRI-"Major Research Instrumentation," $100K–$4M) that, it is believed, would serve as an excellent model for Canada.

The CFI awards are tied to the university's strategic plan. The strategic plan is often developed by administrators targeting things they feel are needed on campus. This does not necessarily translate into promoting the best or most innovative scientists.

Concerns were raised regarding the criteria used to evaluate CFI annual reports. The questions that the CFI asks researchers to respond to in these reports focus on the direct impact on Canadian industry and society, and not at all on whether any major scientific discoveries were made.

The CFI is focused on large infrastructure projects. The expectation that industry will pay for equipment is unwarranted. However, industry often expects universities to provide appropriate equipment.

8. NSERC's Industrial Postgraduate Scholarships to foreign students are permitted up to a maximum of 20 percent of the program as a whole. Is it desirable to extend the same policy to the other NSERC postgraduate and postdoctoral scholarship programs that are currently open to Canadian citizens and permanent residents only?

Most respondents were in favour of lifting such restrictions. Reasons provided for this were as follows: (i) There's a huge shortage of Canadian CS undergraduates moving on to graduate school, and the cost of supporting international graduate students remains prohibitively high at many Canadian universities. (ii) International students, upon graduation, often stay (or would prefer to stay) in Canada, contributing their brain trust to our industries and universities. This is a huge boon to the country. (iii) Availability of scholarships for such students would undoubtedly increase the average quality of students in our graduate programs, while restricting scholarships will imply that we will lose our competitive advantage in attracting top-quality foreign students for graduate programs in Canada. (iv) Canada relies on immigrants for its prosperity and productivity. International students/post-docs tend to remain in Canada anyway so there seems little to lose. In fact, other countries have already paid for their prior education. (v) There is a great opportunity for Canada to combine graduate/pesto scholarships for international students with a fast-track immigration process to give these folks permanent residence upon successful completion of their program.

The small number of responses that raised concerns about lifting the restrictions made the following arguments: (i) Politics has to be factored in, and since Canadians are paying taxes to fund this, an argument can be made for limiting it to Canadians only. (ii) We are already challenged in attracting sufficient numbers of domestic graduate students; reducing opportunities for domestic students needs to be prevented.

9. Rate the usefulness of the following programs to CS researchers on a scale from 1 (not at all useful) to 5 (extremely useful):

Program	Average Score
a. Postgraduate Scholarships (non-industrial)	4.8
b. Postdoctoral Fellowships (non-industrial)	4.4
c. Undergraduate Student Research Awards (non-industrial)	4.4
d. Industrial Postgraduate Scholarships	2.5
e. Postdoctoral Industrial R&D Fellowships	2.2
f. Industrial Undergraduate Student Research Awards	2.1
g. Collaborative Research and Training Experience (CREATE) Program	3.2

Overall there was strong support for a), b) and c).

While CREATE programs were not universally strongly supported, three (out of a total of 21 responses to this question) expressed very strong support for this program (top score of 5) and five other institutions expressed strong support (score of 4).

10. How do you think that Canadian CS researchers can be effective in advocating for research support that best supports discovery and innovation in Canada?

The responses addressed three facets of this question: What should the key messages be? What are effective mechanisms for communicating the key messages? Who are the target audiences?

<u>What should the key messages be?</u>

- Communicate a sense of vision. Communicate why funding programs for CS are of strategic importance. One simply needs to attend a talk by Jeannette Wing (ex-Director of NSF CISE) and listen to the strength of her vision of the strategic importance of CS in education, robotics, machine learning, green computing and computational thinking. CS research also contributes to the well-being of Canadian health and the work environment, while augmenting the quality of our lives.
- Communicate success stories that trace Canadian technology industry innovations to NSERC basic research grants. Highlight how much of our research is used by industry (both within and outside Canada). Knowledge transfer to industry is also enabled through the hiring of HQP.
- Recognize CS as having the needs of a lab science and as being one of the most strategically important disciplines on the planet. Canada has the potential, in terms of the quality of its CS departments and researchers, to play a leading role in shaping the IT landscape of the future, which, in turn, can translate into Canadian economic strength.
- Just as in other times certain disciplines were rightly recognized as having a strategic role for discovery and innovation, it is critical for Canada's

competitiveness and future prosperity to recognize that today Computer Science is in this position, and to act upon this recognition.

- Support curiosity-driven, longer-term funding models and avoid project-oriented, task-driven, artifact-producing funding models. Avoid dangerous dichotomies, like “applied vs. theoretical,” as both are useful and sometimes impossible to separate given how they interact. Avoid emphasis on research funding programs that over-emphasize short-term development. Achievements in applied research depend on a solid foundation of basic research, and a shift away from basic research shows a lack of understanding about the complexities of the discipline.
- Communicate to small Canadian institutions the importance of research funding, in part because these institutions train excellent graduates who go on to graduate programs at larger research institutions.
- Emphasize the importance of research quality and the peer review process.
- Broaden the definition of “innovation.” This is not necessarily equal to “higher profit” or “new product.” New results, new insights, new theories and new models are influential when they open up new avenues.
- Encourage very early stage venture capital to encourage risk-taking start-ups by students and even professors. The climate for early-stage start-up activities in Canada is much less encouraging than in the US.
- Appeal to Canadian national pride and present a unified voice.

Who are the target audiences?

- There should be strong emphasis on government. Nothing less than a broad-spectrum wake-up call to the federal government leadership will bring about the recalibration of funding priorities that recognizes the impact and importance of our discipline.
- In the long term, the strongest chance of support for basic research would occur when the general public is genuinely interested in science and has some understanding of how scientific research unfolds. Children are probably much more open to being educated about this than adults.
- We should get our research into the popular press, to improve public understanding of CS.

What are effective mechanisms for communicating the key messages?

- A national advocacy organization, along the lines of the CRA in the US, could be effective. The CRA has had a great influence on national political funding decisions and even has influence with the Office of the US President. An organization that represents the CS community just for NSERC’s purposes, while useful, will only fine-tune the distribution of a fixed pot of money. “High-flying” individuals should build awareness, at the highest levels of government, of the potential societal/economic impact of increased funding for computer science.
- Messages about the strategic importance of Computer Science must come from the highest levels of government in response to a concerted effort from not only our CS representatives at NSERC and the leadership of NSERC, but also from

the leadership of our most elite Canadian CS departments and the leadership of our most innovative and research-intensive companies.

- A Canada-wide Computer Science professional research society could communicate via a newsletter and host an annual meeting featuring a variety of events, such as strategic coordination and discussion, workshops (e.g. grant writing, women in CS), presentations and interaction with NSERC (locally and nationally), networking opportunities, industrial exhibits, graduate-student poster sessions, invited keynote talks, submitted research talks and mini-symposia (similar to the Canadian Mathematical Society meetings).
- A CS Research Institute, whose mission could include fundamental advancement of the field – spanning the very applied (engineering) parts, all the way to the mathematical parts – as well as forging external linkages, could be an effective mechanism. Such an institute could help "translate CS research outwards," thereby realizing the incredible potential for Computer Science to impact other disciplines and society at large. Leaders within the Canadian CS research community would need to expand on this vision and champion it.
- Find industry advocates who understand the value of basic research. For example, Bill Buxton made compelling arguments at a recent CHI conference.
- Adopt NSF's model for developing innovative funding programs. In addition to gathering input from its advisory committees such as CISE, NSF organizes workshops that bring together international panels of experts to look at important emerging research directions and to provide advice on productive research directions. Discussions and reports from these workshops guide new funding programs. NSF also funds the Computing Community Consortium (www.cra.org/ccc), a broader initiative aimed at mobilizing the US computing research community to engage in visioning the future of computing and in identifying major research opportunities for the field. Could Canadian CS researchers work in partnership with NSERC to organize workshops and consortiums in Canada, to solicit ideas on emerging research opportunities and challenges that could then guide new funding programs?
- Create a website in which every NSERC-funded project is listed.
- Programs like "Bacon and Eggheads" (see www.pagse.org) are useful at reaching members of Parliament.

Appendix IV: Report on the Canadian Computer Science Research and Innovation System, prepared by the OST for the LC

September 2012

Observatoire des sciences et des technologies

CANADIAN COMPUTER SCIENCE RESEARCH AND INNOVATION SYSTEM

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EXECUTIVE SUMMARY

Using a number of reliable data sources, this study presents the relative importance of Canadian Computer sciences (CS) in the world, as well as the main trends of its development in the Canadian context. Four dimensions of CS are explored here:

- The scientific production of research institutions (mostly academic) is measured through bibliometric data;
- The inventive activity and its related intellectual property, through data on patents;
- The investment in industrial and academic research, through data of the Research and Development Survey and through data on grants awarded by the Natural Sciences and Engineering Research Council of Canada;
- The training and employment of the workforce in the domain of CS, through Canadian data on university enrolment and graduation and through OECD data on ICT skills and employment.

SCIENTIFIC PUBLICATIONS

Bibliometric data shows that the annual number of Canadian scientific publications in the field of Information and Communication Technology (ICT) grows notably between 2003 and 2007 and remains between 7,000 and 7,700 until 2010. During the same period (2003-2010), Canada's specialization in ICT decreases while the scientific impact of its papers increases substantially (section 2.1).

Two subfields out of the eight included in ICT account for more than 70% of all Canadian publications in this field: Artificial Intelligence & Image Processing (33%) and Networking & Telecommunications (40%). These two subfields are also those with the highest impact among the eight ICT subfields. However, Canada's highest specialization indexes are for Computation Theory & Mathematics (1.71) and Medical Informatics (1.85) (section 2.1).

At world level, with 49,642 ICT publications between 2003 and 2010, Canada holds the 7th rank among the field's leading countries. In terms of relative effort, its specialization index is the third one among the same countries. As measured by the average of relative citations, Canada shares the 2nd rank with the United Kingdom in terms of scientific impact and its number of publications places it among the top 10 countries in each of the eight ICT subfields: Canada ranks range from 3rd in Medical Informatics to 10th in Artificial Intelligence & Image Processing. In terms of scientific impact (ARC), from one ICT subfield to the other, Canada's rank ranges from the 2nd to the 8th one (section 2.2).

INVENTIVE ACTIVITIES: PATENTS AND TRIADIC PATENTS

Patents indicators are presented from the point of view of the assignees as a measure of intellectual property and also from the point of view of inventors as a measure of inventive activities.

For intellectual property, from 2003 to 2009, the annual number of ICT patents granted by USPTO to Canadian assignees remains stable between 1,000 and 1,200 and increases notably to 1,532 in 2010. On the other hand, the number of patents granted to Canadian inventors increases markedly from about 1,300 patents between 2003 and 2005 to more than 2,700 in 2010. This growth of Canadian ICT patenting activity echoes a similar growth at world level. Thus, the world share of Canadian assignees decreases from 1.6% to 1.4% and the share of Canadian inventors increases from 1.9% to 2.3% (section 3.1).

Using the number of UPSTO patents included in triadic families as an indicator allows capturing the inventions with the highest commercial potential. Contrary to what is seen with USPTO data, triadic data shows that the world share of Canadian assignees is increasing with time, from 0.53% to 0.93% between 2003-2005 and 2006-2010. During the same period, Canadian inventors also increase their world share of ICT triadic patents (section 3.1).

When measured by the number of USPTO patents, Canada is among the top 10 countries in ICT for the intellectual property (country of the assignee) it owns, as well as for its inventive activity (country of the inventor). Using the same criteria, Canada is also among the top 10 countries in each of the four ICT fields. However, the commercial potential of Canadian ICT USPTO patents (as measured by the share of triadic) doesn't appear as good as that of the United States. However, in the Computer field and also in the Other ICT field, the share of triadic in Canadian patents is higher than that of Taiwan and South Korea (section 3.2).

RESEARCH AND DEVELOPMENT

The data from the Natural Sciences and Engineering Research Council of Canada (NSERC) shows that the total grants awarded to computer science rises steadily from $37 million in 2003 to $61 million in 2010. During the same period, the share of CS in NSERC total awarded grants increases from 6.1% to 7.1%. The breakdown of CS grants by programs shows that, over the 2003-2010 period, the most important source of funds is the Discovery Grants program, followed by the Canada Research Chairs and the Strategic Grants. Four Canadian universities each received more than 30 million $ over the 2003-2010 period for CS research projects: the University of British Columbia, the University of Waterloo, Simon Fraser University and the University of Toronto (section 4.1),). It should be noted however that Simon Fraser University's results are largely due to a major NCE grant accounting for about half its total CS research funding.

Regarding business enterprise research and development expenditures (BERD) in the ICT sector, Canada ranks 9th among the leading countries in 2007. However, when the specific CS sector is considered, Canada holds the 5th position among the leading countries. The share of GDP devoted to R&D expenditures by the Canadian ICT manufacturing sector decreases between 1997 and 2005. On the other hand, the share of R&D expenditures in GDP for the Canadian ICT services sector (which includes telecommunications and computer) increases during the same period (section 4.2).

As to the total number of ICT R&D personnel and ICT R&D researchers, Canada ranks respectively 6th and 7th among the leading countries. However, in CS specifically, Canada ranks 2nd as to the total number of R&D personnel, as well as for the number of researchers, just behind the United States (section 4.2).

UNIVERSITY TRAINING PROGRAMS AND HUMAN RESOURCES

The trends in bachelor enrolment and graduation in mathematics, computer and information science programs in Canada clearly suggest an important effect of the information technology bubble; its rise at the end of the 1990s and its burst in 2000 (section 5.1). For graduate studies however, this phenomenon's impact is less clear, since enrolments only stop increasing after 2004. For master programs in the more specific CS field, enrolments are even declining between 2004 and 2008. On the other hand, doctoral enrolment and graduation show a continuous growth from 2000 to 2008 (section 5.2).

With 16 CS graduates per 100,000 population in 2008, Canada is behind most OECD countries. In 2010, Canada is also among the OECD countries showing the smallest share of ICT intensive users in the workforce. On the other hand, the share of ICT-specialist users (workers who create, program, maintain, etc. the ICT) in the Canadian workforce places it among the top 10 leading countries (section 5.3).

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INTRODUCTION

To carry out its mandate of strengthening interactions between the Natural Sciences and Engineering Research Council of Canada (NSERC) of Canada and the Canadian academic CS research community, NSERC recently established the Computer Science Liaison Committee (LC). In cooperation with the Canadian Association of Computer Science / *Association d'informatique canadienne* (CACS/AIC), this committee has, as one of its first tasks, to assess the current and future state of CS research in Canada and at the international level. In this context, the committee has formulated the eight following questions:

1. *How does Canadian CS fare in an international comparison? What is the impact of Canadian CS research: nationally and internationally? In which sub-disciplines of CS does Canada excel?*
2. *What are the distinguishing features of CS research vs. that of other disciplines?*
3. *How does the publication pattern in CS differ from that of other disciplines (impact factors of CS journals vs. other disciplines, publication in refereed conferences vs. journal publications, highly specialized working groups and workshops, patents, and technology transfers)? What indicators can be used to assess the quality of the venues used by the CS community?*
4. *What collaboration networks currently involve CS researchers?*
5. *In what ways does CS research support the current Canadian S&T strategy, as defined in Mobilizing Science and Technology to Canada's Advantage[1]?*
6. *What is the impact of CS research on the IT industry (nationally and internationally)?*
7. *How does CS funding compares to funding of other areas in NSE?*
8. *What are important directions for CS research in the future, as witnessed e.g., by government initiatives and coordinated efforts world-wide (Asia, Europe, Americas)?*

Asked by the Liaisons Committee to submit a proposal for a study on these questions, the *Observatoire des sciences et des technologies* (OST) has suggested concentrating on data that is already available to provide answers to questions #1, #2, #3, #4, #6 and #7. Using information from a large variety of sources, this study shows the relative importance of Canadian CS in the world, as well as the main trends of its development in the Canadian context. Since CS is part of the larger field of Information and Communication Technologies (ICT), several statistics presented in this report are related to the latter and thus give a sense of the larger context in which evolve the CS. As far as possible, however, those ICT statistics are also broken down by subfields in order to better capture the specific trends associated with CS.

After the description of the data sources and the indicators used in this study, we first examine Canadian scientific publications in the field of ICT and its eight subfields. From this point of view, we compare the Canadian performance to that of other top countries in the field on the volume of publications, specialization index and citations analysis. Along the same line, the third section presents data on ICT patents which allow to characterize the Canadian production and to compare it to the production of other top countries. The fourth section presents data on research and development in CS: we measure the evolution of CS research funding from 2003 to 2010 and we identify the main performing Canadian institutions through an analysis of the Natural Sciences and Engineering Research Council of Canada (NSERC) grants. We also compare Canada to other top countries in CS R&D through an analysis of OECD data. Finally, the last section presents Canadian and international data on the training and employment of human resources in CS.

The overall picture emerging from our findings shows that the field of CS has maintained its growth in Canada during the first decade of the 21st century despite some apparent slowdowns in scientific publications and undergraduate training. At world level, Canada is among the leading countries in CS.

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[1] http://www.ic.gc.ca/eic/site/ic1.nsf/eng/00871.html

1 METHODS: DATA SOURCES AND INDICATORS

1.1 Scopus bibliometric database

This part of the study is made in collaboration with Science-Metrix, which computed all bibliometric indicators using the Scopus database (Elsevier). These indicators cover the whole field of Information and Computer Technology (ICT) as defined in Science-Metrix's journal classification. This definition of the ICT field includes 580 scientific journals as well as more than 2,200 conferences proceedings. This field can be broken down into the eight following subfields: 1) Artificial Intelligence & Image Processing, 2) Computation Theory & Mathematics, 3) Computer Hardware & Architecture, 4) Distributed Computing, 5) Information Systems, 6) Medical Informatics, 7) Networking & Telecommunications and 8) Software Engineering.

Data includes the following documents types: articles, conference papers, reviews and short surveys (short surveys are similar to reviews but are typically shorter). The leading countries are identified using the number of ICT publications they produced during the studied period (2003-2010). It should be noted that publications signed by authors from more than one country (international collaboration) are counted as one complete publication for each of the participating countries. In other words, we don't use fractional counting, but whole counting. The performances of leading countries are also assessed using the following two indicators:

Average of Relative Citations (ARC): This indicator is based on papers' citation counts, providing a direct measure of scientific impact. The indicator is normalized to account for different citation patterns across scientific fields and subfields and for differences in the age of papers. When the ARC is above 1, an entity (e.g., country, institution) scores better than the world on average; when it is below 1, an entity publishes papers that are not cited as often as the world average.

$$\boldsymbol{ARC} = \frac{\sum_{p=1}^{n} \frac{X_{psy}}{\bar{X}_{sy}}}{N}$$

Where:

X_{psy} = Number of citations received by the paper (p) of the speciality (s) published in a given year (y);

$\bar{X}_{sy}$= Average number of citations by papers of the speciality (s) published in the same year (y);

N = Total number of papers (of a given country or institution).

- **Specialization index (SI):** This indicator is a measure of the relative effort that an entity invests in a field, compared to the world's average effort in the same field. A S.I. value above 1 means that a given group of researchers is specialized compared to the world average, while an index value below 1 means the opposite.

$$\boldsymbol{SI} = \frac{(X_s/X_t)}{(N_s/N_t)}$$

Where:

X_s = Number of papers from entity X in a given research speciality (e.g., Canadian papers in Computer Sciences);

X_t = Total number of papers from entity X in a reference set of papers (i.e., Canadian papers in Scopus database);

N_s = Number of papers from the reference entity N in a given research specialty (e.g., World papers in Computer Sciences);

N_t = Number of papers from the reference entity N in a reference set of papers (i.e., World papers in Scopus database).

Two other indicators on Canadian publications are also presented in this report:

- **International collaboration:** Papers in international collaboration bear the addresses of at least two different countries. The rate is calculated by dividing the number of papers written in international collaboration by an entity by its total number of papers.
- **Canadian national inter-institutional collaboration:** Papers written in inter-institutional collaboration bear the addresses of at least two different Canadian institutions. The rate for a given entity is calculated by dividing the number of papers written in inter-institutional collaboration by its total number of papers.

It should be noted that complementary bibliometric indicators are provided in the Excel workbook named "SM_Databook_UQAM_Computer_Science_Liaison_Committee_v2.xlsx" accompanying this report:

- **Average relative impact factor (ARIF)**: This indicator provides an indirect measure of scientific impact based on the impact factors of journals in which papers are published. When the ARIF is above 1, it means that an entity scores better than the world average; when it is below 1, it means that, on average, an entity publishes in journals that are not cited as often as the world average.

$$ARIF = \frac{\sum_{p=1}^{n} \frac{X_{psy}}{\bar{X}_{sy}}}{N}$$

Where:

X_{psy} = Impact factor of the paper (p) of the speciality (s) published in a given year (y);

$\bar{X}_{sy}$ = Average impact factors of papers of the speciality (s) published in the same year (y);

N = Total number of papers (of a given country or institution).

- Distribution by country of citations to Canadian ICT papers; comparison of observed number of citations per country with expected values to take into account the variability in country size.
- Matrix of provincial cross-citations in ICT.

Also, while the tables and figure of the present report mostly show the top ten countries in ICT (since Canada is always among the top ten), this workbook presents the results for the top 20 countries.

1.2 USPTO and OECD Triadic Patent Databases

Patent indicators are good proxy measures of the inventive activity and they also provide valuable insights into the development of intellectual property.

Two databases are used in this report for the production of patents indicators: 1) The United States Patent and Trademark Office (USPTO) database and 2) the triadic patent family database developed by OECD[2]. The main advantage of USPTO database is that it offers a good coverage of patented inventions produced all around the world. Indeed, since the American market is one of the largest single market in the world, if not the largest one, the owners of inventions have a strong incentive to seek a protection in this market and hence, to get a patent at USPTO. Since they are close neighbors, Canadians are strongly inclined to seek protection at USPTO for their invention. However, patent data of national offices such as the USPTO presents two problems. Firstly, alongside quite valuable inventions, there are also numerous inventions of low commercial potential. Secondly, innovations from inventors residing in the country of the intellectual property office tend to be overrepresented in the data of national offices such as USPTO; creating what is called a "home advantage". Indeed, the first step of most inventors is to protect their inventions on their national market and often, when the commercial potential of their inventions does not justify a protection on foreign markets, the patent granted by the national office will be the only one issued and no other foreign protection will be sought. Hence, in any given national patent office, inventions from residing inventors or owned by residing assignees tend to be overrepresented.

Triadic patents families correct, at least in part, these two problems. Triadic families are series of corresponding patents filed at the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO) sharing a common priority application. Since getting protection for a single invention at three distinct offices (US, EU and Japan) is costly, triadic patent families tend to isolate high-value patents. Since they cover a very large and international market (United States, Europe and Japan), the other benefit of using the triadic families is to avoid the aforementioned "home-advantage" encountered with the data from national IP offices such as USPTO. Thus, they allow for more accurate comparisons between countries.

However, triadic families also have their drawback. Because of the way they are constituted (application at Japan and EU offices BUT grant at USPTO), patent families generally become complete at the grant of the USPTO patent since it is usually the process requiring the most time. Obviously, because of the time lag between the applications and the grants, several months could have elapsed between the deposit of the first application (the so-called priority application) and the moment a family becomes complete. This has the effect of decreasing the number of patents families near the end of the period. One should not account this for a decrease in patenting activities but only as an effect of the methodology. Hence, recent data should be interpreted with carefulness.

Along the same line, it should be noted that the annual number of patents delivered by USPTO (or any other patent office) is not only related to the number of inventions produced and application filed, but also to the work pace in the treatment of applications. At USPTO for example, the total annual number of issued patents remains between 140,000 and 170,000 between 2003 and 2009 and suddenly increases to 216,000 in 2010, due in part to administrative changes to accelerate the treatment process of backlogged applications. Annual variations should therefore be interpreted with cautious. Nevertheless, over a long period, it does reflect a true increase of inventive activities.

In order to capture the patents in computer technologies, we use a definition of Information and Communication Technologies (ICT) patents developed by OECD and based on the World Intellectual Property Office's (WIPO) International Patent Classification (IPC)[3]. This definition categorizes ICT patents in 4 sub-groups:

- Telecommunications
- Consumer Electronics

[2] http://www.oecd-ilibrary.org/science-and-technology/triadic-patent-families-methodology_443844125004

[3] From http://www.oecd.org/dataoecd/5/19/37569377.pdf, p.15

- Computers, Office Machinery
- Other ICT

Of course, patents indicators do not necessarily cover all the computer related inventions, but it should be noted that patenting is more and more used in ICT industry, even for software[4].

Using OECD definition of ICT, the performances of Canada and other leading countries are measured with the following indicators:

- **Number of USPTO patents:** Number of utility patents granted by USPTO between 2003 and 2010, by the year they were issued. It should be noted that patents involving inventors or assignees from more than one country are each counted as one complete patent for each participating country. As for publications, we use whole counting for patents.

- **Number of USPTO patents included in triadic patent families:** This indicator also refers to utility patents granted between 2003 and 2010, according to the year they were granted at USPTO. As mentioned above, triadic patent families allow for more accurate comparisons between countries.

- **Share of USPTO patents included in triadic families:** By definition, every triadic patents family counts one (or more) UPTSO patents. On the other hand, not every USPTO patent is a member of a triadic family: only those protecting inventions with high commercial potential are worth the expenses of seeking protection on 3 distinct markets. The share of triadic patent among all USPTO patents is then an indicator of the relative value of inventions produced by different countries and patented in United States.

For these indicators, the data series are presented by the country of the inventors (as a measure of the inventive activity) and by the country of the assignees (as a measure of intellectual property). They are presented for the field of ICT as a whole and by its subfield.

- **Number of patents by institutional sector:** Number of Canadian institutionally-owned utility patents, distributed by an institutional sector attributed by OST during the standardization of the raw data.

It should be noted that complementary technometric indicators are provided in the Excel workbook named "Patents_Statistics_V2.xlsx" accompanying this report.

- Specialization index (SI): This is an indicator of the intensity of patenting activities of countries and institutional sectors in ICT in relation to the global intensity (world total) in the same domain. A SI value above 1 means that a given group of researchers is specialized compared to the world average, while an index value below 1 means the opposite.

- Number of patents with co-invention: Co-invention is defined by the presence of at least two inventors on the same patent. We ventilate this indicator by the country of the inventors and the year of grant.

- Number of co-owned patents: Co-ownership is defined by the presence of at least two assignees on the same patent. This indicator is broken down by the country of the inventors and the year of grant.

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[4] Norhème Chabchoub and Jorge Niosi, "Explaining the Propensity to Patent Computer Software", Technovation, vol 25, 2005, 971-978.

1.3 Natural Sciences and Engineering Research Council of Canada (NSERC) Awards database

Data on CS research funding awarded by NSERC are drawn from the Council's Awards Search Engine (1991-2010). Grants in CS are identified using the following method, developed in collaboration with the Computer Science Liaison Committee.

First, we selected all the grants awarded between 1991 and 2010 by the four following committees, which are known as CS committees:

- #7 – Computing and Information Science – From 1978 to 1999
- #330 – Computing and Information Sciences A – From 2000 to 2009
- #331 – Computing and Information Sciences B – From 2000 to 2009
- #1507 – Computer Science – Since 2010

Since the researchers who obtained one or several grants from these committees can be considered as computer scientists, we picked in a second step, all the grants they received, regardless of the committees that awarded them. This procedure allows us to also retrieve grants awarded for CS projects by committees that are not specifically dedicated to CS, such as the various partnership or strategic committees, the research chairs committees, the committee of the Networks of Centres of Excellence, and so on.

However, since there is no personal identifier for researchers in the database, this second step also retrieved numerous grants belonging to homonyms of CS researchers. In order to correct that problem, we manually cleaned the dataset by identifying these homonyms and removing their grants.

In order to assess the structure of CS research funding across NSERC programs, we also implemented a grouping of programs into the 6 following classes:

1. Canada Research Chairs
2. Networks of Centres of Excellence
3. Industrial Research Chairs
4. Strategic Grants
5. Collaborative Research and Development Grants
6. Other Grants

From this dataset, we compiled the following indicators for the 2003-2010 period:

- **Amount of CS grants:** It should be noted that the statistics are presented by fiscal year and not by competition year, which means that the amounts refer to the payments made each year by the Council. Also, since fiscal years cross calendar years, we should precise that the covered period goes from 2003-2004 to 2010-2011.

- **Share of CS grants in total NSERC grants:** Expressed in percentage, this indicator shows the relative importance of CS in NSERC priorities and funding.

1.4 OECD Data on industrial Research and Development

First, it should be mentioned that OECD statistics on R&D are collected and compiled according to the methods of the Frascati manual, thus ensuring their international comparability.

OECD offers several sources of data on R&D expenditures and personnel but the biannual publication series called *Information Technology Outlook* provides valuable information specifically on ICT. Among others, it gives an operational definition of the ICT sector based on the *International Standard Industrial Classification* (ISIC, rev.3.1). As shown in Table 1-1,

Table 1-1 Definition of the ICT Sector Used for R&D Expenditures and Personnel Statistics

Code (ISIC)	Title
	ICT Manufacturing
30	Office, accounting and computing machinery
32	Radio, television and communication equipment
33	Medical, precision and optical instruments
	ICT Services
642	Telecommunications
72	Computer and related activities

Sources : OECD Information Technology Outlook: 2010, p.294

From this definition, we extracted a more computer-specific definition that includes only the service sector of "computer and related activities" (code ISIC # 72). Using the various data sources provided by OECD, we selected the data on R&D expenditures and personnel according to these two definitions: the first, broad one is labelled as "ICT sector" and includes the five classes of Table 1-1 and a second, narrower definition labelled "Computer and related activities" only including class # 72.

Using these definitions and the various data sources, we tried to retrieve data for the most recent period available. Two broad indicators are presented here:

- **Business Enterprise R&D (BERD) Expenditures:** R&D expenditures in ICT and computer sectors are presented according to the purchasing power parity of each country, as a percentage of GDP and as a share of the total BERD.

- **Business Enterprise R&D (BERD) Personnel:** Data on R&D personnel is expressed in full-time equivalent (FTE). This report presents the data for total R&D personnel and for the subgroup of researchers in ICT and Computer sectors. In each case, we present the raw numbers of FTE personnel and the share that ICT and Computer sectors represent in the total BERD.

1.5 Data on Education in Computer Sciences

In order to get the most accurate picture of university studies in computer sciences, we used two information sources:

The first one is the *Postsecondary Student Information System* (PSIS) which is a national survey conducted annually by Statistic Canada. PSIS provide data on enrolments and graduations for all Canadian public postsecondary institutions. We accessed PSIS data through two distinct sources. For data on undergraduate studies, we relied on CANSIM database (Table series 477-0019, 477-0020) and for data on graduate studies; we had access to custom tabulations provided by Statistic Canada to the Canadian Association of Graduate Studies (CAGS).

PSIS data is collected according to the Classification of Instructional Programs (CIP) which contains several classes related to computer sciences. To the extent of available information, we tried to select the classes representing computer sciences as precisely as possible but we had to compromise in certain circumstances.

For example, the disciplinary classification offered in the various CANSIM tables only counts 13 larges classes called "Primary Groupings" and the tool does not allow for further breakdown. Hence, for data on undergraduate studies, we selected the primary grouping #7 "Mathematics, Computer and Information Science (MCIS)" which is the only relevant one even though it includes disciplines more or less related to computer sciences such as mathematics and library science (Table 1-2).

Table 1-2 CIP Classes Selected for the Production of Statistics on University Education in Computer Sciences in Canada

Primary Groupings		Constituent CIP Series and Subseries	
Code	**Title**	**Code**	**Title**
7	**Mathematics, Computer and Information Sciences (MCIS)**	27.	Mathematics and Statistics
		30.08	Mathematics and Computer Science
		11.	Computer and Information Sciences and Support Services
		30.06	Systems Science and Theory
		25.	Library Science

Source: Statistic Canada, Classification of Instructional Programs (2000) and Special Aggregation Structure—Primary Groupings.

Table 1-3 Subseries of Computer Sciences Series in CIP

Code	Title
11.	**Computer and Information Sciences and Support Services**
11.01	Computer and Information Sciences and Support Services, General
11.04	Information Science/Studies
11.05	Computer Systems Analysis/Analyst
11.07	Computer Science
11.08	Computer Software and Media Applications
11.10	Computer/Information Technology Administration and Management

Source: Statistic Canada, Classification of Instructional Programs (2000).

On the other hand, our data on graduate studies are much more detailed, allowing the selection of classes specific to computer sciences. So, to begin we present data on graduate studies by using the same classes as the one used for the undergraduate level (MCIS, Primary group #7), thus providing a consistent data series from undergraduate to graduate studies. In a second step, we focus on constituent code #11 (Computer and Information Sciences and Support Services) which is much closer to computer science in its strict sense (see details Table 1-3).

As for the levels of studies, the data on undergraduate studies presented in this report refers to bachelor degrees only (excluding certificates and other short programs), while data on graduate studies includes only Masters and PhD programs. We focus on those levels because they are comparable across provinces and countries.

The second source of information on computer science education is OECD Education and Skills dataset which provides comparative international data on Computer sciences education. This database uses the International Standard Classification of Education (ISCED) which defines comparable level and disciplines. Data presented in this report focuses on levels 5A (corresponding to bachelor and master degrees in Canada) and on level 6 - Advanced Research Qualifications (corresponding to PhD in Canada). As for the field of study, it focuses on the class #480 "computing".

1.6 ICT Skills in Workforce

ICT skills in workforce are measured using categories built by OECD from a selection of occupations (or classes) in the International Standard Classification of Occupation (ISCO 88) and from other national occupational classifications. Two definitions are provided (see Table 1-4): a narrow definition that only includes specialists whose job is directly related to ICT; such as computing professionals, computer systems analysts and scientists, programmers, information systems and data processing managers, electrical and electronics engineers, computer engineers, electrical and electronics engineering technologists and technicians, and so on. A broader definition includes jobs that use ICT as an essential component of everyday work, but that are not specifically dedicated to ICT, such as scientists and engineer and even office worker. Jobs that use ICT only as ancillary tools and those that do not use them are excluded.

Table 1-4 OECD ICT categories in employment

Three categories of ICT competencies are distinguished:	**Narrow measures - ICT specialist**	**Broad measure - Intensive ICT user**
1. ICT specialists: who have the ability to develop, operate and maintain ICT systems. ICTs constitute the main part of their job – they develop and put in place the ICT tools for others.	X	X
2. Advanced users: competent users of advanced, and often sector-specific, software tools. ICTs are not the main job but a tool.		X
3. Basic users: competent users of generic tools (e.g. Word, Excel, Outlook, PowerPoint) needed for the information society, e-government and working life. Here too, ICTs are a tool, not the main job.		X

Source: OCDE (2005), "New perspectives on ICT skills and employment", p.6. This report uses the first category for the narrow measure of ICT-skilled employment, and the sum of all three categories for the broad measure of ICT-skilled employment.

Of course, these statistics do not provide a picture of the employment of computer scientists, but it gives a measure of the relative importance and needs in the economy for the knowledge and skills developed by them (at least in part). It is, in a certain way, an indicator of the impact of computer science research and education in the society.

2 SCIENTIFIC PUBLICATIONS

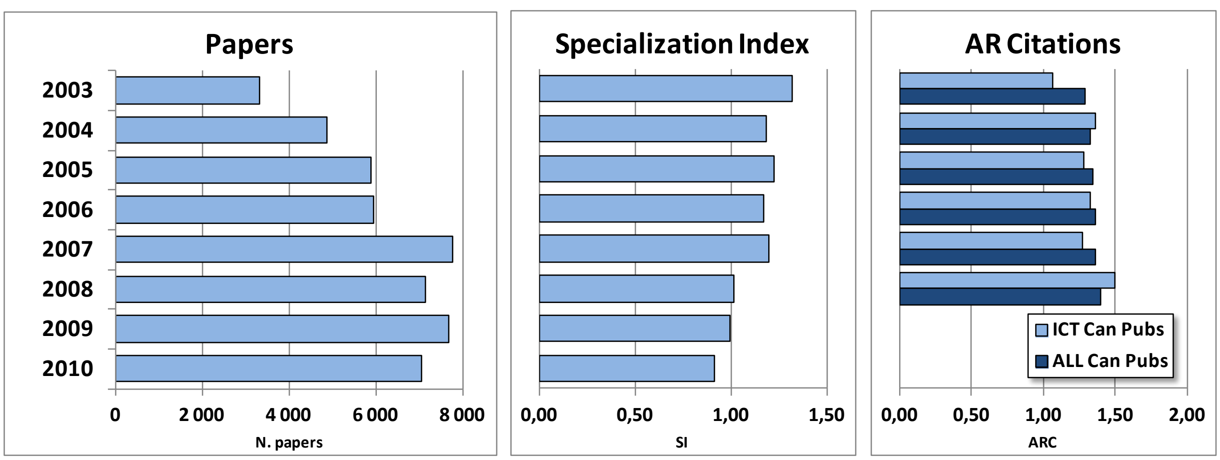
In a first step, this section examines the production of Canadian ICT publications over the 2003-2010 period; the evolution of the volume of production, the scientific impact, the international collaboration and the specialization of Canada in this field. With the same indicators, we also examine the 8 subfields constituting the ICT field. In a second step, Canadian scientific production is compared with that of other leading countries. These comparisons are made for the ICT field as a whole as well as for each of its 8 subfields.

2.1 Canadian Publications in ICT

Figure 2-1 presents data on Canadian publication for ICT as a whole from 2003 to 2010. It shows that:

- The annual number of Canadian ICT papers grows from 3,332 in 2003 to 7,765 in 2007 and remains between 7,000 and 7,700 ever since;
- The specialization index, which was relatively high in 2003 (SI= 1.32), decreases steadily since that time to 0.92 in 2010. Hence, Canada is in 2010 under-specialized in ICT while it was quite specialized only seven years before..
- On the other hand, the impact of Canadian ICT publications grows over time. Their average of relative citations (ARC) grew from 1.06 in 2003 to 1.50 in 2008; meaning that their impact is 50% higher than the world average. Moreover, it should be noted that the ARC of Canadian ICT publications is slightly lower than the ARC calculated for all Canadian publications from 2003 to 2007, but it is higher in 2008 at 1.50 (for ICT) against 1.40 (for all publications).

Figure 2-1 Annual Indicators for Canadian Publications in ICT, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

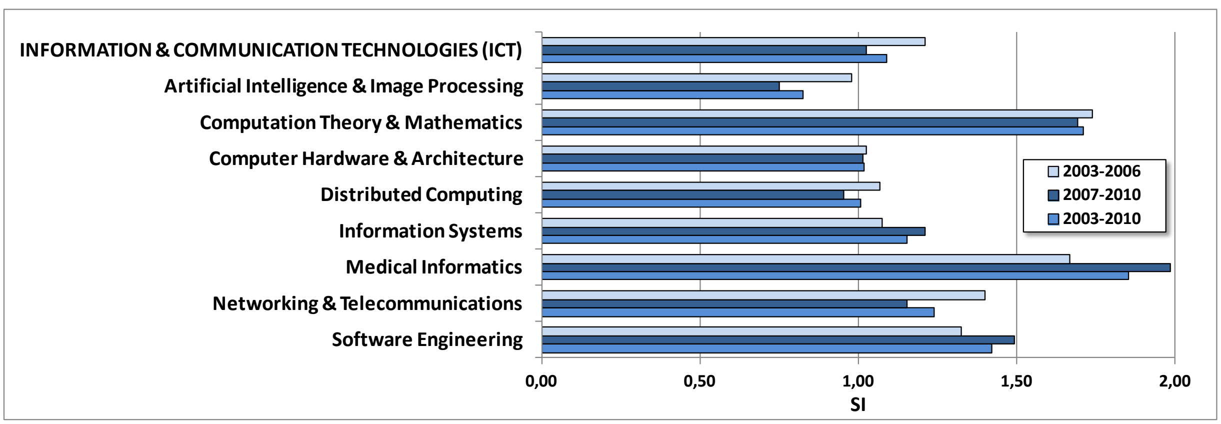
Table 2-1 Annual Number of Publications in ICT by Subfield, Canada, 2003-2010

Number of Publications	2003	2004	2005	2006	2007	2008	2009	2010	All Year
INFORMATION & COMMUNICATION TECHNOLOGIES (ICT)	**3 332**	**4 874**	**5 871**	**5 950**	**7 765**	**7 128**	**7 670**	**7 052**	**49 642**
Artificial Intelligence & Image Processing	1 086	1 577	1 883	2 028	2 340	2 319	2 665	2 412	16 310
Computation Theory & Mathematics	382	373	443	529	493	582	666	500	3 968
Computer Hardware & Architecture	80	168	155	163	170	201	197	185	1 319
Distributed Computing	58	115	144	155	160	136	93	98	959
Information Systems	124	200	234	314	378	338	324	386	2 298
Medical Informatics	88	134	158	194	204	236	297	247	1 558
Networking & Telecommunications	1 299	1 956	2 445	2 160	3 463	2 794	2 850	2 724	19 691
Software Engineering	215	351	409	407	557	522	578	500	3 539
Percentage of ICT Publications									
INFORMATION & COMMUNICATION TECHNOLOGIES (ICT)	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Artificial Intelligence & Image Processing	33%	32%	32%	34%	30%	33%	35%	34%	33%
Computation Theory & Mathematics	11%	8%	8%	9%	6%	8%	9%	7%	8%
Computer Hardware & Architecture	2%	3%	3%	3%	2%	3%	3%	3%	3%
Distributed Computing	2%	2%	2%	3%	2%	2%	1%	1%	2%
Information Systems	4%	4%	4%	5%	5%	5%	4%	5%	5%
Medical Informatics	3%	3%	3%	3%	3%	3%	4%	4%	3%
Networking & Telecommunications	39%	40%	42%	36%	45%	39%	37%	39%	40%
Software Engineering	6%	7%	7%	7%	7%	7%	8%	7%	7%

Source : Computed by Science-Metrix using the Scopus database (Elsevier).

The breakdown by subfield of Canadian ICT publications (Table 2-1) shows that two subfields account for more than 70% (with 36 001 publications) of the total 2003-2010 production in that field: Networking & Telecommunications (16 310 for 40%) and Artificial Intelligence & Image Processing (33% with 19 691 publications). The third and fourth most important subfields are Computation Theory & Mathematics (8%) and Software Engineering (7%) with respectively 3 968 and 3 539 publications, but still far less than the first and second position.

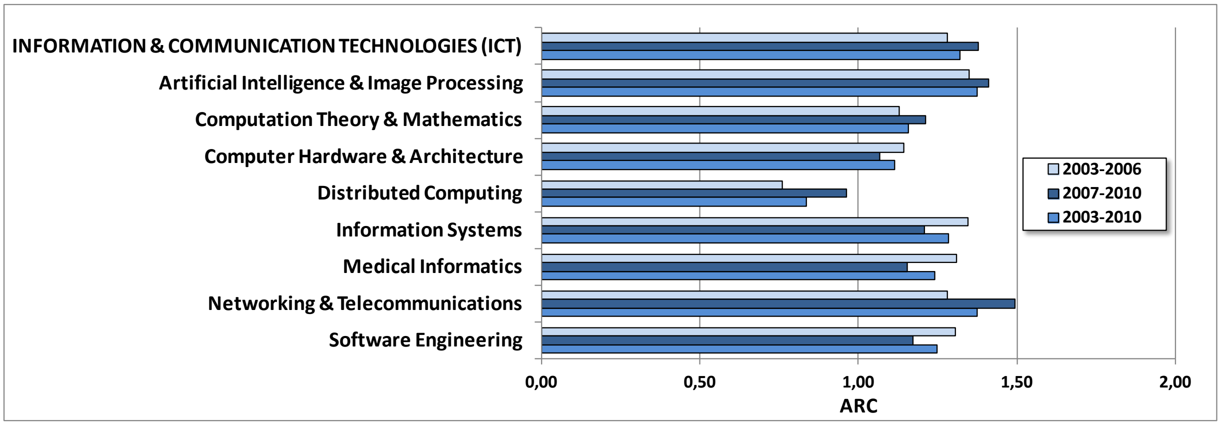
Figure 2-2 Specialization Index in ICT by Subfield and Four-Year Period, Canada, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

However, Canadian relative effort (Figure 2-2) appears lower than the world average for the subfield Artificial Intelligence & Image Processing (0.83 over the 2003-2010 period) but it is quite higher for Medical Informatics (1.85), Computation Theory & Mathematics (1.71) and Software Engineering (1.42). For five subfields out of eight, the specialization index is decreasing over time, while it increases for Information Systems, from 1.07 in 2003-2006 to 1.21 in 2007-2010, for Medical Informatics (from 1.67 to 1.98) and Software Engineering (from 1.33 to 1.49).

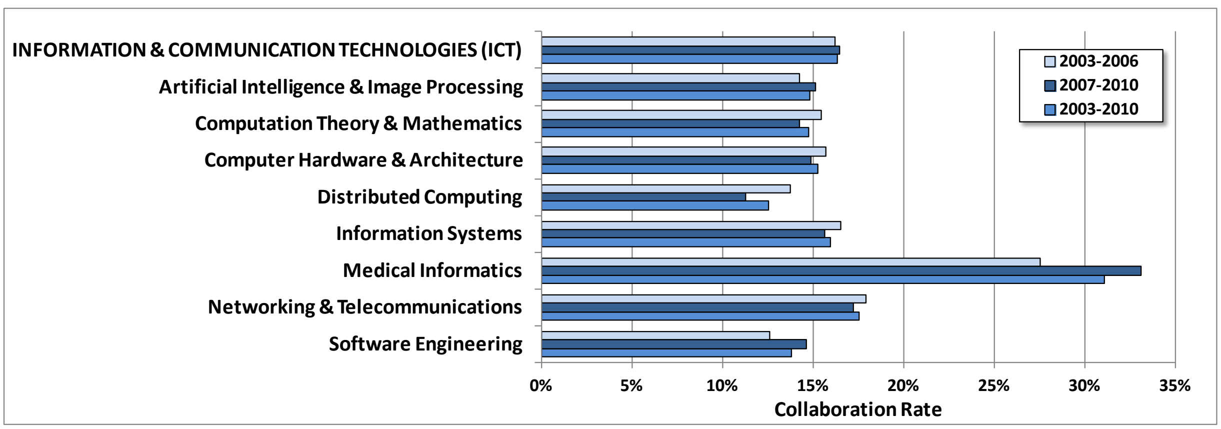
Figure 2-3 Average of Relative Citations of Publications in ICT by Subfield and Four-Year Period, Canada, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

The Figure 2-3 shows that the scientific impact of Canadian publications in ICT is well above the world average (1.32 for the 2003-2010 period), as are each of its constituting subfields, with the exception of Distributed computing (0.84 for the 2003-2010 period). The two subfields with the highest ARC are Networking & Telecommunications (1.38) and Artificial Intelligence & Image Processing (1.38). It should also be noted that these two subfields increase their ARC between the two periods, as does Computation Theory & Mathematics (from 1.13 to 1.21).

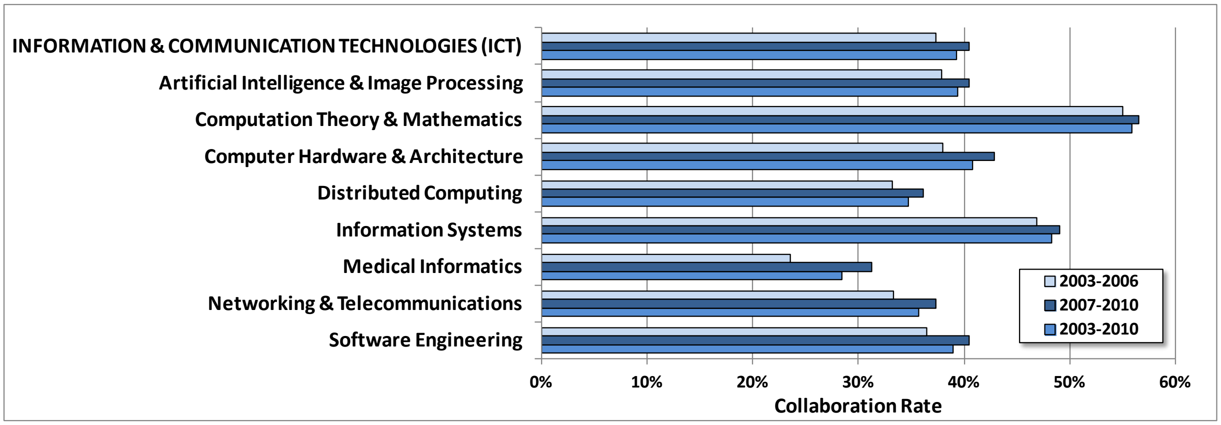
Figure 2-4 Interinstitutional Collaboration Rate in ICT by Subfield and Four-Year Period, Canada, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

Figure 2-4 shows that Canadian interinstitutional collaboration rate appears to be somewhat low for the ICT field as a whole (16% for the 2003-2010 period) when compared to the rate calculated on all Canadian publications (25%). However, it should be explained that interinstitutional collaboration is less frequent in natural sciences and engineering and more frequent in life and health sciences (see the Excel file SM_Databook... table X provided with this report). In this respect, one should note the higher rate of Medical Informatics (33% for the 2007-2010 period).

Figure 2-5 International Collaboration Rate in ICT by Subfield and Four-Year Period, Canada, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

On the other hand, Figure 2-5 shows that international collaboration is much more frequent. The rate for the ICT field is 39% for the period under study (2003-2010). For some subfields, this rate is even higher: Computation Theory & Mathematics shows a rate of 56% while it is 48% for Information Systems. We should also note that it tends to increase over time for all ICT subfields, as it does also for all Canadian publications.

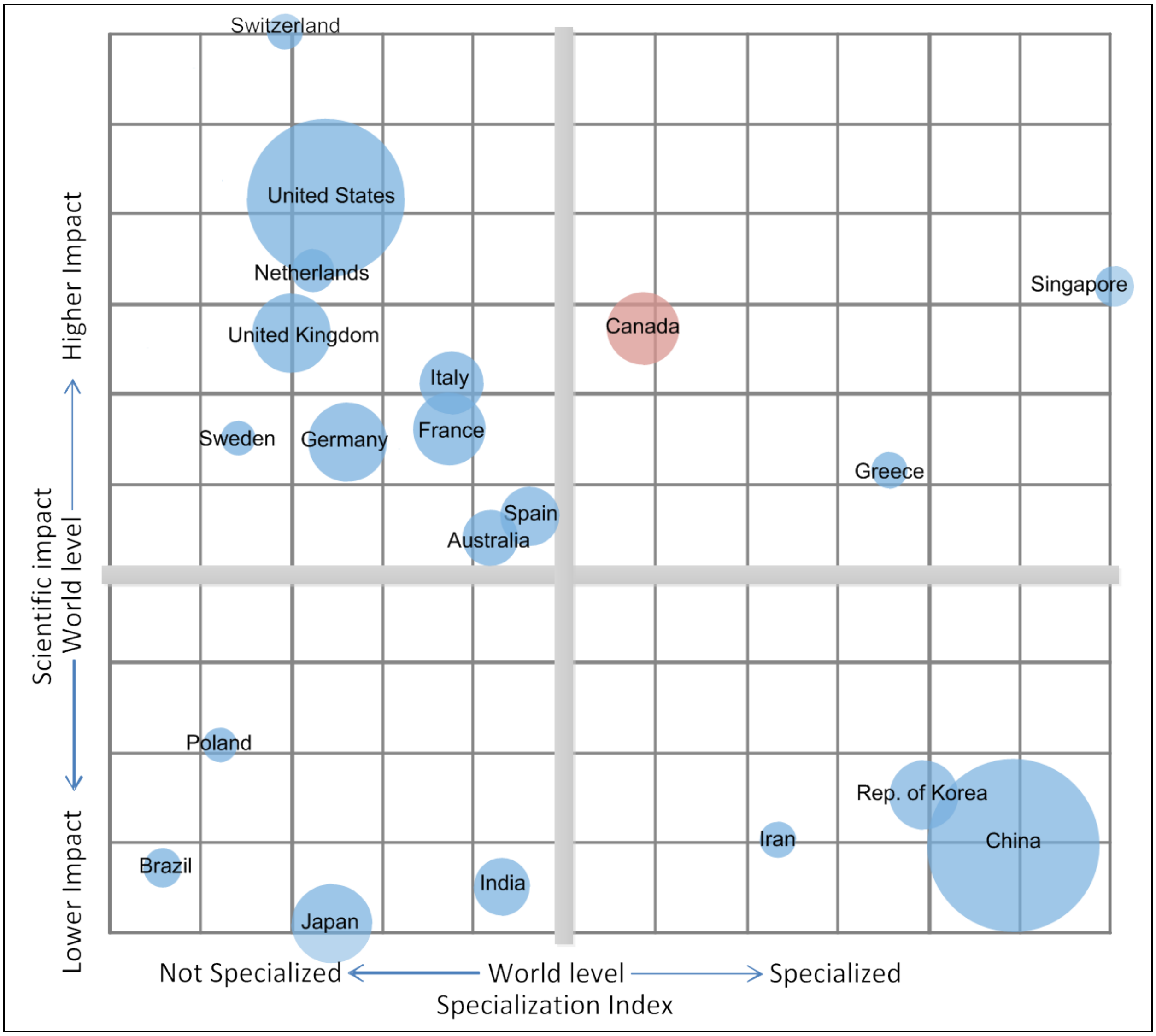
2.2 International Comparisons

The Figure 2-6 (page 15) presents a positional analysis of the publications of the top 20 countries in ICT (based on the number of publications) for the whole period (2003-2010). The size of the circles corresponds to the number of papers, while scientific impact (ARC) is on the horizontal axis and specialization index (SI) is on the vertical axis. For both ARC and SI, the gray line corresponds to the world average. Appearing in the upper right part of the figure, Canada is then specialized in ICT and had, at the same time, a scientific impact higher than the world average. Singapore is the only other country which has both a higher specialization index (SI) and a higher Average of Relative Citations (ARC) than Canada.

The Figure 2-6 also shows that while other western countries are not specialized in ICT, their scientific impact is higher than the world average. The United States, the Netherlands and Switzerland present higher impacts, but lower specialization than Canada. Reciprocally, China, South Korea, Greece and Iran are more specialized than Canada, but their publications have lower scientific impact.

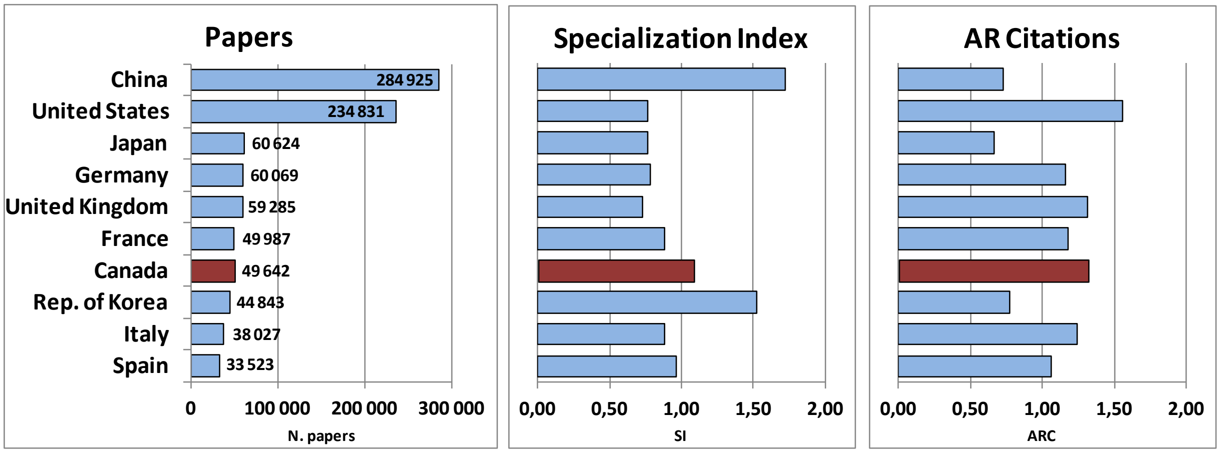
The following nine (9) figures focus on the top ten countries in terms of number of publications for the ICT field as a whole, as well as for its 8 subfields.

Figure 2-6 Positional analysis of the top 20 countries in ICT, 2003-2010



Number of papers (area of circles), scientific impact (ARC), specialization index (SI)
Source: Computed by Science-Metrix using the Scopus database (Elsevier).

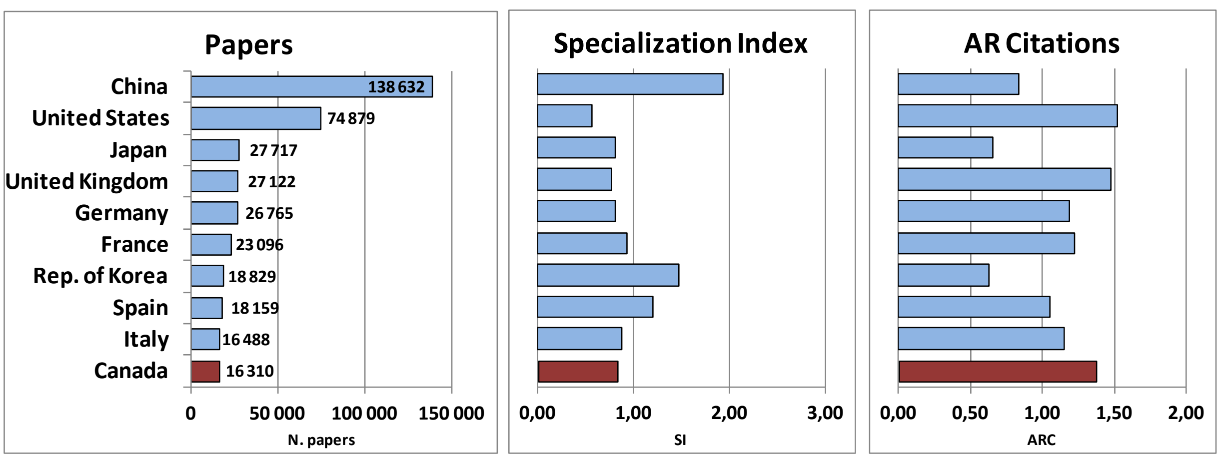
Figure 2-7 Publications in ICT, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

Figure 2-7 shows that with 49,642 ICT publications between 2003 and 2010, Canada ranks in seventh place, well above Korea (44,843) and just behind France (49,987). In terms of specialization, Canada is third among the top 10 countries, behind China and Korea. Canada's scientific impact (ARC= 1.32) is lower than the United States' (1.56), but is on par with that of the United Kingdom and well above the other top 10 countries.

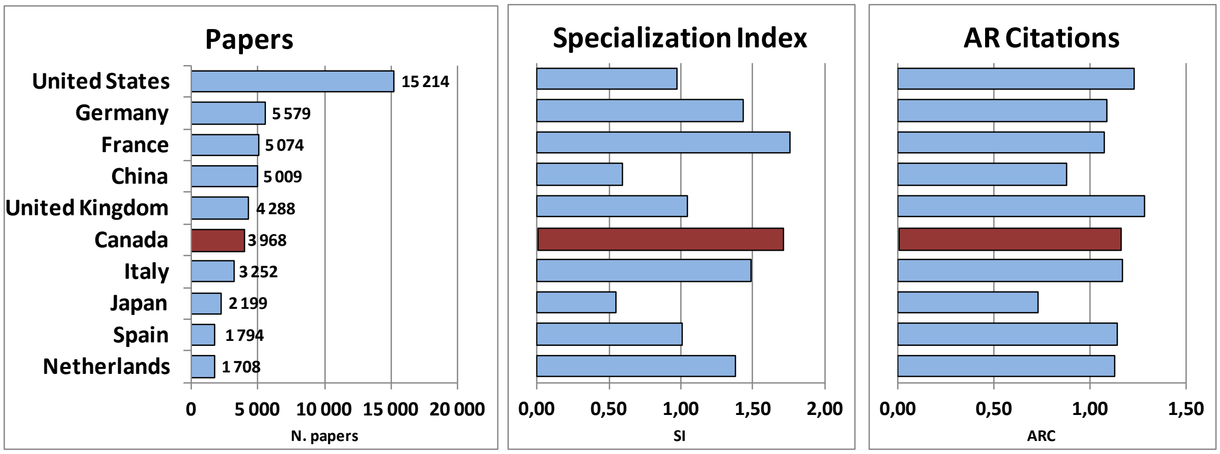
Figure 2-8 Publications in Artificial Intelligence & Image Processing, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

In the second largest ICT subfield: Artificial Intelligence & Image Processing (Figure 2-8), Canada ranks last in the top 10 countries in terms of publication volume. Its specialization index is also lower than the world average but one should note that it is also the case for the majority of these top 10 countries. Indeed, only China, Korea and Spain have a specialization index above the world average (1.0). As for scientific impact however, Canada ranks third (1.38), behind the United Kingdom (1.48) and the United States (1.52) but is well above France (1.23), fourth in terms of impact.

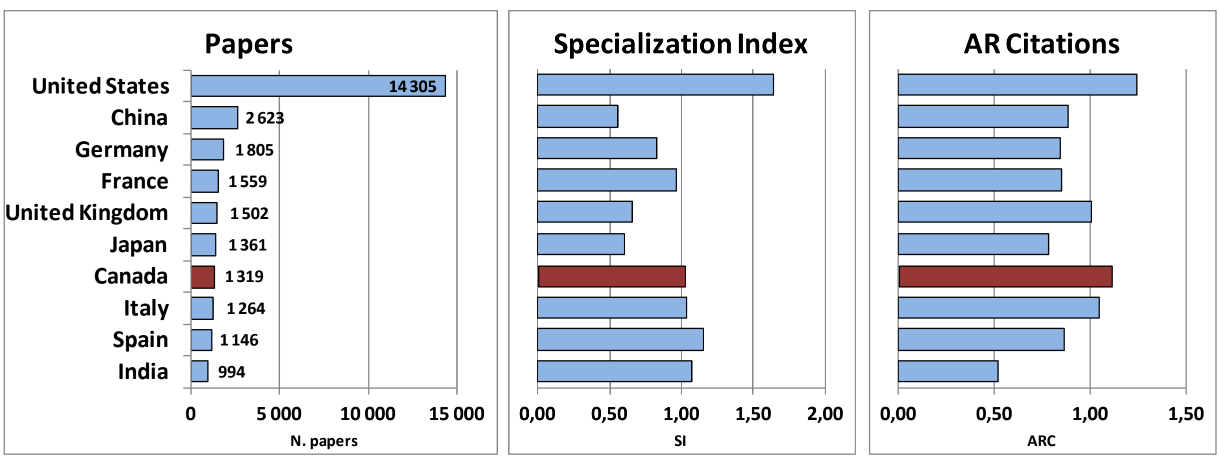
Figure 2-9 Publications in Computation Theory & Mathematics, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

In the subfield of Computation Theory & Mathematics (Figure 2-9), Canada ranks sixth with 3,968 papers between 2003 and 2010. Since this subfield does not account for a very large number of publication at the world level, Canada's relative effort (SI= 1.71) is the second highest of the top 10 countries, just behind France (1.76). In terms of scientific impact, with an ARC of 1.16, Canada holds the fourth place, behind Italy (1.17), the United States (1.23) and the United Kingdom (1.28).

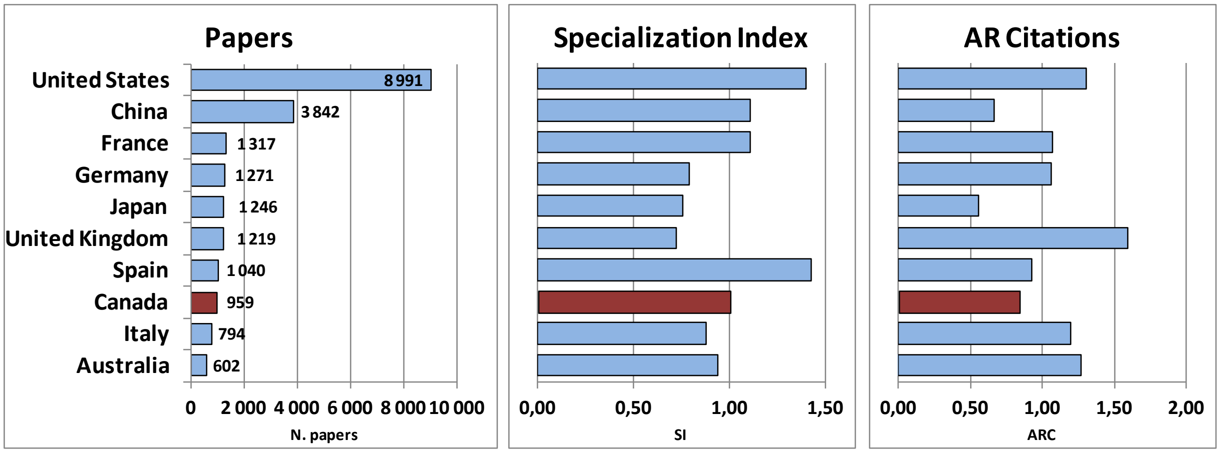
Figure 2-10 Publications in Computer Hardware & Architecture, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

With 1,319 papers for the 2003-2010 period, Canada occupies the seventh place among the top ten countries in the subfield of Computer Hardware & Architecture (Figure 2-10). Its relative effort (SI = 1.02) in this subfield is almost equal to the world average, meaning that it is neither specialized nor under-specialized. In terms of scientific impact, Canada (1.11) holds the second place after the United States (1.24) and ranks before Italy (1.05) and the United Kingdom (1.01).

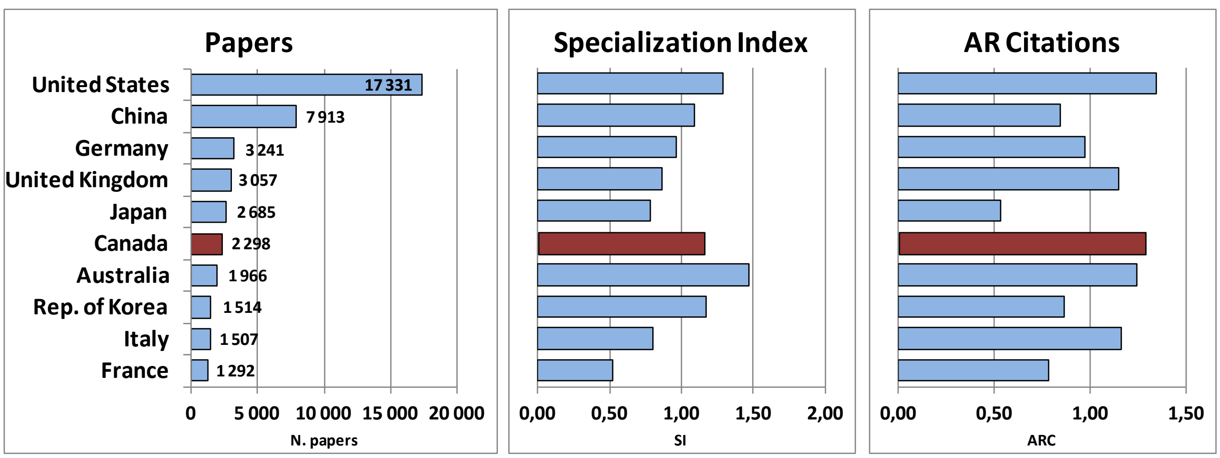
Figure 2-11 Publications in Distributed Computing, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

The subfield of Distributed Computing is the smallest of the eight ICT subfields. With 959 papers over the 2003-2010 period, Canada ranks eighth among the top 10 country (Figure 2-11). Its relative effort (SI = 1.01) is almost equal to the world average, but its scientific impact is well below (0.84).

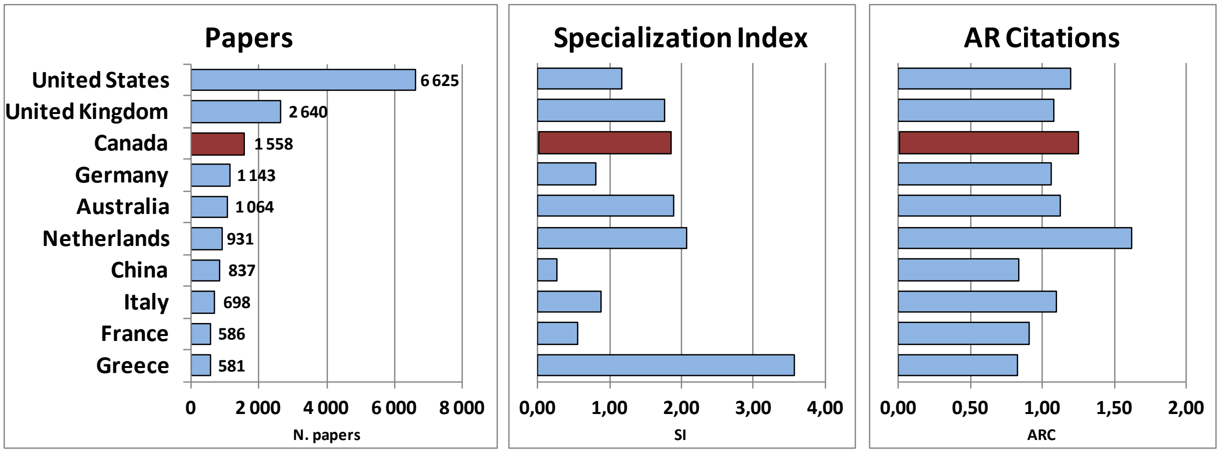
Figure 2-12 Publications in Information Systems, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

Canada ranks sixth in the subfield of Information Systems with 2,298 papers between 2003 and 2010. Its relative effort (SI = 1.15) is fairly above world average and its scientific impact (1.28) is second among the top 10 countries; behind the United States (1.35) and ahead of Australia (1.24).

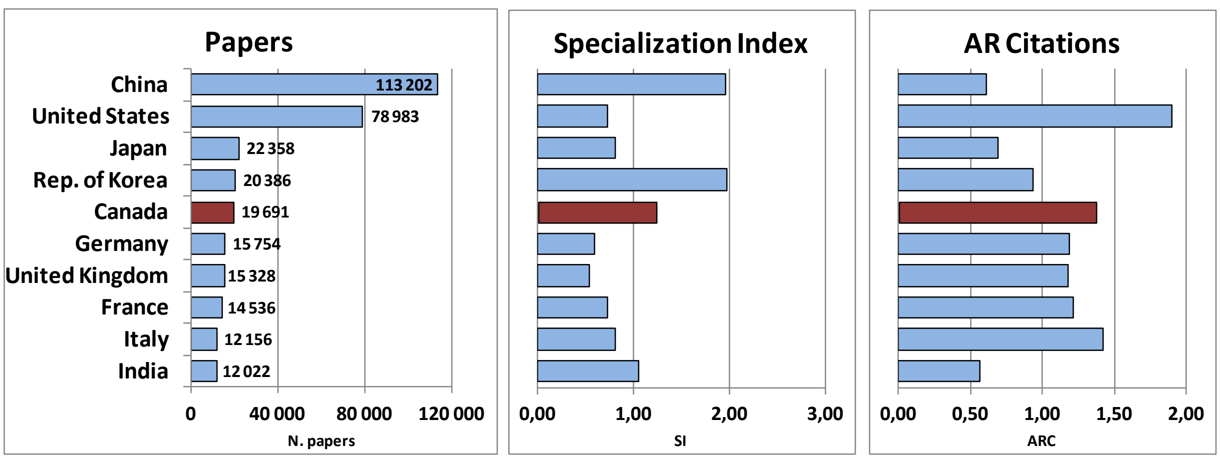
Figure 2-13 Publications in Medical Informatics, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

Canada ranks third in Medical Informatics with 1,558 papers between 2003 and 2010. It is also the fourth most specialized country (SI = 1.85) in this subfield, after Greece (3.56), the Netherlands (2.07) and Australia (1.88). In terms of scientific impact, Canada ranks second (1.24), after the Netherlands (1.62) and before the United States (1.20).

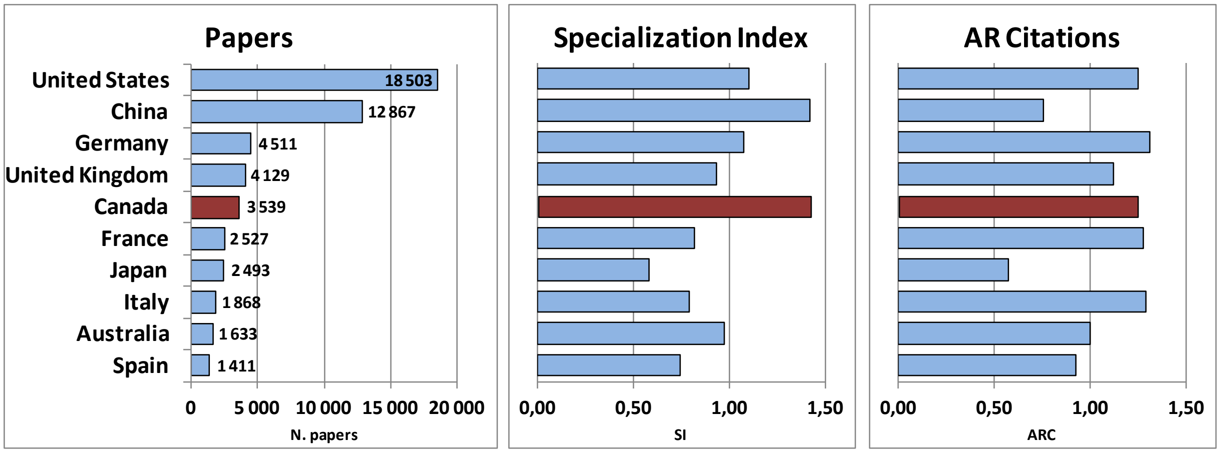
Figure 2-14 Publications in Networking & Telecommunications, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

Networking & Telecommunications is the largest of the eight ICT subfields and with 19,691 papers for the 2003-2010 period, Canada's contribution is the fifth one in terms of importance (Figure 2-14). Not as important as China's or Korea's, Canada's relative effort in this subfield (1.24) is nevertheless well above world average and the third one among the top countries. Its ARC (1.38) is also the third strongest, well behind that of the United States (1.90), but not that far from Italy (1.42).

Figure 2-15 Publications in Software Engineering, Top 10 Countries, 2003-2010



Source: Computed by Science-Metrix using the Scopus database (Elsevier).

Canada also ranks fifth in the subfield of Software Engineering with 3,539 papers between 2003 and 2010 (Figure 2-15). Canada's specialization index (1.42) is also the highest of the top 10 countries, *ex equo* with China (1.42). In terms of scientific impact, Canada (1.25) shares the fourth place with the United States, while the first place is held by Germany (1.31).

In short, bibliometric indicators clearly show that, in terms of number of publications, Canada is among the top 10 countries in ICT between 2003 and 2010. Canada is also among the top 10 countries in each of the eight ICT subfields. The scientific impact of Canadian ICT publications also appears pretty good and it tends to improve with time. On the other hand, since the annual number of Canadian ICT publications stops to increase in 2007 while it continues to grow in the rest of the world, Canadian specialization in ICT declines.

It should be recalled that bibliometric indicators mainly measure the scientific output of academic research. As a matter of fact, about 80% of all Canadian publications bear the address of at least one university, while no more than 6% bear the address of a business enterprise. By contrast, the patents indicators presented in the next section have much more to do with industrial R&D than with university research.

3 INVENTIVE ACTIVITIES: PATENTS AND TRIADIC PATENTS

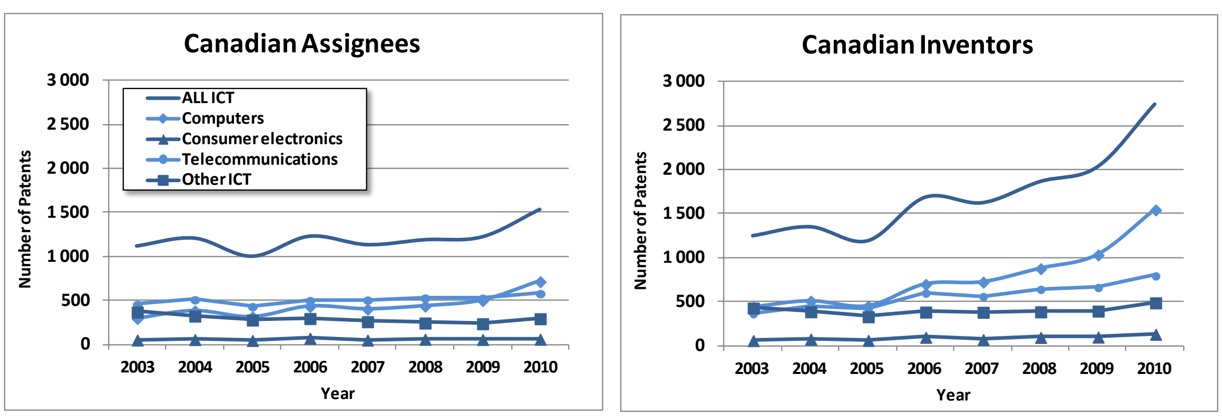
The patents indicators presented in this section are compiled using the country of the assignee and the country of the inventor. In the first case, the indicators relate to intellectual property that can be used in an innovation process, while in the second case, they relate to inventive activities *per se* and to the work of researchers.

Statistics on United States Patent and Trademark Office (USPTO) patents and triadic USPTO patents are presented for ICT as a whole and for each of its four fields, as defined by OECD. First, we look at Canadian data: the raw number of patents, the share of Canadian ICT patents in the world's total and their distribution across institutional sectors. Then, we compare the Canadian production of ICT patents with that of other leading countries by using the number of USPTO patents and the number of USPTO patents included in triadic families. The share of triadic patents in the total number of USPTO patents is also presented since it provides an indication of the relative value or quality of the inventive activities behind the patents.

3.1 Canadian ICT Patents

The Figure 3-1 presents the evolution of the number of ICT patents delivered to Canadian assignees and inventors by USPTO. From 2003 to 2009, the annual number of patents granted to Canadian assignees remains stable between 1,000 and 1,200 and increases notably to 1,532 in 2010; an increase of 36%. Patents granted to Canadian inventors increases more rapidly, from about 1,300 patents between 2003 and 2005, to 2,746 in 2010; an increase of 139%. Among the four ICT fields, Computers increases the more rapidly with a growth rate of 139% for Canadian assignees and 249% for Canadian inventors. The second field is Telecommunications which increases 27% for assignees and 117% of inventors; follows Consumer electronics, increasing16% for assignees and 113% for inventors; and lastly is Other ICT with rates of -20% for assignees and 14% for inventors.

Figure 3-1 Annual Number of USPTO ICT Patents Granted to Canadian Assignee and Inventors, by Field, 2003-2010

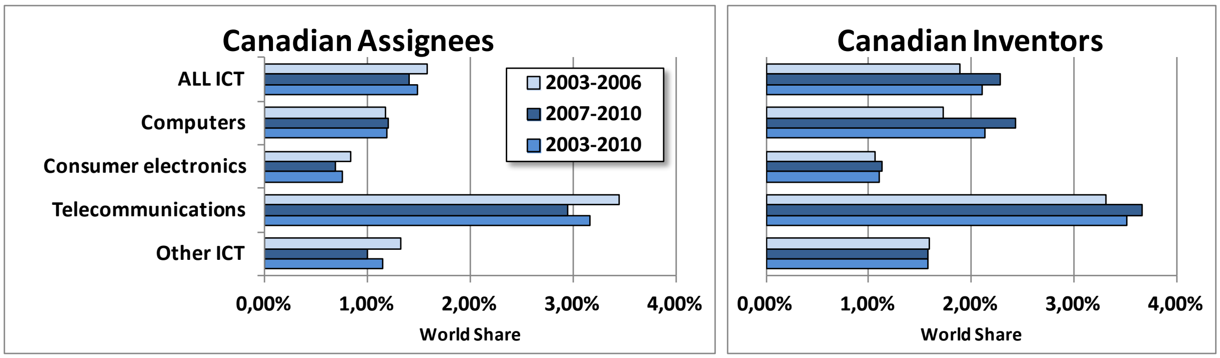


Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

It should be noted that the number of patents delivered to Canadian assignees is lower than the number of patents delivered to Canadian inventors. Put in other words, there are more inventions created by Canadian researchers than inventions owned by Canadian assignees. Such differences, however, are observed at various degrees for almost every country since patents involving international collaboration of inventors are more frequent than patents involving international co-ownership between assignees. Moreover, the phenomenon is not specific to ICT patents: between 2003 and 2010, 24,369 USPTO patents were granted to Canadian assignees while 32,769 patents bear the name of at least one Canadian inventor.

This growth of Canadian ICT echoes the worldwide growth of this domain. For example, ICT-related patents account for 33% of all USPTO patents in 2003 and for 40% in 2010. This is particularly due to the Computers field, which increases from 12% to 18% of the total number of USPTO patents.

Figure 3-2 World Share of USPTO ICT Patents Granted to Canadian Assignee and Inventors, by Field, 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

The gap between the number of ICT patents delivered to Canadian assignees and the number of patents delivered to Canadian inventors is increasing over time. Between the 2003-2006 and the 2007-2010 periods, the world share of ICT patents delivered to Canadian assignees decreases from 1.6% to 1.4% while the share of Canadian inventors increases from 1.9% to 2.3% (Figure 3-2, see ALL ICT). The explanation for this phenomenon would require a study in itself, but we could already point out the internationalization of R&D and the evolution of enterprises' IP management practices.

The world share of Canadian assignees and inventors varies notably from one ICT field to another (Figure 3-2). The Telecommunications field shows the highest share: for both assignees and inventors, it is more than 3% for the period (2003-2010). Between 2003-2006 and 2007-2010, the world share of Canadian assignees decreases notably from 3.4% to 2.9% while that of Canadian inventors increases from 3.3% to 3.7%. By contrast, Canadian assignees maintain their world share at 1.2% in the Computer field while Canadian inventors' share increases from 1.7% to 2.4%. For the Consumer electronics and Others ICT fields, the share of Canadian assignees also decreases with time, while that of inventors remains stable. In short, for ICT as a whole, the world share of USPTO patents granted to Canadian assignees tends to decrease over the period; it is for the case of three fields out of the four, the exception being the Computer field which maintains its relative position. On the other hand, the world share of Canadian inventors increases over time, mainly because of an increase in Telecommunications (from 3.3% to 3.7%) and Computer, which share grows from 1.7% to 2.4%.

The Table 3-1 presents the number of patents granted to Canadian institutional assignees[5] by institutional sectors. Without surprise, it shows that the vast majority of ICT patents are owned by Industries (93.6%). A share of 2.7% ranks the Postsecondary sector second, closely followed by the Federal government sector (2.4%). However, it should be noted that while the Postsecondary sector's share tend to increases with time, that of the Federal Government seems to be declining, while the three other sectors appear as marginal actors in ICT patenting.

[5] Assignees can also be individuals but since institutional sectors cannot be attributed to individuals, only institutional assignees are considered.

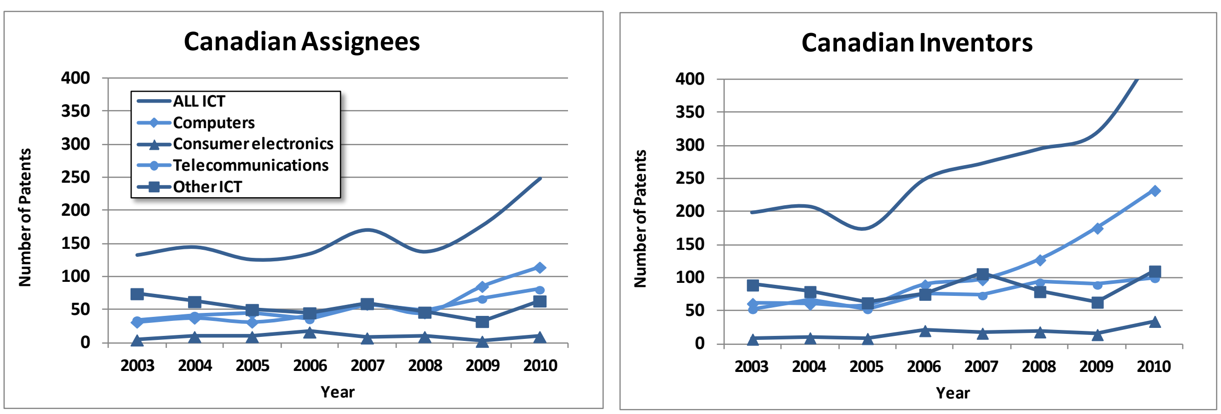
Table 3-1 Annual Number of USPTO ICT Patents Granted to Canadian Institutional Assignees, by Institutional Sector, 2003-2010*

Number of Patents	2003	2004	2005	2006	2007	2008	2009	2010	All Year
All sectors	**1 013**	**1 113**	**901**	**1 097**	**1 018**	**1 102**	**1 101**	**1 337**	**8 682**
Industry	928	1 023	842	1 045	959	1 025	1 049	1 252	8 123
Postsecondary	29	29	25	22	21	30	32	46	234
Federal Government	35	38	21	20	26	32	16	20	208
Hospital	4	6	5	3	5	5	3	7	38
Provincial Government	3	3	1			1	1	3	12
Other	18	16	10	8	9	10	5	14	90
Percentage of All Sectors									
All sectors	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**
Industry	91,6%	91,9%	93,5%	95,3%	94,2%	93,0%	95,3%	93,6%	93,6%
Postsecondary	2,9%	2,6%	2,8%	2,0%	2,1%	2,7%	2,9%	3,4%	2,7%
Federal Government	3,5%	3,4%	2,3%	1,8%	2,6%	2,9%	1,5%	1,5%	2,4%
Hospital	0,4%	0,5%	0,6%	0,3%	0,5%	0,5%	0,3%	0,5%	0,4%
Provincial Government	0,3%	0,3%	0,1%	0,0%	0,0%	0,1%	0,1%	0,2%	0,1%
Other	1,8%	1,4%	1,1%	0,7%	0,9%	0,9%	0,5%	1,0%	1,0%

Source: Observatoire des sciences et des technologies, USPTO database, November 2011.
* The total number of patents for all sectors does not included patents delivered to individual assignees or institutional assignees of unknown sector.

As mentioned in the methodological section, USPTO patents included in triadic families are generally related to inventions showing a high commercial potential. Also, data on triadic patents are more comparable from one country to another since they correct (at least in part) the so-called home-advantage which biases cross-country comparisons when using data from a single national IP office such as USPTO. Obviously, since triadic patents are a subset of USPTO, they are less numerous.

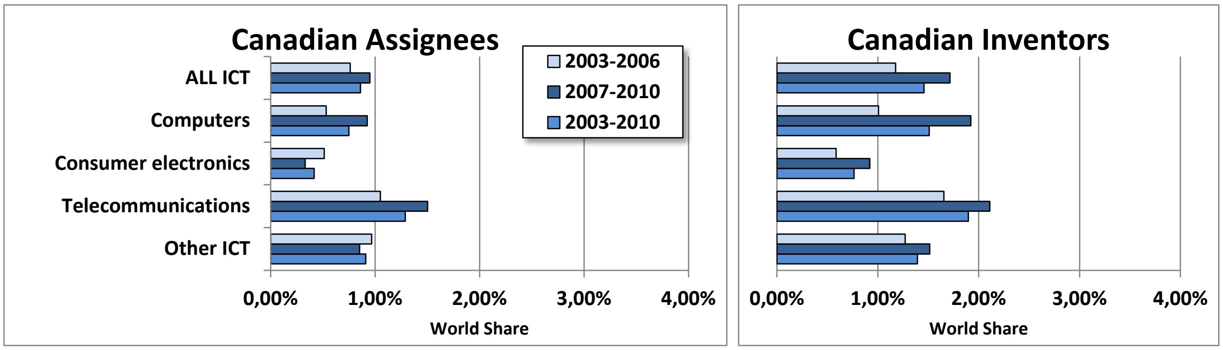
Figure 3-3 Annual Number of USPTO ICT Patents Included in Triadic Families Granted to Canadian Assignee and Inventors, by Field, 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

That said, Figure 3-3 shows that the main trends observed for USPTO data are also observed for triadic USPTO patents. From 2003 to 2009, the annual number of ICT triadic patents granted to Canadian assignees remains stable around 150 and increases notably to 249 in 2010; a growth of 87%, which is higher than the rate calculated for all USPTO patents (36%, see Figure 3-1 left hand). Patents granted to Canadian inventors increases even more rapidly, going from about 200 patents between 2003 and 2006, to 440 in 2010: an increase of 121%. With increases of 259% for Canadian assignees and 276% for Canadian inventors, the Computers field shows the fastest growth over the period. The Telecommunications field increases more rapidly for Canadian assignees (131%) than for Canadian inventors (89%). The Other ICT field remains somewhat stable at 50 to 100 triadic patents a year while the Consumer Electronics field remains almost negligible with less than 20 patents annually for the studied period, except for inventors, who are responsible for 35 patents in 2010.

Figure 3-4 World Share of USPTO ICT Patents Included in Triadic Families Granted to Canadian Assignee and Inventors, by Field, 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

Figure 3-4 shows that, contrary to what is observed for USPTO patents, Canadian assignees increase their world share of triadic patents between 2003-2006 and 2007-2010 in the Computers field (from 0.53% to 0.93%) and in Telecommunications (from 1.05% to 1.50%). By comparison, the world share of Canadian assignees for all technological domains remains at around 1.2% during the period (2003-2010). In the two other ICT fields, Canadian assignees are losing ground with time.

Canadian inventors increase their world share in every field and more particularly in Computers (from 1.01% to 1.92%). By comparison, the world share of Canadian inventors for all technological domains increases from 1.6% in 2003-2006 to 2.0% in 2007-2010.

Table 3-2 Annual Number of USPTO ICT Patents Included in in Triadic Families Granted to Canadian Institutional Assignees, by Institutional Sector, 2003-2010

Number of Patents	2003	2004	2005	2006	2007	2008	2009	2010	All Year
All sectors	**117**	**139**	**117**	**128**	**156**	**131**	**164**	**230**	**1 182**
Industry	103	130	110	122	149	125	159	209	1 107
Postsecondary	6	5	7	5	4	5	4	14	50
Federal Government	4	3	1		1	1	1	2	13
Hospital	1	1		1	1			6	10
Provincial Government	2								2
Other	1	1			1			2	5
Percentage of All Sectors									
All sectors	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**100,0%**
Industry	88,0%	93,5%	94,0%	95,3%	95,5%	95,4%	97,0%	90,9%	93,7%
Postsecondary	5,1%	3,6%	6,0%	3,9%	2,6%	3,8%	2,4%	6,1%	4,2%
Federal Government	3,4%	2,2%	0,9%	0,0%	0,6%	0,8%	0,6%	0,9%	1,1%
Hospital	0,9%	0,7%	0,0%	0,8%	0,6%	0,0%	0,0%	2,6%	0,8%
Provincial Government	1,7%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,2%
Other	0,9%	0,7%	0,0%	0,0%	0,6%	0,0%	0,0%	0,9%	0,4%

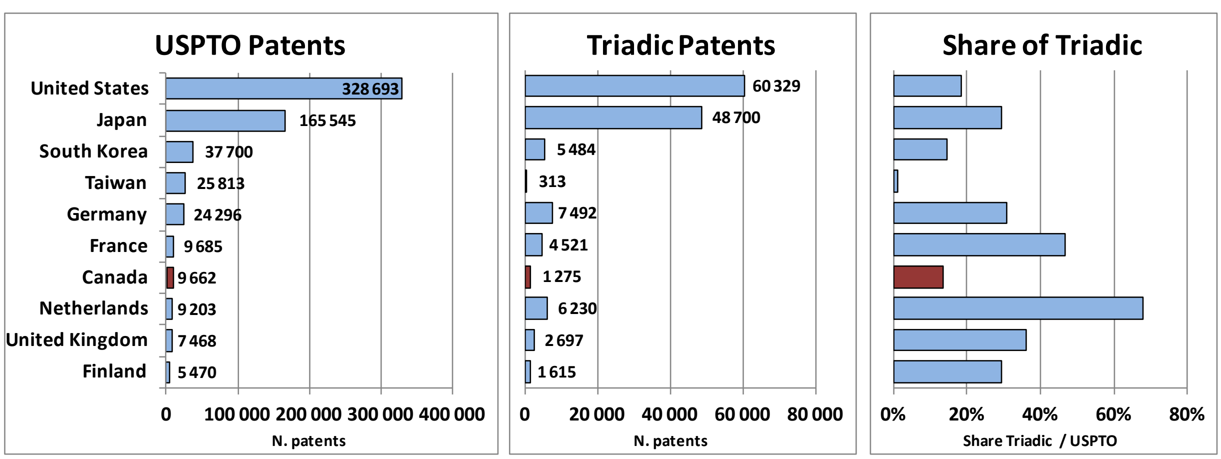
Source: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

Table 3-2 shows the breakdown of triadic USPTO patents granted to Canadian institutional assignees by institutional sectors. Here again, Industries (93.7%) own the vast majority of ICT patents. The Postsecondary sector ranks second once again and at 4.2%, its share of Canadian triadic patents is higher than what was calculated for USPTO patents (2.4%, see Table 3-1). All things being equal, the commercial potential of the Postsecondary sector's inventions appears higher than those of industries, since 21% (50/234) of its USPTO patents are members of triadic families against 14% for Industry (1,107/8,123).

3.2 International Comparisons

The international comparisons presented in this section rely on three indicators: 1) the number of USPTO patents gives a measure of the presence of the countries' ICT inventions on the American market; 2) the number of patents included in a triadic family allows for comparisons between countries as to their relative importance on the international market; 3) and finally, the share of USPTO patents that also are triadic gives a picture of the relative value of inventions patented at USPTO by each country. As to the latter, it should be noted that inventions patented in USA (at USPTO) by Japan and European countries are more likely to be also part of a triadic family. Since the domestic market of those countries is already included in one of the three territories of the so-called triad, the inventions from those countries that are granted USPTO patents already meet two out of the three conditions to be part of a triadic family (patents granted at USPTO and filed at Japan and European IP offices). So, the patents' owners and inventors already are in the process of obtaining a protection on a large international market and the third condition (an application filed to European or Japanese offices) would appear to them as a kind of formality. By contrast, Canadians are quite close to the American market and thus, for a given invention, they are more likely than Japanese or Europeans to file for a USPTO patent *only*, without necessarily applying for European and Japanese patents. Thus, this factor should be taken into account when interpreting the differences between European countries and Japan on the one hand and Canada on the other hand. For one part, these differences reflect the relative market value of the covered inventions, but they also depend on the distance between the different markets (the geographical and commercial closeness to the United States being in this case, a handicap). On the other hand, the comparison with the United States provides a fair benchmark of Canadian performance because they almost share the same market. Lastly, since they are not among the countries of the so-called Triad, Taiwan and South Korea are also good candidates for comparisons.

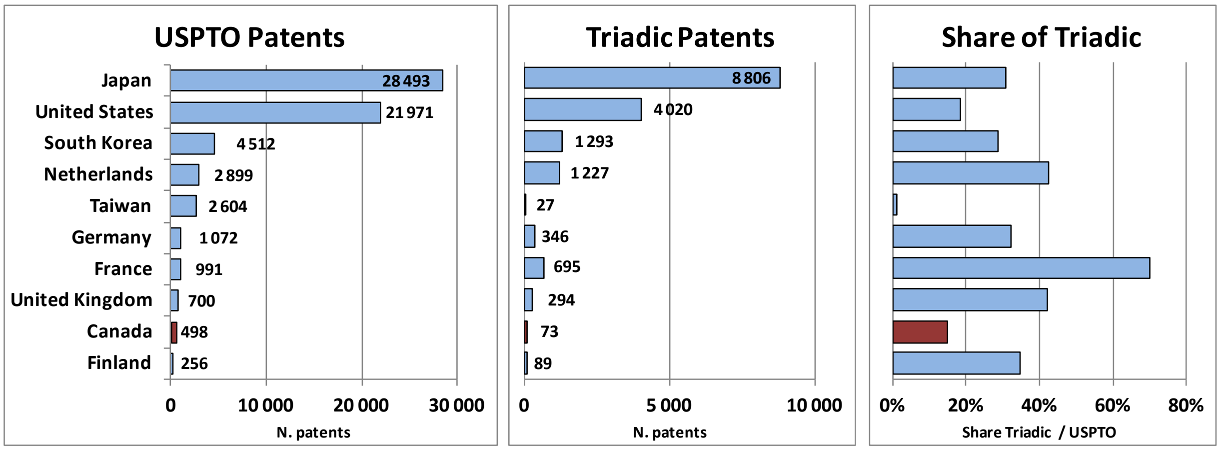
Figure 3-5 Number of ICT Patents, Top 10 Countries (Country of the Assignee), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

Figure 3-5 presents the top 10 countries as measured by ownership of ICT USPTO patents. Unsurprisingly, with more than 320,000 patents between 2003 and 2010, the United States ranks first; it is followed by Japan and South Korea. Canada ranks 7th with 9,662 USPTO patents, slightly below France (9,685). As for the number of triadic patents, Canada ranks 9th, well above Taiwan (313), but clearly below Finland (1,615). The share of Canadian USPTO patents that also are triadic patents (13%) is above that of Taiwan (1%) but below the United States (18%) which is, as mentioned above, a good benchmark for Canada. All things being equal, the commercial potential of Canadian intellectual property in this domain is not as good as the American one.

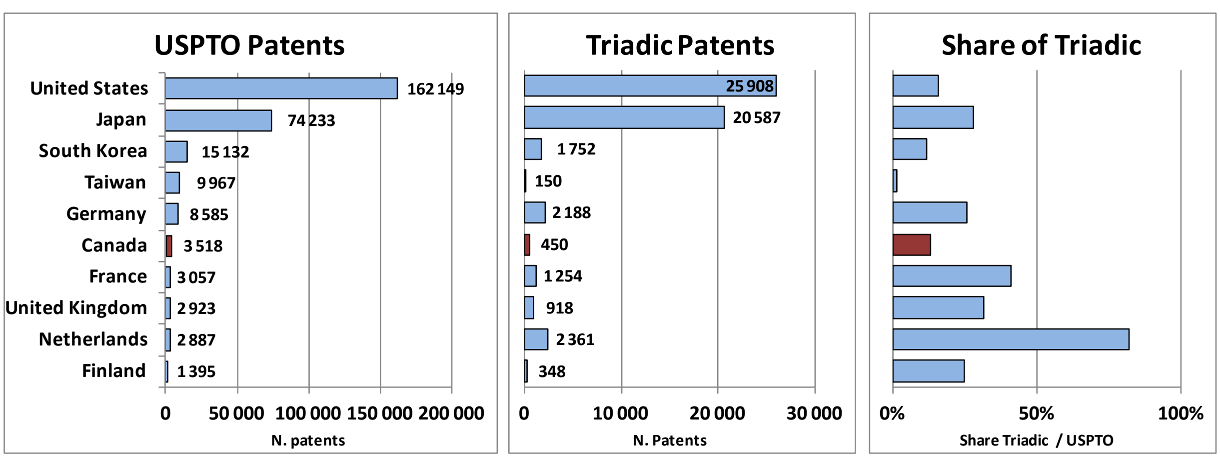
Figure 3-6 Number of Patents in the "Consumer Electronics" Field, Top 10 Countries (Country of the Assignee), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Consumer Electronic field (Figure 3-6), Canada ranks 9th for the number of USPTO patents (498) as well as for the number of triadic patents (73). Its share of triadic patents (15%) is also below that of the United States (18%) and South Korea (29%). Hence, from an IP point of view, this field is not Canada's strength.

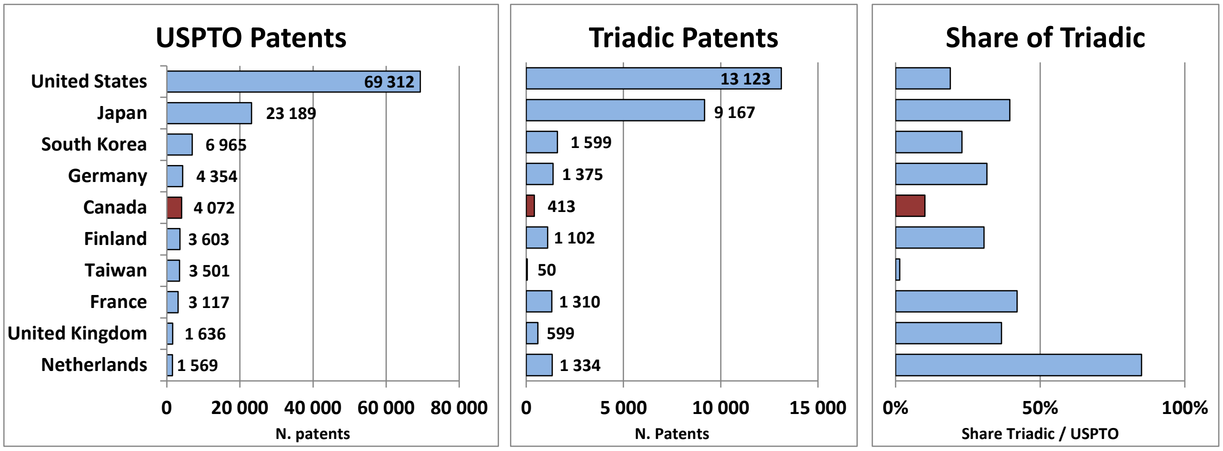
Figure 3-7 Number of Patents in the "Computers" Field, Top 10 Countries (Country of the Assignee), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Computers field (Figure 3-7), Canada ranks 6th for the number of USPTO patents (3,518) and 8th for the number of triadic patents (450), before Taiwan (150) and Finland (348). Again, Canada's share of triadic patents (13%) is well above that of Taiwan (2%) and slightly above South Korea (12%), but below the United States (16%).

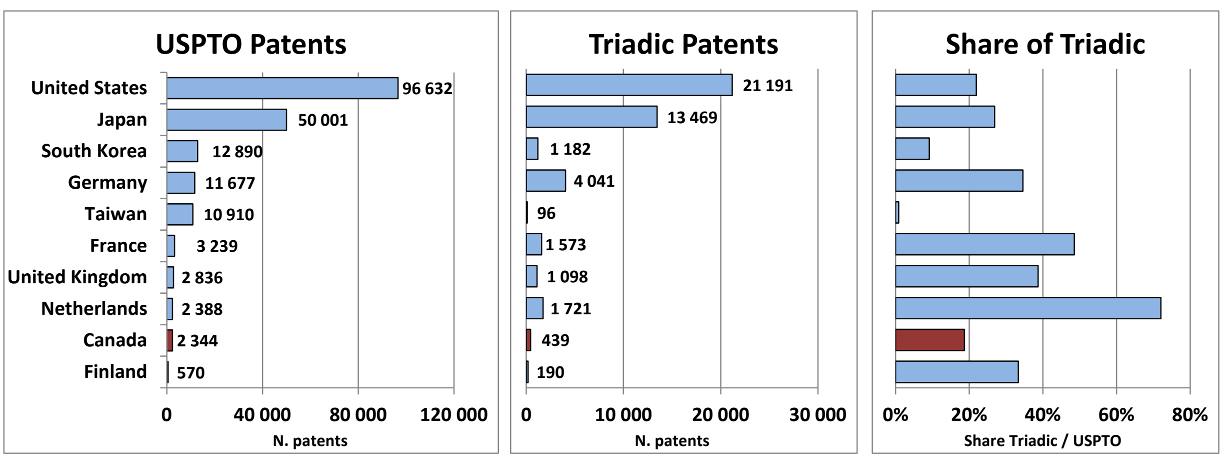
Figure 3-8 Number of Patents in the "Telecommunications" Field, Top 10 Countries (Country of the Assignee), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Telecommunications field (Figure 3-8), Canada ranks 5th for its number of USPTO patents (4,072) and 9th for triadic patents (413). Here again, the share of triadic in Canadian USPTO patents (10%) is well above that of Taiwan (1%), but clearly below the United States (19%) and South Korea (23%).

Figure 3-9 Number of Patents in the "Other ICT" Field, Top 10 Countries (Country of the Assignee), 2003-2010

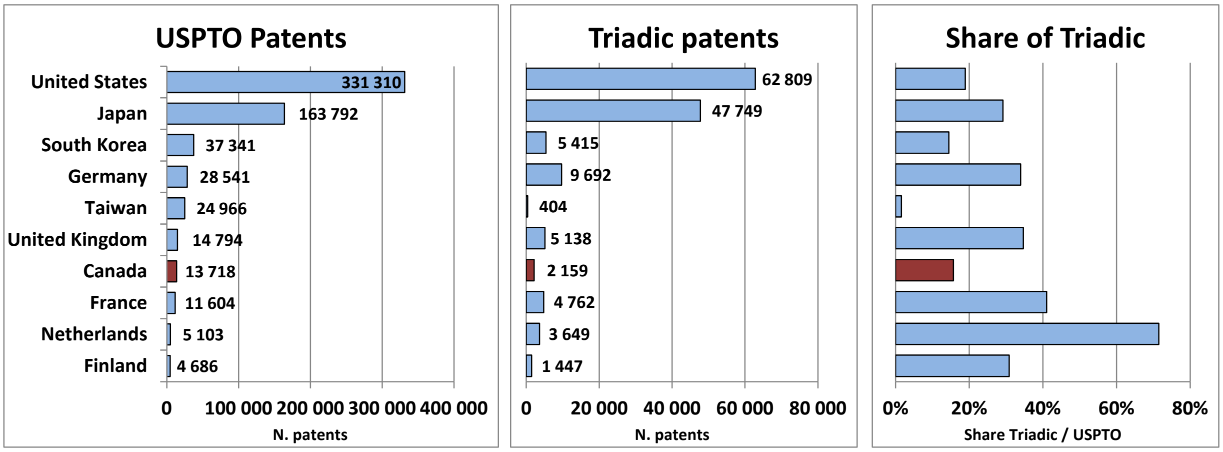


Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Other ICT field (Figure 3-9), which includes various electronic apparatus used for measurement, detection and control, Canada ranks 9th for USPTO patents (2,344) and 8th for triadic patents (439). Its share of triadic USPTO patents (19%) is well above that of Taiwan (1%) and South Korea (9%) and slightly below the Unites States (22%).

This overview of intellectual property shows that Canada is in the top 10 countries for ICT as a whole, as well as for its four fields. However, with about 1.5% of all USPTO patents and less than 1.0% of triadic patents, Canada is not a major player in the global ICT industry.

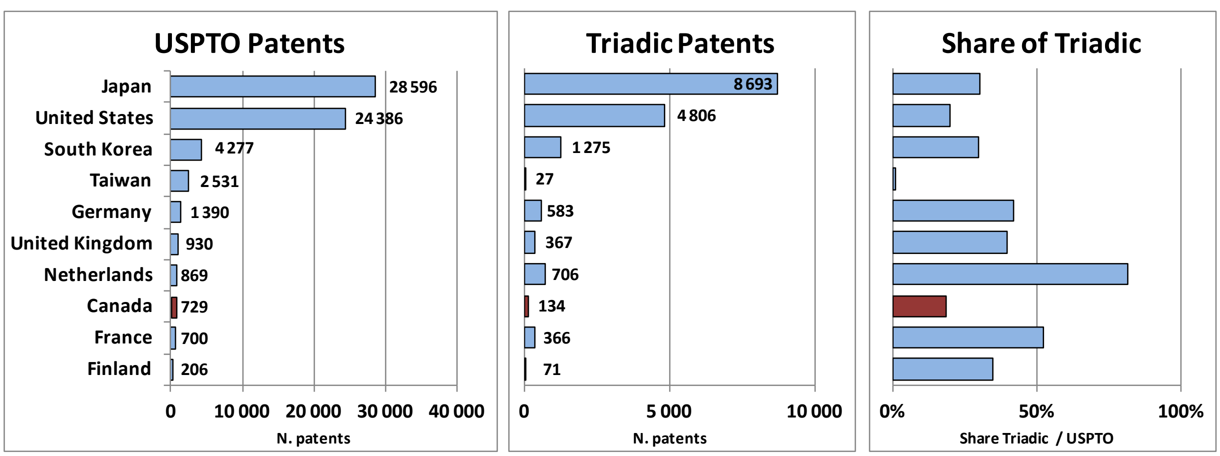
Figure 3-10 Number of ICT Patents, Top 10 Countries (Country of the Inventor), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

As previously mentioned (section 1.2), patent data produced from the country of inventors relates to inventive activities per se and to the work of researchers. The Figure 3-10 shows that, from the inventive point of view, Canada ranks 7th among the top 10 countries for USPTO patents in ICT (13,718) and 8th for the number of triadic patents (2,159). The share of Canadian USPTO patents that also are triadic (16%) is below that of United States (19%), but slightly above South Korea (15%).

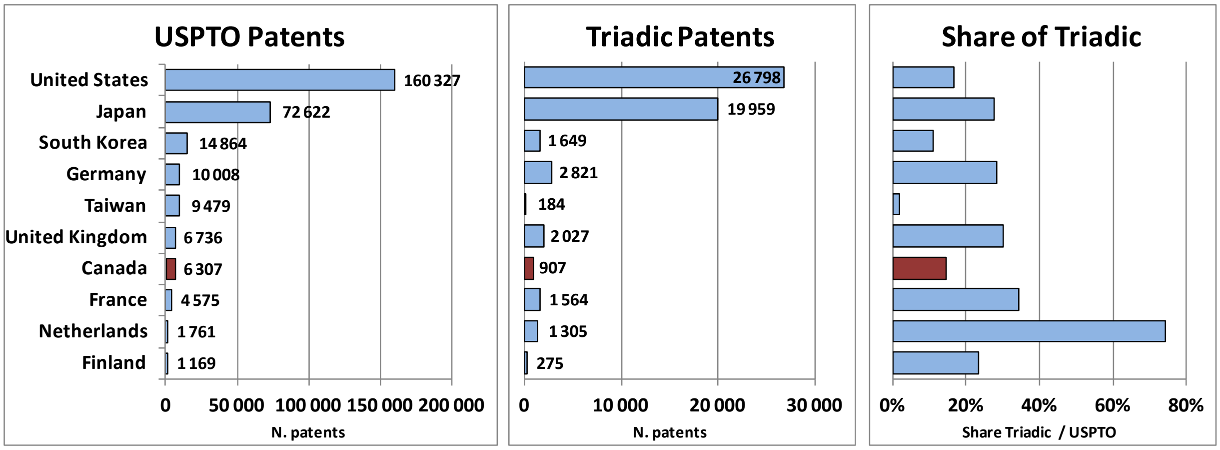
Figure 3-11 Number of Patents in the "Consumer Electronics" Field, Top 10 Countries (Country of the Inventor), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Consumer Electronics field (Figure 3-11) Canada ranks 8th for USPTO patents (729) and 8th for triadic patents (134). Its share of triadic patents (18%) is close to that of the United States (20%), but clearly below South Korea (30%).

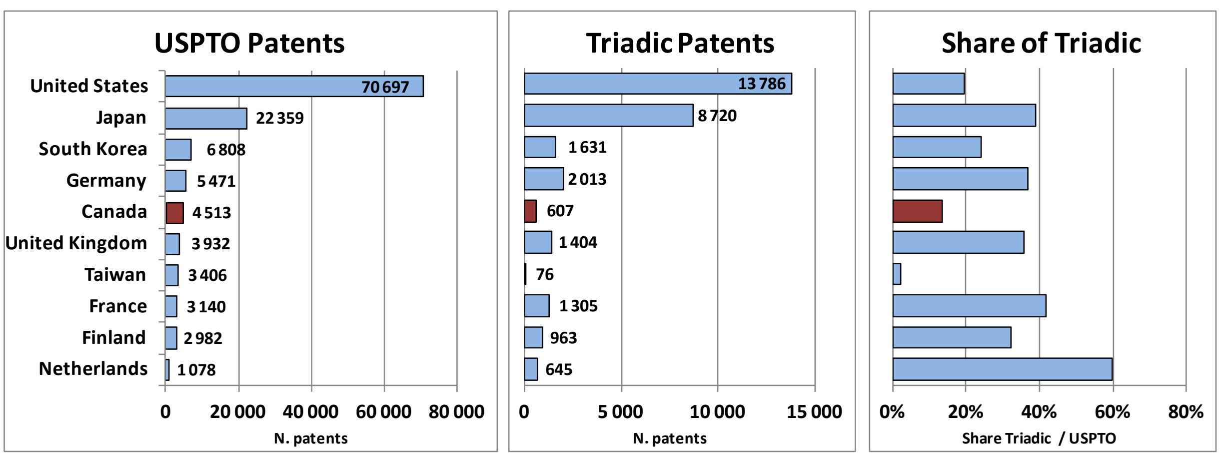
Figure 3-12 Number of Patents in the "Computers" Field, Top 10 Countries (Country of the Inventor), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Computers field (Figure 3-12) Canada ranks 7th for USPTO patents (6,307) and 8th for triadic patents (907). Its share of triadic patents (14%) is below that of the United States (17%), but is fairly above South Korea (11%); which is not the case in the Consumers Electronics and Telecommunications fields.

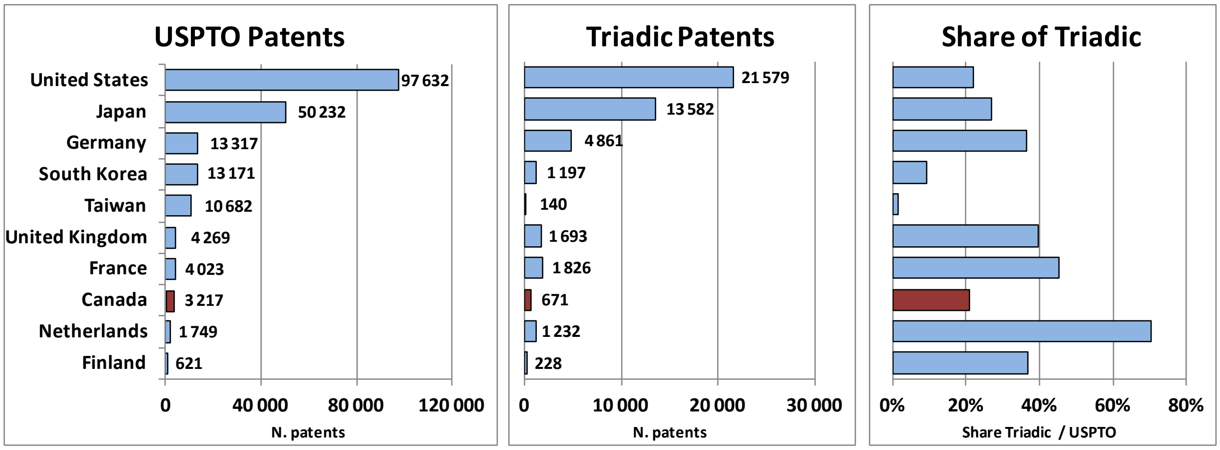
Figure 3-13 Number of Patents in the "Telecommunications" Field, Top 10 Countries (Country of the Inventor), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Telecommunications field (Figure 3-13), Canada ranks 5th for USPTO patents (4,513) but 9th for triadic patents (607). The share of Canadian USPTO patents included in triadic patents families (13%) is clearly below that of the United States (20%) and South Korea (24%).

Figure 3-14 Number of Patents in the "Other ICT" Field, Top 10 Countries (Country of the Inventor), 2003-2010



Sources: Observatoire des sciences et des technologies, USPTO database, November 2011; OECD, Triadic Patent Families database, July 2011.

In the Other ICT field (Figure 3-14), Canada ranks 8th for both the number of UPSTO patents (3,217) and the number of triadic patents (671). It should be noted here that its share of triadic patents (21%) is quite close to that of the United States (22%) and clearly above that of South Korea (9%).

In short, patent indicators show that the inventive activities and the protection of intellectual property in ICT tend to accelerate at world level. Despite this context of increasing competition, the world share of Canadian inventors increases nonetheless. As measured through USPTO patents, the share of Canadian assignees tends to decrease over the studied period, but through triadic patents (which capture the inventions with the highest commercial potential), it increases.

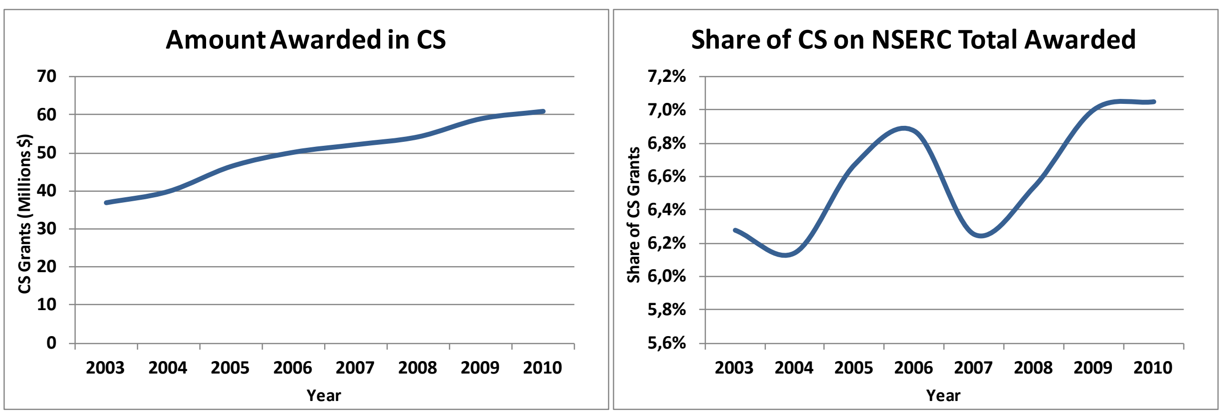
4 RESEARCH AND DEVELOPMENT

The statistics on computer science research and development are presented according to three categories. First, Canadian Federal Government's investments in university research are analyzed through the data of the Natural Sciences and Engineering Research Council of Canada (NSERC). It should be noted that OEDC data on university research cannot be broken down into disciplines or domains. Hence, there is no possibility of international comparison of university research in CS. By contrast, the statistics on business enterprise R&D expenditures provided by OECD allow for comparisons between Canada and other leading countries in Information and Communication Technologies (ICT) and Computer Sciences (CS) sectors. Similar international comparisons are also presented using OECD statistics on R&D personnel.

4.1 NSERC Grants

As mentioned in section 1.3, the data on NSERC investment in CS refers to all grants awarded to researchers who have been successful at least once in the competitions of one of the four computer science NSERC committees between 1991 and 2010.

Figure 4-1 NSERC Grants Awarded in Computer Science, 2003-2010



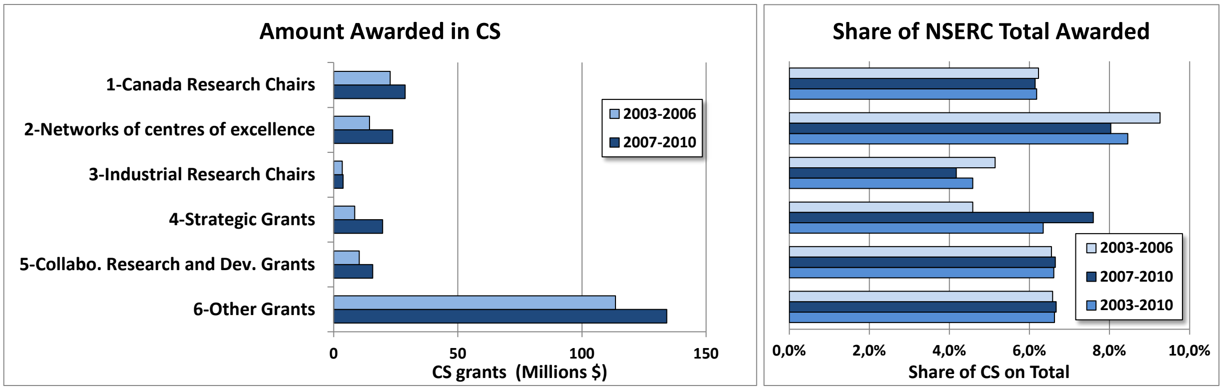
Source: NSERC Awards Search Engine, compiled by Observatoire des sciences et des technologies.

As shown in Figure 4-1, the annual amount of grants awarded in CS rises steadily from $37 million in 2003 to $61 million in 2010. The share of CS in NSERC total grants fluctuates significantly from year to year, ranging from a low 6.1% in 2004 to a high 7.1% in 2010, thus making it difficult to be categorical about the general trend, even though it seems to increase over the period. Between 2003 and 2006, grants awarded in CS account for 6.5% of all NSERC grants, while between 2007 and 2010, they account for 6.7%.

The breakdown of CS grants by group of programs (Figure 4-2) shows that the most important source of funds (62% over the 2003-2010 period) is the Other Grants group which includes, as its main component, the NSERC Discovery Grants Program. The Canada Research Chairs (14%) is the second most important source of funding and the Strategic Grants (7%) is the third one. The Network of Centres of Excellence (6%) and the Collaborative Research and Development Grants (6%) rank fourth *ex aequo* and the Industrial Research Chairs (3%) come last.

Figure 4-2 also shows that between 2003-2006 and 2007-2010, the total amount awarded in CS increases notably in all groups of programs except for the Industrial Research Chairs, where the total awarded increases by less than 400,000$ (from $3.45 million to $3.81 million). The share of NSERC total funding devoted to CS varies from one group of programs to another (Figure 4-2, right hand). The highest share goes to the Networks of Centres of Excellence with 8.5% for the 2003-2010 period while the lowest is for the Industrial Research Chairs with 4.6%. CS share in total NSERC funding ranges from 6.2% and 6.6% for the four other groups of program. It should also be noted that, between 2003-2006 and 2007-2010, CS share in total NSERC funding decreases in the three following groups of programs: Canada Research Chairs (from 6.2% to 6.1%), Networks Centres of Excellence (from 9.3% to 8.0%) and Industrial Research Chairs (from 5.1% to 4.2%). By contrast, CS share increases slightly for the Other Grants group (from 6.6% to 6.7%) and for Collaborative Research (6.5% to 6.6%), while it increases notably for Strategic Grants (4.6% to 7.6%).

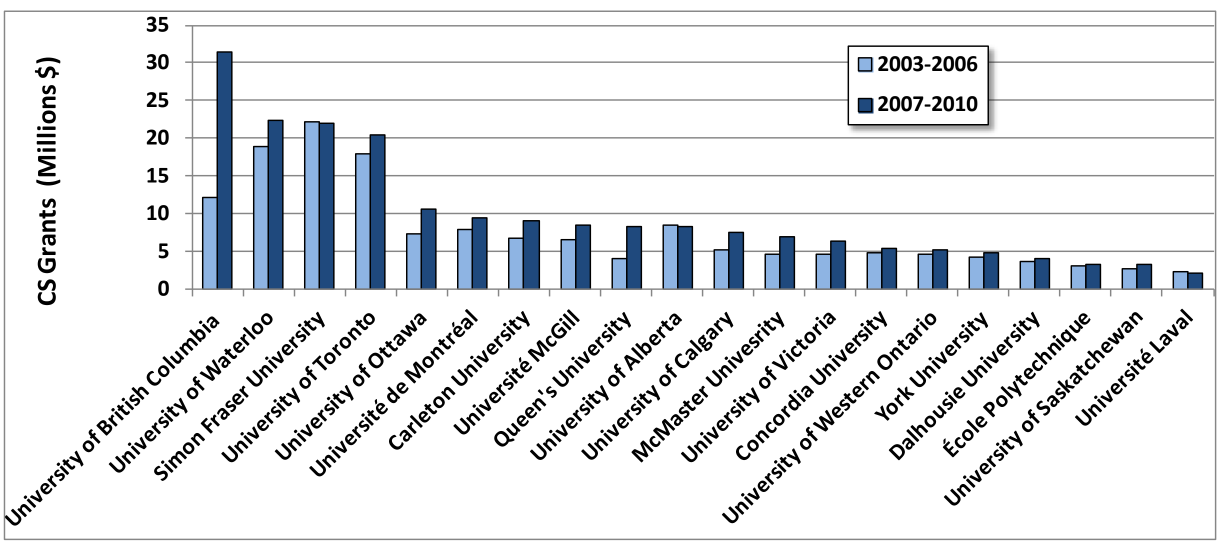
Figure 4-2 NSERC Grants Awarded in Computer Science by Group of Programs, 2003-2010



Source: NSERC Awards Search Engine, compiled by Observatoire des sciences et des technologies.

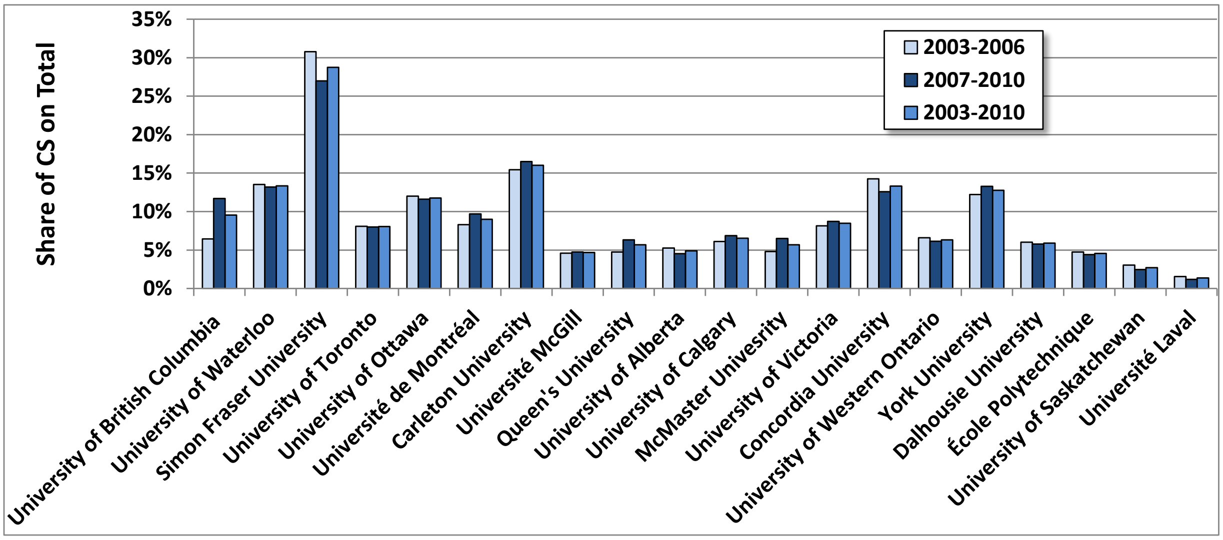
Figure 4-3 presents the amount for CS research grants received by major Canadian institutions between 2003 and 2010. It shows that University of British Columbia became the first recipient ($31.5 million) in 2007-2010, followed by the University of Waterloo ($22.4 million), Simon Fraser ($21.9 million) and the University of Toronto ($20.5 million). With a significantly smaller amount of $10.6 million, the University of Ottawa ranked 5th, closely followed by the Université de Montréal ($9.4 million) and Carleton University ($9.0 million).

Figure 4-3 NSERC Grants Awarded in Computer Science, Top 20 Institutions, 2003-2010



Source: NSERC Awards Search Engine, compiled by Observatoire des sciences et des technologies.

Figure 4-4 Share of CS in NSERC Total Awarded, Top 20 institutions, 2003-2010



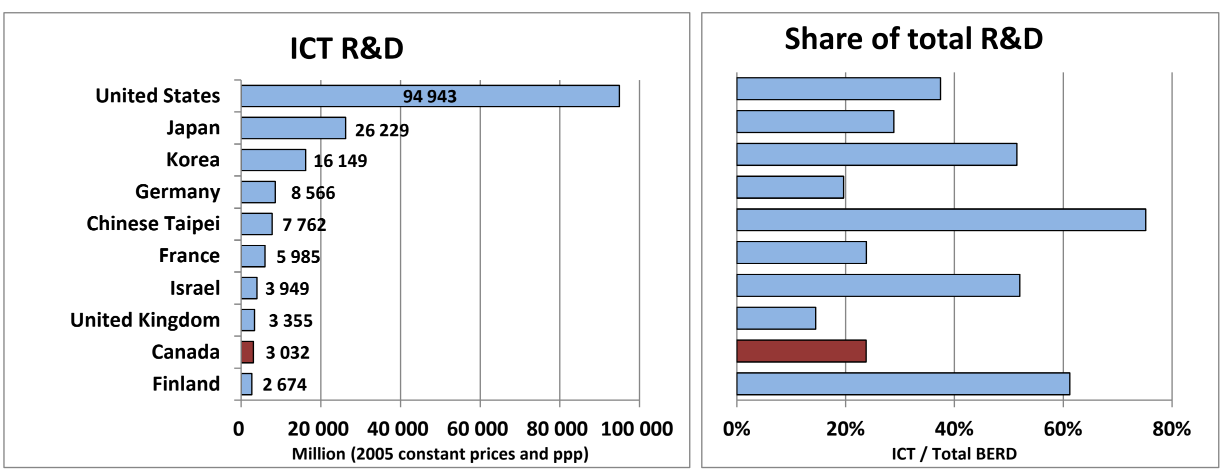
Source: NSERC Awards Search Engine, compiled by Observatoire des sciences et des technologies.

Figure 4-4 shows that Simon Fraser is, by a large margin, the institution with the highest percentage of its NSERC funding in CS (29% between 2003 and 2010). In this respect, this high share could be explained in part by the fact that Simon Fraser is the host institution of an important Network of Centres of Excellence grants in CS. It is followed by Carleton (16%), the University of Waterloo (13%), Concordia University (13%), York University (13%) and the University of Ottawa (12%).

4.2 Business Enterprise R&D Expenditures: International Comparison

Based on an internationally recognized and used methodology, the statistics of this section allow for comparisons between Canada and the other leading countries on their business enterprise R&D in ICT and CS. Firstly, we present the data in constant 2005 dollars at purchasing power parity (PPP) for the whole ICT industrial sector and secondly, for the specific computer science sector (see section 1.4).

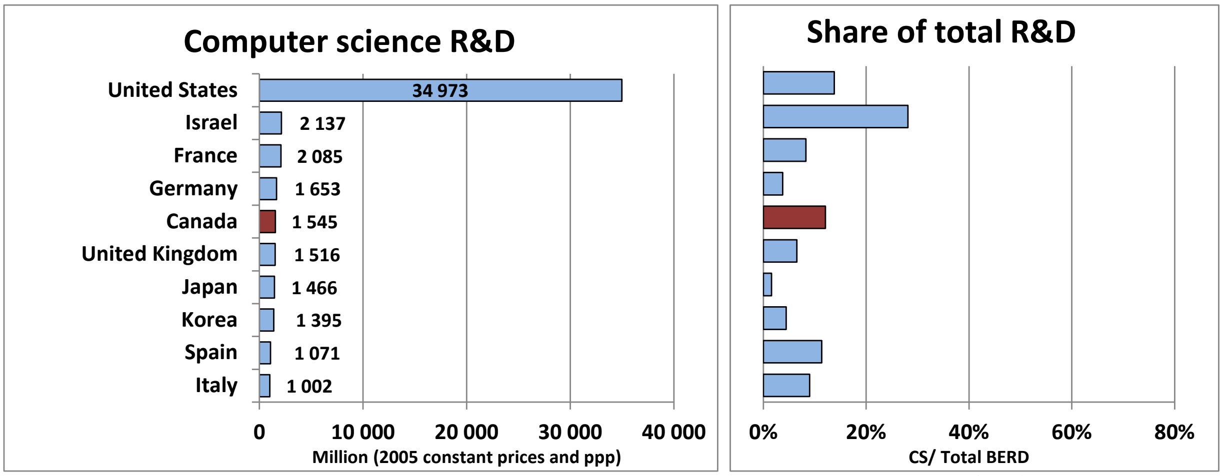
Figure 4-5 Business Enterprise R&D Expenditures in the ICT Sector, Top 10 Countries, 2007 (in Million 2005 Dollars - Constant prices and PPPs)



Source: OECD Science, Technology and R&D Statistics, Research and Development Statistics (RDS), Dataset: Business enterprise R-D expenditure by industry, Data extracted on 28 Mar 2012.

Figure 4-5 shows that with expenditures of $3,032 million in 2007, Canada ranks 9th among the top 10 countries in terms of ICT business R&D, just below the United Kingdom ($3,355 million) and above Finland ($2,674 million). ICT represents 24% of all Canadian business R&D expenditures, which is similar to France (24%), Germany (20%) and even Japan (29%) but Canada's share is clearly below Chinese Taipei (75%), Finland (61%), Israel (52%) and Korea (51%) at the 8th position.

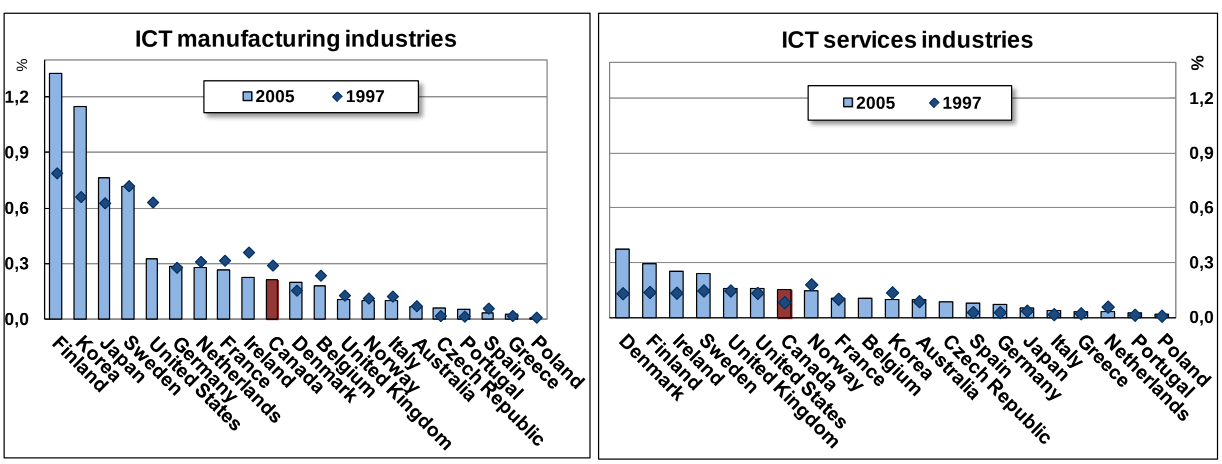
Figure 4-6 Business Enterprise R&D Expenditures in the CS Sector, Top 10 Countries, 2007 (in Million 2005 Dollars - Constant prices and PPPs)



Source: OECD Science, Technology and R&D Statistics, Research and Development Statistics (RDS), Dataset: Business enterprise R-D expenditure by industry, Data extracted on 28 Mar 2012.

On the other hand, for computer sciences (CS) specifically (Figure 4-6), which is a subset of ICT (see Table 1-1, ISIC core #72), Canada ranks 5th for its business R&D expenditures with $1,545 million in 2007, just above the United Kingdom ($1,516 million) and slightly below Germany ($1,653 million). CS accounts for 12% of all Canadian business R&D expenditures, which is clearly below Israel (28%), but comparable to the United States (14%) and Spain (11%), and quite above the other leading countries.

Figure 4-7 Business R&D Expenditure by Selected ICT Manufacturing and Services Industries, 1997 and 2005, as a percentage of GDP



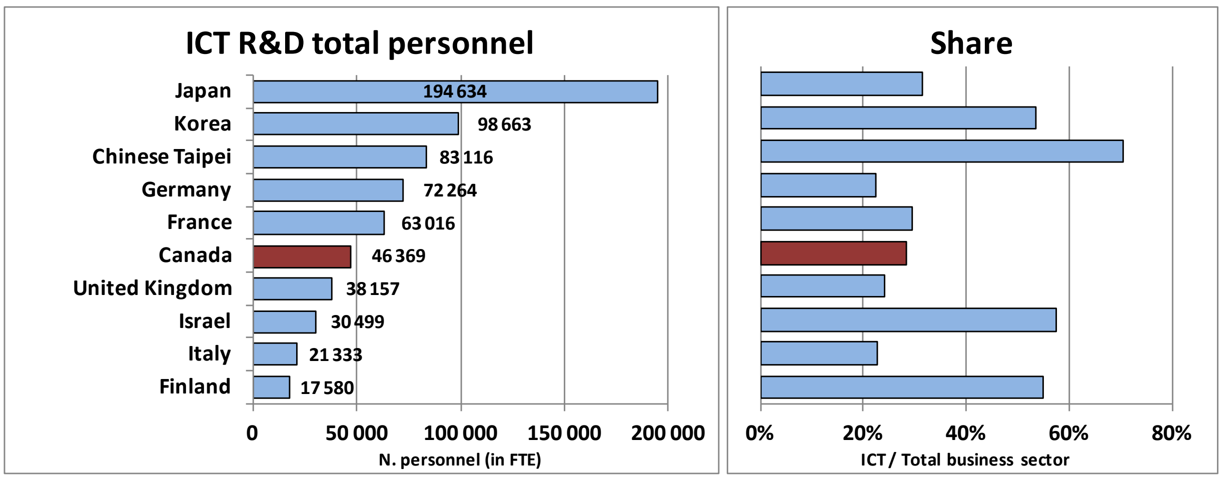
Source: OECD Information Technology Outlook 2008, Graph 3.6.

The Figure 4-7 presents the business R&D expenditures as a percentage of countries' GDP by type of ICT industry. It shows that Canada ranks 10th in 2005 among the leading countries for expenditures in ICT manufacturing industries. Also, Canada seems to be losing ground: the R&D expenditures of its ICT manufacturing sector accounts for 0.30% of GDP in 1997 and 0.22% in 2005. On the other hand, Canada's relative effort of its ICT services industries (which includes telecommunications and computer) rises from 0.08% of GDP in 1997 to 0.15% in 2005, improving Canada's rank among the leading countries from 11th to 8th.

4.3 R&D personnel

As for R&D expenditures, statistics on R&D personnel are presented for the whole ICT industrial sector as well as for the more specific sector of computer science (CS). In each case, statistics are expressed in number of full-time equivalent (FTE) personnel and as a share of total business enterprise R&D personnel.

Figure 4-8 Business Enterprise R&D Total Personnel in ICT sector, Top 10 Countries, 2007



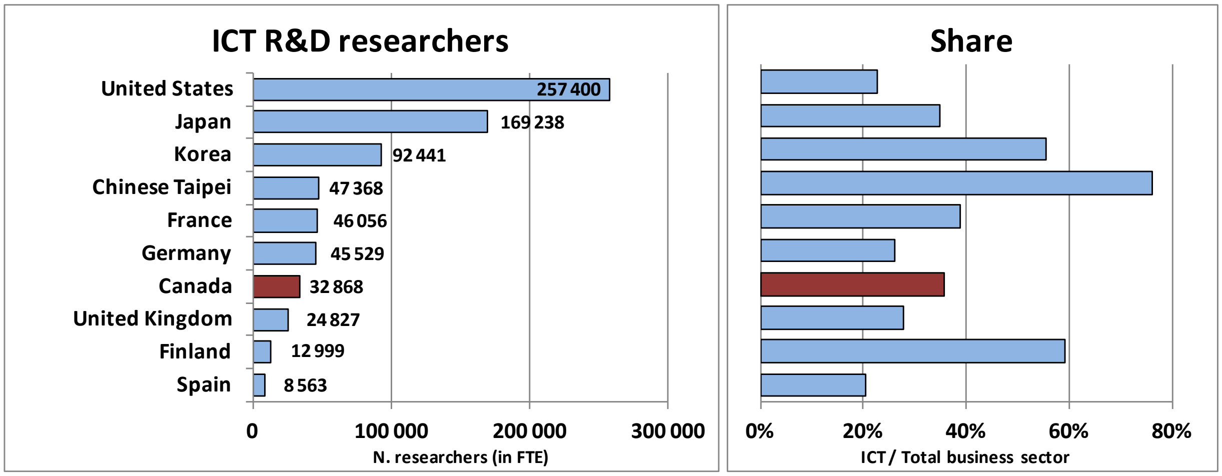
Source: OECD Science, Technology and R&D Statistics, Research and Development Statistics (RDS), Dataset: R-D personnel by sector of employment and occupation, Data extracted on 28 Mar 2012.

Figure 4-8 shows statistics regarding total personnel: researchers, technicians and the administrative staff assigned to ICT R&D. Unfortunately, due to the unavailability of data, the United States does not appear on this figure (neither in Figure 4-10). However, although the exact number remains unknown, it is certain that they would appear in 1st place. Indeed, the mere number of their researchers (257,400 see Figure 4-9) exceeds the number of R&D total personnel of Japan. Hence, Canada which is ranked 6th on the figure should rather be ranked 7th in real world.

ICT R&D personnel accounts for 28% of all Canadian R&D personnel (Figure 4-8, right hand); a share comparable to France (30%) and even Japan (31%), but well below Chinese Taipei (70%), Israel (57%), Finland (55%) and Korea (53%). It should be noted that the picture of R&D personnel is similar to that of R&D expenditures (see Figure 4-5), which is perfectly normal since the larger share of R&D expenditures is devoted to salaries. Thus, the ranking of countries according to the total amount they invest in ICT R&D is similar to the ranking of their total ICT R&D personnel, and it is also the same for the share of total business R&D devoted to ICT.

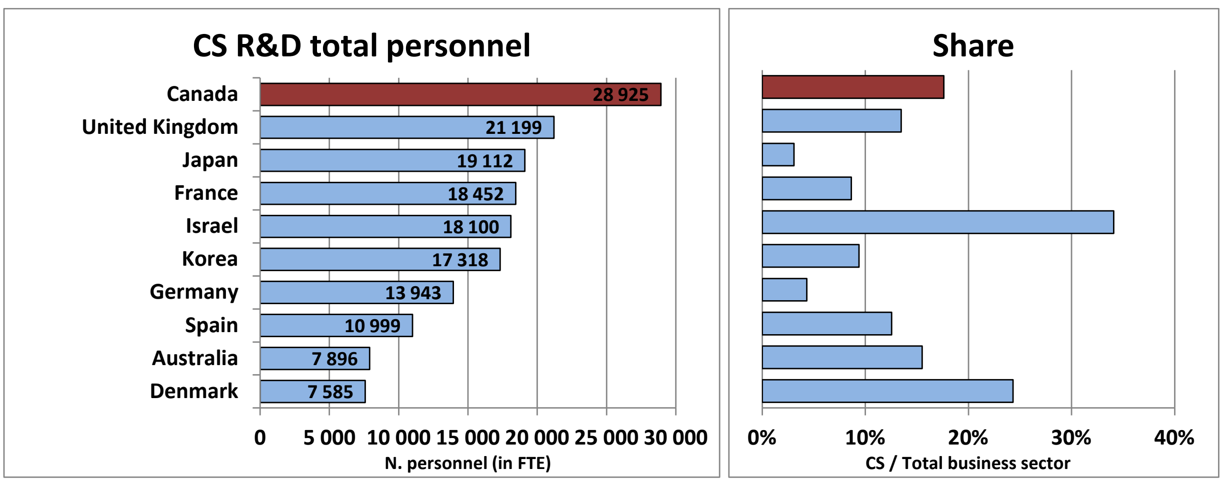
Along the same line, the data on researchers presented in Figure 4-9 (page 36) shows that Canada also ranks 7th, with 32,868 FTE researchers in 2007. This number represents 35% of all the researchers in Canadian business enterprise R&D, a proportion comparable to those of Japan (35%) and France (39%), but clearly below those of Chinese Taipei (76%), Finland (59%) and Korea (56%).

Figure 4-9 Business Enterprise R&D Researchers in ICT sector, Top 10 Countries, 2007



Source: OECD Science, Technology and R&D Statistics, Research and Development Statistics (RDS), Dataset: R-D personnel by sector of employment and occupation, Data extracted on 28 Mar 2012.

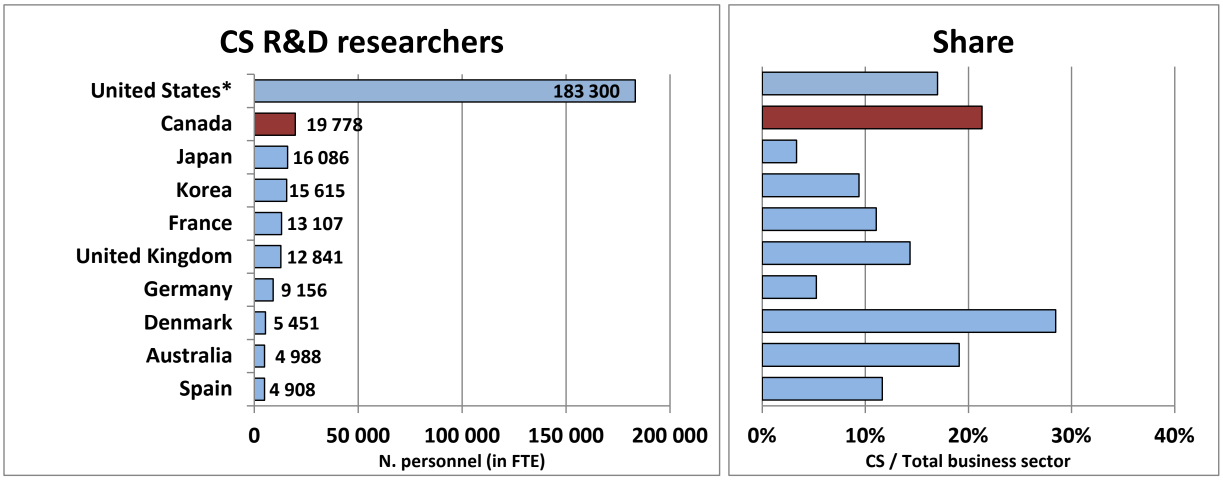
Figure 4-10 Business Enterprise R&D Total Personnel in the CS Sector, Top 10 Countries, 2007



Source: OECD Science, Technology and R&D Statistics, Research and Development Statistics (RDS), Dataset: R-D personnel by sector of employment and occupation, Data extracted on 28 Mar 2012.

Data on Figure 4-10 focuses on the more specific field of computer science (CS) R&D. Data on total R&D personnel in the United States is unavailable, but if it were, it would certainly appear in the 1st rank for the number of R&D personnel in computer science. Hence, in reality, Canada would not be ranked 1st, but 2nd. Nonetheless, this Canadian performance is truly remarkable since its number of CS R&D personnel exceeds that of many countries with larger population, such as the United Kingdom, Japan or France. With 28,925 FTE, CS R&D personnel also represent 62% of all ICT R&D personnel and 18% of total Canadian business R&D personnel. The latter share is clearly below that of Israel (34%) and Denmark (24%), but also above that of Australia (16%), the United Kingdom (13%), Spain (13%) and all the other countries shown on Figure 4-10.

Figure 4-11 Business Enterprise R&D Researchers in the CS Sector, Top 10 Countries, 2007



*Source: OECD Science, Technology and R&D Statistics, Research and Development Statistics (RDS), Dataset: R-D personnel by sector of employment and occupation, Data extracted on 28 Mar 2012. *Data for 2005, the last available year.*

As for CS R&D researchers, Canada also offers an impressive performance given the size of its population (Figure 4-11). Of course, the United States ranks first in this regard with almost ten times (183,300) the number of Canadian researchers (19,778). However, in 2nd position, Canada is comfortably ahead of Japan (16,086). As for the percentage that CS researchers represent on the total number of business sector R&D researchers, Canada also ranks 2nd (21%) behind Denmark (28%), but ahead of Australia (19%), the United States (17%), the United Kingdom (14%) and all other countries shown on the figure.

In short, NSERC grants data shows CS research's funding has steadily increased between 2003 and 2010 and that it represents a growing share of total NSERC funding. As for business enterprises, OEDC data shows that the Canadian ICT manufacturing industry's R&D expenditures represent a decreasing share of GDP, while its share grows for the ICT services industry. In terms of R&D personnel, the Canadian ICT sector holds the 6th rank among the leading countries regarding its total R&D personnel and the 5th rank for the number of researchers. In the more specific field of CS, Canada holds the 2nd position for its total R&D personnel and its number of researchers, just behind the United States.

5 UNIVERSITY TRAINING PROGRAMS AND HUMAN RESOURCES

As explained in the methodological section (section1.5), statistics on university training are presented for two groups of programs based on the Classification of Instructional Programs (CIP). Firstly, for undergraduate and graduate programs, we used the most accurate class offered in Statistic Canada's CANSIM database, which is the primary grouping "Mathematics, Computer and Information Science (MCIS)". This is not perfect since it includes programs that are not part of computer science *per se* (such as mathematics and information science), but at least, it gives an idea of the general trends affecting computer science.

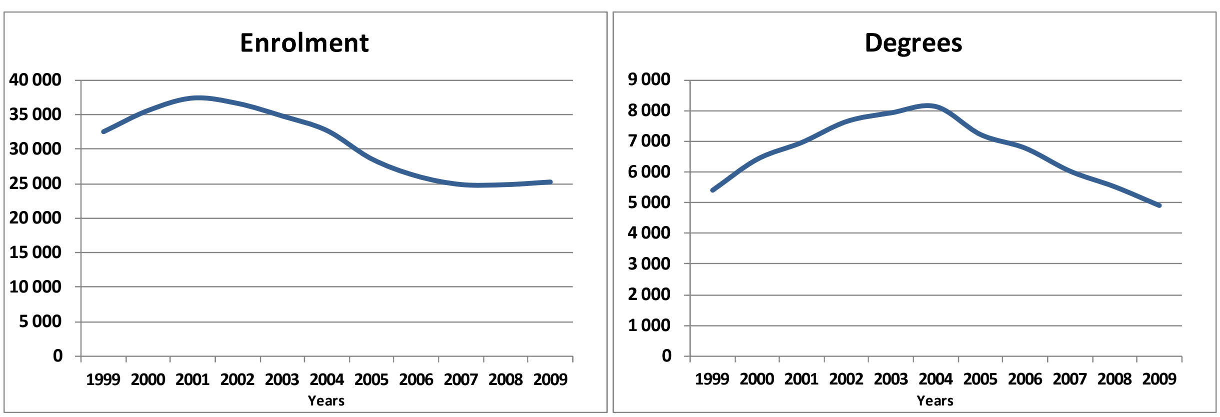
For graduate programs, however, thanks to the work performed by OST on CAGS report, we have access to much more detailed data at the level of CIP series and subseries, allowing a breakdown of the MCIS primary grouping to isolate computer science (CS) from mathematics and information science. Hence, contrary to statistics on undergraduate studies which are limited to MCIS program, statistics on graduate studies provide a closer and more specific look at computer science (CS).

5.1 Undergraduate Studies

Figure 5-1 presents undergraduate enrolment and degrees awarded in the fields of mathematics, computer and information science (MCIS). It shows that enrolments grow between 1999 and 2001 and then decline sharply until 2006 to stabilize around 25,000 between 2007 and 2009. With a four-year lag, the number of bachelor degrees essentially follows the same trends: it increases from 5,406 to 8,121 between 1999 and 2004, and then it steadily decreases to 4,911 diplomas in 2009. Given that enrolments stabilize around 2006 and 2007, it is very likely that the annual number of degrees awarded is stabilizing around 5,000 in 2010 and will remain at this level until 2013 at least.

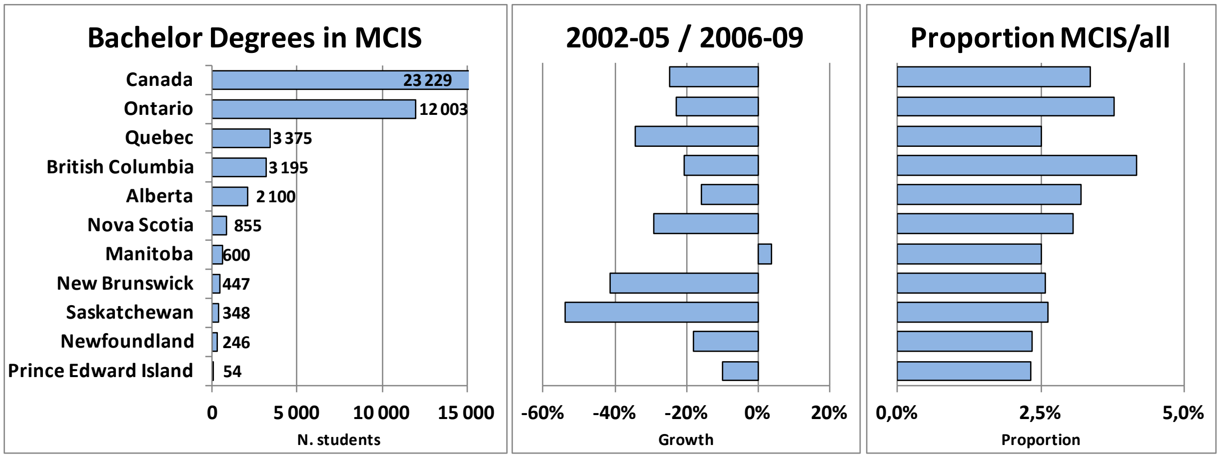
One obvious explanation of such trends of enrolment (and its delayed impact on graduation) is certainly the rise of the information technology bubble and its burst in 2000.

Figure 5-1 Bachelor Enrolment and Degrees Awarded in MCIS, Canada, 1999-2009



Source: Statistic Canada, CANSIM Table 477-0019 & 477-0020.
Note: MCIS stands for Mathematics, Computer and Information Sciences (CIP_PM 7).

Figure 5-2 Bachelor Degrees Awarded in MCIS by Province, Canada, 2006-2009



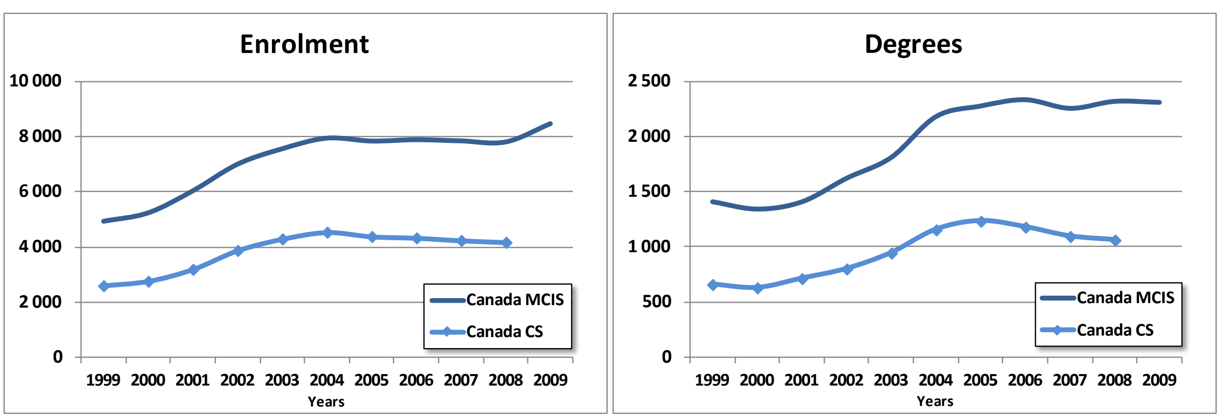
Source: Statistic Canada, CANSIM Table 477-0020.

Figure 5-2 presents the number of bachelor degrees awarded in Canada, broken down by province for 2006-2009. Not surprisingly, it shows that most of MCIS Canadian diplomas are awarded by Ontarian universities. It should also be noted that MCIS represents a relatively large share (3.8%) of all undergraduate degrees awarded in Ontario. The only other province showing a larger share of degrees awarded in MCIS is British Columbia (4.2%). Between the two four-year periods 2002-2005 and 2006-2009, the number of MCIS diplomas awarded in Canada decreases by 24.8% (Figure 5-2 middle area). This decline is occurring (with varying intensity) in all provinces, except in Manitoba which experiences a small growth of 3.6%.

5.2 Graduate Studies

For the whole MCIS field, as well as for the more specific subset of Computer science (CS), Figure 5-3 presents graduate studies enrolment and degrees awarded between 1999 and 2009. Contrary to undergraduate enrolment, which decreases from 2001, graduate enrolment increases markedly between 1999 and 2004. For MCIS, it goes from 4,944 to 7,953 and for CS, from 2,598 to 4,536. Enrolment then stabilizes for MCIS while it slightly decreases for CS; from 4,536 in 2004 to 4,170 in 2008. Unfortunately, the CS series ends in 2008 and, hence, we can't confirm that the observed increase for MCIS in 2009 is also reflected at the level of CS.

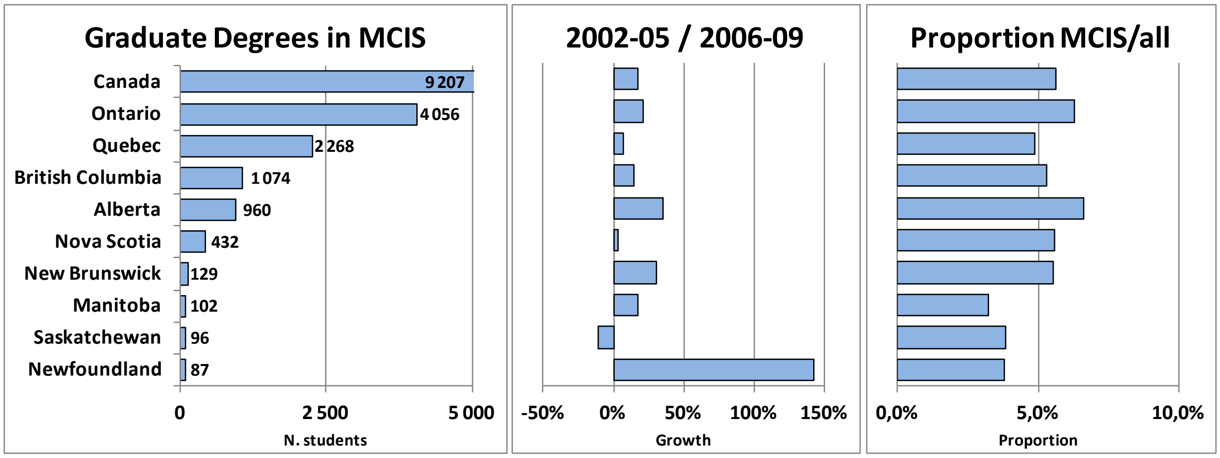
Figure 5-3 Canadian Graduate Enrolment and Degrees Awarded in MCIS and CS, Canada, 1999-2009



Source: Statistic Canada, CANSIM Table 477-0019 and 477-0020 & Statistic Canada and CAGS 39th Report, special tabulations compiled by the Observatoire des sciences et des technologies.

Obviously, trends in graduate degrees are similar to those of enrolments (Figure 5-3, right hand). After a fairly rapid growth between 2000 and 2005, annual numbers of MCIS degrees stabilize at around 2,300 until 2009 (at least). On the other hand, the number of CS degrees declines slowly from 1,233 in 2005 to 1,062 in 2008.

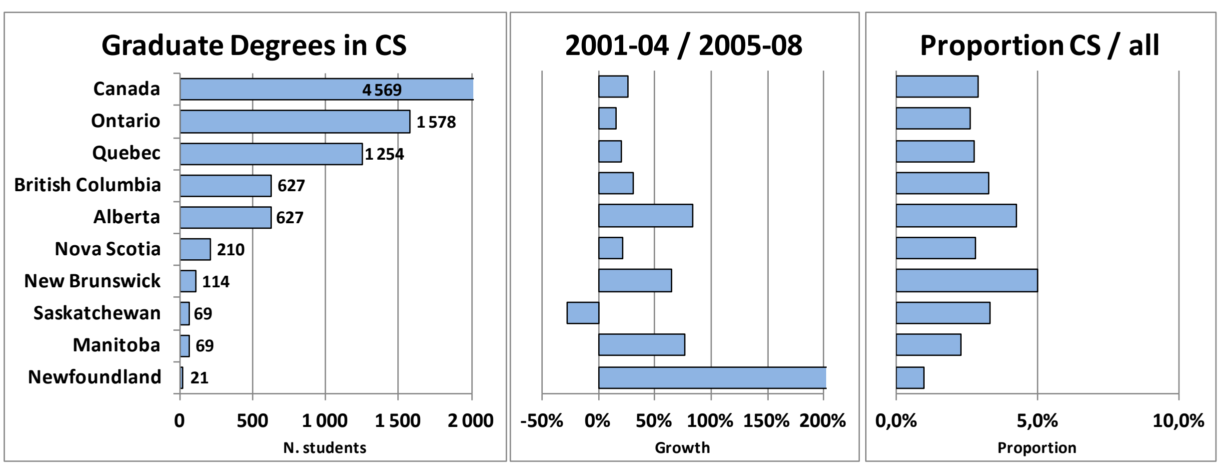
Figure 5-4 Graduate Degrees Awarded in MCIS, by Province, Canada, 2006-2009



Source: Statistic Canada, CANSIM Table 477-0020.

Figure 5-4 shows that Ontario produces more than 4,000 out of the 9,207 (44%) Canadian MCIS graduates between 2006 and 2009. MCIS also represent 6.3% of all Ontarian graduate degrees awarded, a relatively large proportion, only exceeded by that of Alberta (6.6%). Between the two four-year periods 2002-05 and 2006-09, Newfoundland is the province experiencing the fastest increase (142%), but one should take into account that such growth is only possible because raw numbers are quite low (from 36 in 2002-05 to 87 in 2006-2009). In that sense, Alberta's growth (35%, from 711 to 960) and even Ontario's (21%, from 3,363 to 4,056) should appear more important.

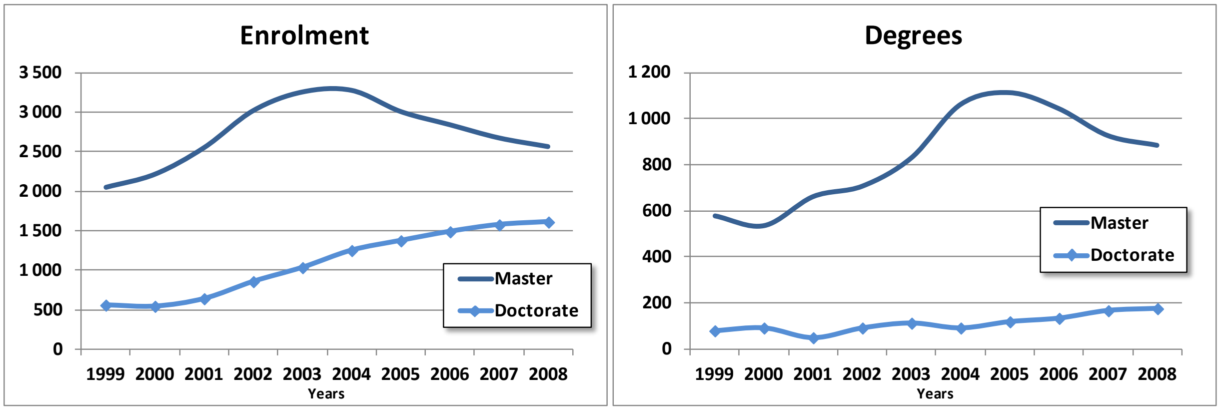
Figure 5-5 Graduate Degrees Awarded in CS by Province, Canada, 2005-2008



Source: Statistic Canada and CAGS 39th Report, special tabulations compiled by the Observatoire des sciences et des technologies.

The Canadian production of CS graduate degrees is notably less concentrated in Ontario than what it is observed for MICS (Figure 5-5). Between 2005 and 2009, Ontario accounts for 35% of all Canadian graduation in CS, against 44% in MICS. Consequently, other provinces are more involved in this field. Here again, with the exception of Newfoundland (with a growth of 600% but only from 3 to 21 degrees), Alberta is the province showing the fastest growth (83%). Also, CS represents a relatively large share (4.3%) of all graduate degrees awarded in Alberta; a proportion only exceeded in New Brunswick (5.0%) and well above the Canadian average (2.9%)

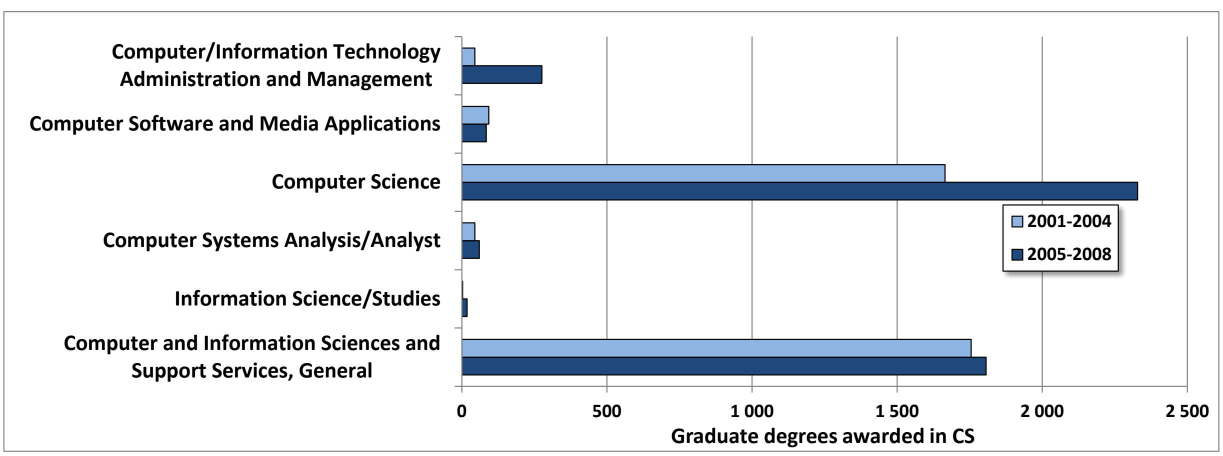
Figure 5-6 Graduate Enrolment and Degrees Awarded in CS by Level of Study, Canada, 1999-2008



Source: Statistic Canada and CAGS 39th Report, special tabulations compiled by the Observatoire des sciences et des technologies.

As mentioned in the methodology (section 1.5), data on graduate studies only concerns master and PhD programs and thus excludes all kinds of short programs. Figure 5-6 presents the data on graduate studies broken down by level of studies. It shows that the decline of enrolment from 2004 and of graduation from 2006 should only be attributed to master programs. As a matter of fact, doctoral enrolment in CS steadily increases from 561 in 1999 to 1,611 in 2008. Of course, the number of awarded CS PhD increases during the same period, from 81 in 1999 to 171 in 2008.

Figure 5-7 Graduate Degrees Awarded in CS by Subfield, Canada, 2001-2008



Source: Statistic Canada and CAGS 39th Report, special tabulations compiled by the Observatoire des sciences et des technologies.

Figure 5-7 presents the breakdown of CS graduate degrees awarded by subfield. It shows that the vast majority of CS diplomas belong to the subfield of "computer science" (*per se*) and to "computer and information sciences and support services". Together, these two subfields account for 95% of all the degrees awarded between 2001 and 2008. It should be noted that the subfield of Computer Science is growing fast since its number of graduates increases from 1,665 in 2001-04 to 2,328 in 2005-08. The subfield of

"Computer/Information Technology Administration and Management" is also experiencing an important growth; from 45 in 2001-04 to 276 in 2005-2008.

Table 5-1 Master Degrees Awarded in CS, Top 20 Canadian Institutions, 1999-2008

	Institution	1999 -2003	2004 -2008	All Year	Growth
1	Concordia University	297	525	822	77%
2	University of British Columbia	255	336	591	32%
3	University of Ottawa	240	309	549	29%
4	Université de Montréal	240	270	510	13%
5	University of Waterloo	189	270	459	43%
6	Dalhousie University	174	222	396	28%
7	University of Toronto	147	246	393	67%
8	McGill University	168	207	375	23%
9	University of Alberta	159	210	369	32%
10	University of Western Ontario	171	162	333	-5%
11	Athabasca University	0	285	285	--
12	Université du Québec à Montréal	117	147	264	26%
13	Carleton University	108	138	246	28%
14	Queen's University	96	141	237	47%
15	University of Windsor	102	129	231	26%
16	University of Calgary	57	168	225	195%
17	Simon Fraser University	63	153	216	143%
18	University of Victoria	78	138	216	77%
19	University of New Brunswick	66	120	186	82%
20	McMaster University	72	96	168	33%

Source: Statistic Canada and CAGS 39th Report, special tabulations compiled by the Observatoire des sciences et des technologies.

The Table 5-1 (above) presents the numbers of master degrees awarded by the top Canadian institutions in CS. It shows that with more than 450 degrees each for the 1999-2008 period, the top five institutions are the University of Waterloo (459 degrees), Université de Montréal (510), University of Ottawa (549), University of British Columbia (591) and Concordia University (822).

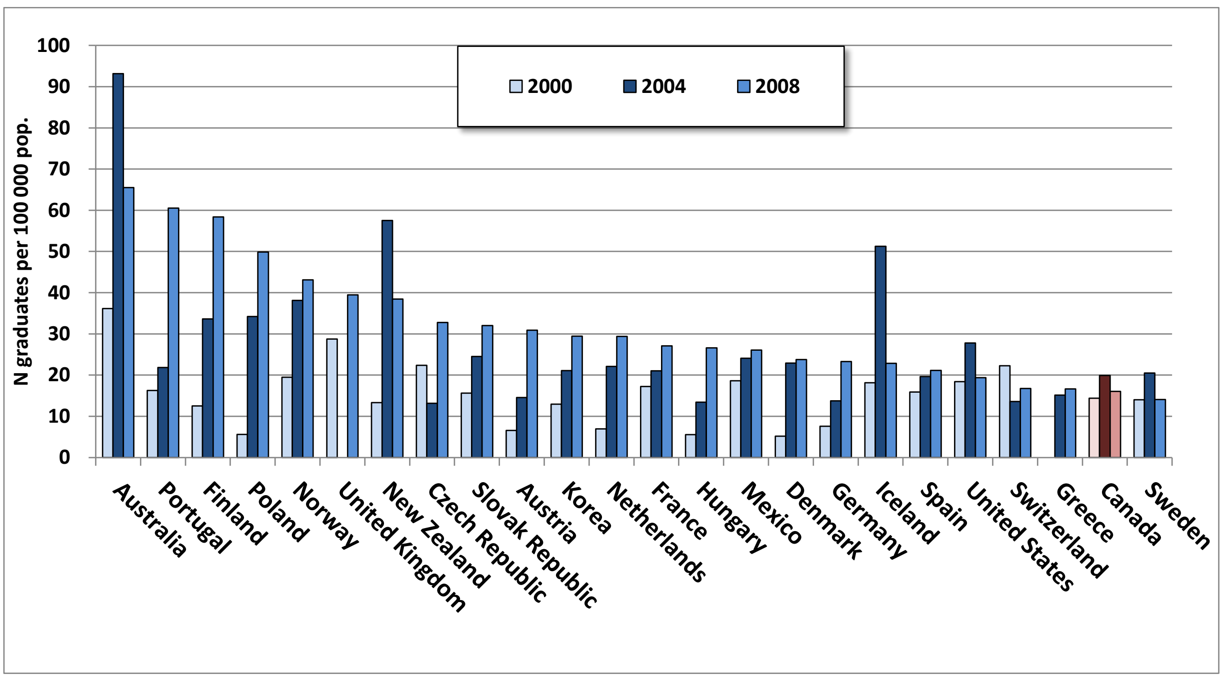
The PhD level, however, offers a rather different picture (see Table 5-2, page 44). With 147 PhD awarded between 1999 and 2008, the University of Toronto is ranked 1st , followed by the University of Waterloo (111), the Université de Montréal (108), the University of Alberta (84), the University of British Columbia (81) and Simon Fraser University (72). It should also be noted that almost everywhere (the only exception being Master's degree at the University of Western Ontario), CS programs are growing, at Master's and PhD levels.

Table 5-2 Doctorate Awarded in CS, Top 15 Canadian Institutions, 1999-2008

Institution	1999 -2003	2004 -2008	All Year	Growth
1 University of Toronto	57	90	147	58%
2 University of Waterloo	39	72	111	85%
3 Université de Montréal	54	54	108	0%
4 University of Alberta	36	48	84	33%
5 University of British Columbia	30	51	81	70%
6 Simon Fraser University	30	42	72	40%
7 University of Ottawa / Université d'Ottawa	15	39	54	160%
8 Carleton University	18	30	48	67%
9 University of Western Ontario	21	27	48	29%
10 Concordia University	15	30	45	100%
11 University of Victoria	18	27	45	50%
12 McGill University	12	30	42	150%
13 Queen's University	15	24	39	60%
14 University of Calgary	9	27	36	200%
15 Université Laval	12	15	27	25%

Source: Statistic Canada and CAGS 39th Report, special tabulations compiled by the Observatoire des sciences et des technologies.

Figure 5-8 Number of Undergraduate and Graduate Degrees Awarded in Computer Science (ISCED 48) per 100,000 population by Country, 2000, 2004 & 2008



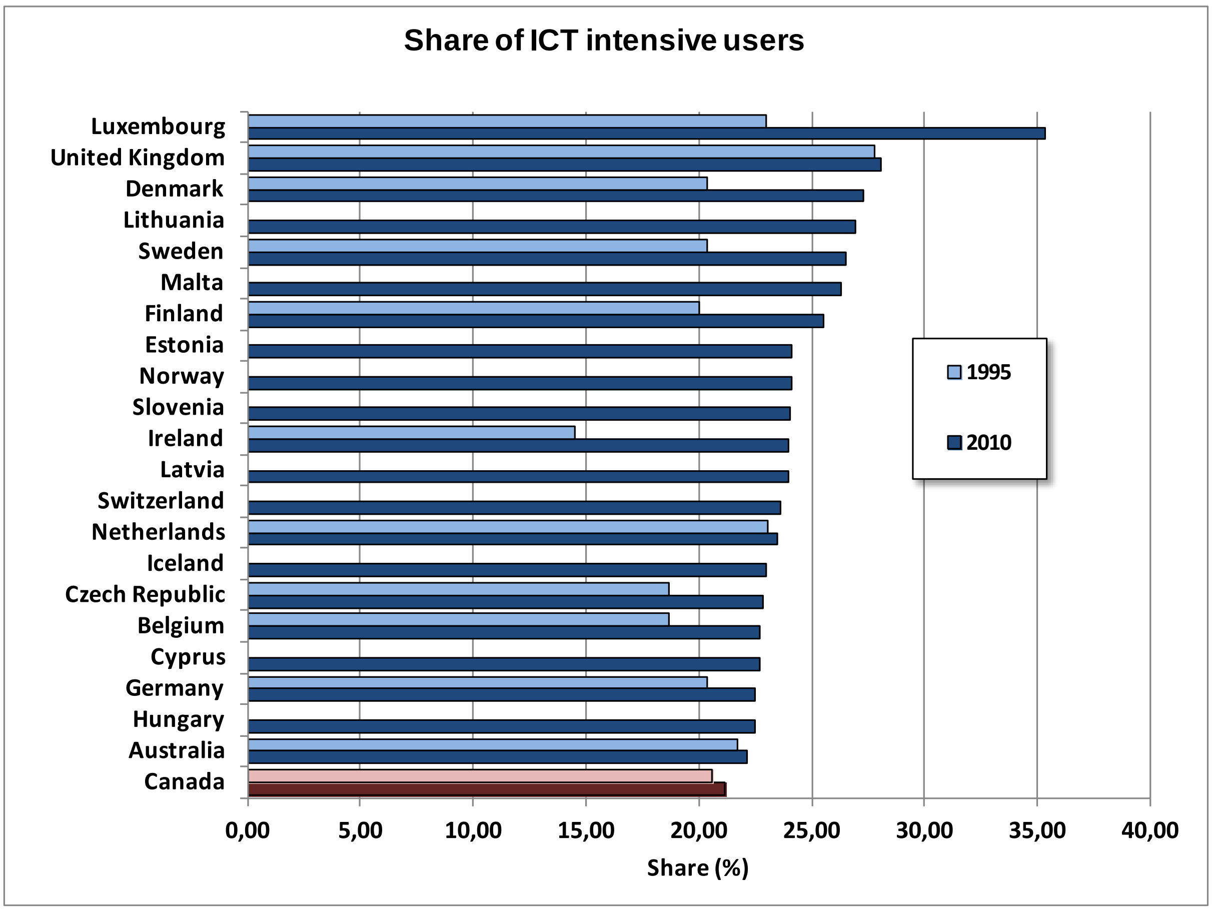
Source: OECD Education and Training, Education and Skills, Dataset: Graduates by field of education and the Annual Labour Force Statistics (ALFS) summary tables, population.

We complement this overview of training in computer science with a comparison between Canada and other leading countries as to their relative effort in the production of graduates. The Figure 5-8 presents the number of degrees per 100,000 population for 2000, 2004 and 2008. It shows that with 16 degrees awarded per 100,000 population in 2008, Canada ranks second last (23[th]), just before Sweden (14 graduates). With 65 graduates per 100,000 population, Australia ranks first, followed by Portugal (61), Finland (58), Poland (50) and Norway (43). It is worth mentioning that the countries having the highest levels of graduation in 2004 – Australia (93), New Zealand (58) and Iceland (51) – see their respective ratio decline between 2004 and 2008. Finally, despite already low ratios in 2004, CS graduation intensity in Canada, the United States and Sweden also decrease over the 2004-2008 period. From 2000 to 2008, the overall growth rates of those three countries were the smallest ones, at 12%, 5% and 0% respectively, while the highest growth rates over the same period are those of Poland (787%) Hungary (379%), Austria (370%), Finland (367%), Denmark (358%).

5.3 Human resources in ICT sectors

Data on ICT skills in the labour market completes this section on training and human resources. As mentioned in the methodological section (section 1.6), two skill levels are considered here. The first level concerns intensive users, whose jobs require a good functional knowledge of those technologies, but not necessarily a specialized knowledge or a formal ICT training. Typically, intensive users are workers who frequently use ICT in their daily tasks.

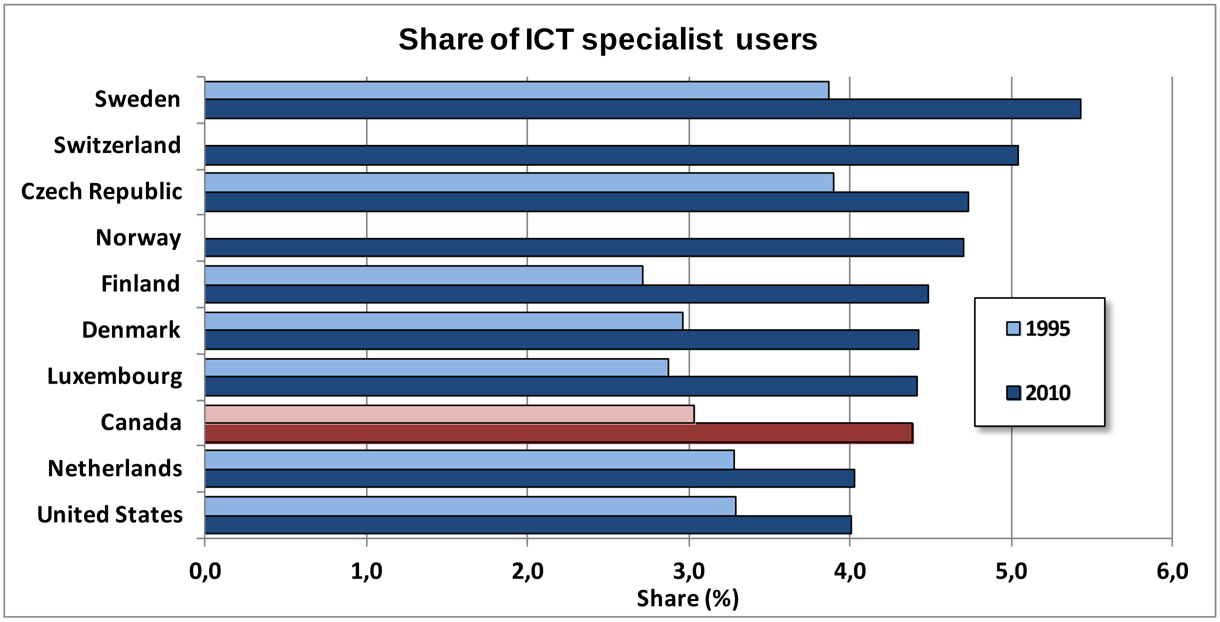
Figure 5-9 Top countries share of ICT-intensive occupations in the total economy, intensive users, 1995 and 2010*



Sources: OECD (2012), "ICT Skills and Employment: New Competences and Jobs for a Greener and Smarter Economy", OECD Digital Economy Papers no. 198, Figure 12.
** For Australia, Finland and Sweden; 1997 instead of 1995. For Australia; 2009 instead of 2010.*

As shown in Figure 5-9, Canada ranks last among the 22 considered countries in 2010 as to the share of ICT intensive users in their respective workforce. Fifteen years earlier, in 1995, Canada was ranking 5th among the 12 countries for which data was available. While the share of intensive users increases slightly in Canada between 1995 and 2010, from 20.6% to 21.2%, it expanded quite rapidly in many other countries. In 2010, in all countries except Luxembourg, the share of ICT intensive users in workforce ranges from 21.2% to 28.1%. For 15 countries out of the 22 shown on Figure 5-9, this share ranges from 21.2% to 24.1%. Hence, if Canada comes last among leading countries, it is nevertheless not that far from most of them.

Figure 5-10 Top 10 countries share of ICT-specialists in the total economy, specialist users, 1995 and 2010*



Sources: OECD (2012), "ICT Skills and Employment: New Competences and Jobs for a Greener and Smarter Economy", OECD Digital Economy Papers no. 198, Figure 6.
**For Finland and Sweden, 1997 instead of 1995.*

The second level of ICT skills concerns specialist users whose jobs are directly related to the conception, creation, programming, maintenance, etc. of ICT. As shown on Figure 5-10, Canada is among the top 10 countries based on the share of ICT specialist users in the global workforce. With a proportion of 4.4% of such ICT-specialists in its workforce, Canada holds the 8th rank in 2010, while the 1st rank is held by Sweden, with a proportion of 5.4%.

It should also be noted that, between 1995 and 2010, all countries shown on Figure 5-10 have notably increased the share of specialist users in their workforce. For example, it increases from 3.0% in 1995 to 4.4% in 2010 in Canada, from 3.3% to 4.0% in the United States, from 2.7% to 4.5% in Finland and to 3.9% to 5.4% in Sweden. This trend, complemented by the other indicators presented in this report, shows the growing importance of ICT in the global economy.

In short, the data presented in this section suggests that the rise and outburst of the technological bubble had an important impact on bachelor enrolment and graduation around 2000. At the level of graduate programs, this impact is less clear. For the whole field of MCIS as well as for CS, enrolments stop growing after 2004 and, for CS master programs, it even declines between 2005 and 2009. On the other hand, doctoral enrolment and graduation show an uninterrupted growth from 2000 to 2008.

At the international level, the number of computer scientists graduating each year in Canada appears rather low, since Canada is behind most OECD countries in this respect. On the other hand, Canada is among the top 10 countries as regards to the share of ICT specialist users in the workforce.

CONCLUSION

This study makes a positional analysis of Canadian Computer Sciences from both a national and international perspective. Using several data sources, it allows for an analysis of several dimensions. Scientific publications, mostly from academic institutions, are assessed through bibliometric data while inventive activities are measured through patents data. Computer Science funding of Canadian university research is measured, at least in part, from NSERC data. International comparisons of business enterprises R&D expenditures are performed using OECD data. OECD data also provides information about researchers and other personnel involved in business R&D. Canada's University training in CS is measured through Statistics Canada data on enrolment and graduation and also through OECD data on graduation. Finally, through occupational data, we measure the use of CS skill in the workforce.

On a national perspective, the publications data shows that the field of ICT grows notably between 2003 and 2007 and remains between 7,000 to 7,700 papers per year until 2010. Given this slowdown, Canadian ICT specialization index decreases over the studied period. On the other hand, as shown by the average of relative citations (ARC), the scientific impact of Canadian ICT publications improves notably. It is below the Canadian average (all scientific fields included) in 2003, but fairly above in 2008. Thus, ICT academic research is doing quite well in Canada.

Patent data is rather related to researches performed in industry. It shows that patenting activities in the Canadian ICT sector grow notably during the studied period. This trend can be seen from the point of view of intellectual property with data on Canadian assignees, and even more importantly from the point of view the inventive activities (per se) in data on inventors. Among the four ICT fields, Telecommunication and Computers are the two most important fields and are also those showing the highest growth rates (as seen in Figure 3-1). These trends are observed from USPTO data as well as from the subset of patents included in triadic families. They are also consistent with findings from OECD data on R&D in ICT industrial sector.

Data on NSERC grants shows that the funding of CS research increases from 37 million $ to 61 million $ between 2003 and 2010. While CS accounted for 6.1% of total grants awarded by NSERC in 2003, this share has grown to 7.1% in 2010. Among the funding programs, Canada Research Chairs and the Strategic Grants represent two important sources, even though the most important is by far the Discovery Grants program. As to business enterprises R&D, the share of GDP invested by ICT manufacturing industries decreases between 1997 and 2005 while it increases in ICT services industries, which include telecommunications and computer.

Data on university training clearly suggests that the rise and burst of the information technology bubble (around 2000) has affected the enrolment (and graduation) in related disciplines, at least at the undergraduate level. At master degree level, such an impact is less clear, while doctoral programs seem unaffected. As to the use of ICT and CS skill, occupational statistics show that the share of "intensive users" (whose jobs require a good functional knowledge of ICT) in the Canadian workforce slightly increases from 20.6% to 21.2% between 1995 and 2010. On the other hand, the share of "specialist users" (who create, program or maintain these technologies) increases notably for the same period, going from 3.0% to 4.4%.

On an international perspective, Canadian ICT and CS show good performances. As a matter of fact, Canada figures among the top 10 countries for the number of scientific publications, the number of USPTO and triadic patents, for expenditures and personnel devoted to business enterprises R&D in ICT and CS sectors, and for the share of ICT specialists users in the workforce. On the other hand, in regard to degrees awarded in computer science (all level included) and to the share of ICT intensive users in the workforce, Canada is behind most OECD countries. In the latter case however, this could depend on some characteristic of Canadian industrial structure.

Appendix A

NSERC Discovery Grants funding in Computer Science, 2003-2010

Back

NSERC Discovery Grants

DATA - NSERC Discovery Grants funding in Computer Science, 2003-2010

Program	2003	2004	2005	2006	2007	2008	2009	2010	2003-2006	2007-2010	2003-2010
Discovery Grants in CS - Total	**23 045 779**	**23 790 150**	**26 544 542**	**27 536 007**	**27 766 149**	**28 510 454**	**28 470 515**	**28 154 383**	**100 916 478**	**112 901 501**	**213 817 979**
Discovery Grants Program - Individual	23 020 779	23 747 150	26 471 542	27 463 007	27 361 149	27 625 454	27 339 270	26 556 383	100 702 478	108 882 256	**209 584 734**
Discovery Grants Program - Accelerator Supplements					350 000	830 000	1 076 245	1 550 000	0	3 806 245	**3 806 245**
Discovery Grants Program - Group	25 000	43 000	73 000	73 000	55 000	55 000	55 000	48 000	214 000	213 000	**427 000**
Discovery Grants in all disciplines - Total	**250 148 668**	**253 154 128**	**274 528 543**	**281 798 902**	**285 625 703**	**287 736 904**	**294 586 266**	**296 041 823**	**1 059 630 241**	**1 163 990 696**	**2 223 620 937**
Discovery Grants Program - Individual	240 835 695	242 852 013	264 151 011	271 686 009	274 795 177	276 840 902	282 391 721	280 605 494	1 019 524 728	1 114 633 294	**2 134 158 022**
Discovery Grants Program - Accelerator Supplements					2 269 400	5 706 200	8 076 200	11 835 972	0	27 887 772	**27 887 772**
Discovery Grants Program - Group	3 254 355	3 118 624	3 169 541	2 742 511	2 412 139	2 252 265	2 205 994	2 190 808	12 285 031	9 061 206	**21 346 237**
Discovery Grants Program - Institutes and Initiatives	*4 002 957*	*4 002 957*	*4 002 957*	*4 002 957*	*3 069 300*				*16 011 828*	*3 069 300*	***19 081 128***
Discovery Grants Program - Ship Time	*937 589*	*877 094*	*878 960*	*968 780*	*857 964*	*1 034 699*	*1 007 351*	*725 249*	*3 662 423*	*3 625 263*	***7 287 686***
Discovery Grants Program - Northern Research Supplement		*500 968*	*580 202*	*650 773*	*1 621 723*	*1 902 838*	*905 000*	*684 300*	*1 731 943*	*5 113 861*	***6 845 804***
Discovery Grants Program - Accelerator Grant	*847 072*	*1 531 472*	*1 474 872*	*1 476 872*	*600 000*				*5 330 288*	*600 000*	***5 930 288***
Discovery Grants Program - Leadership Support	*271 000*	*271 000*	*271 000*	*271 000*					*1 084 000*	*0*	***1 084 000***
Share of Discovery Grants - CS on all disciplines	**9,2%**	**9,4%**	**9,7%**	**9,8%**	**9,7%**	**9,9%**	**9,7%**	**9,5%**	**9,5%**	**9,7%**	**9,6%**
Discovery Grants Program - Individual	9,6%	9,8%	10,0%	10,1%	10,0%	10,0%	9,7%	9,5%	9,9%	9,8%	**9,8%**
Discovery Grants Program - Accelerator Supplements					15,4%	14,5%	13,3%	13,1%		13,6%	**13,6%**
Discovery Grants Program - Group	0,8%	1,4%	2,3%	2,7%	2,3%	2,4%	2,5%	2,2%	1,7%	2,4%	**2,0%**

Source: Observatoire des sciences et des technologies, NSERC Awards Search Engine.

Appendix B
Computer Science Projects Funded by the Canada Foundation for Innovation

Projects Funded by the Canada Foundation for Innovation

Province	Institution / Établissement	Project Leader / Responsable du projet	Project Title / Titre du projet	Maximum CFI contribution / contribution maximale de la FCI	Final Decision / Décision finale
ON	University of Toronto	Jurisica, Igor	Integrative Computational Biology for Cancer Genomics	$292 775	15-nov-11
ON	University of Ontario Institute of Technology	Bradbury, Jeremy	Laboratory for Human-Centered Computer Science Research	$21 152	15-nov-11
ON	Queen's University	Zulkernine, Mohammad	Methods and Tools for Building and Monitoring Reliable and Secure Software Systems	$50 000	15-nov-11
BC	The University of British Columbia	Pattabiraman, Karthik	A computational platform for Web Application Testing, Energy-Efficiency, Reliability and Security (WATERS)	$130 591	14-juin-11
ON	University of Toronto	Jurisica, Igor	Integrative Cancer Informatics	$220 209	14-juin-11
ON	McMaster University	Lawford, Mark	Laboratory Support for Model Driven Engineering of Software for Automotive Applications	$400 000	14-juin-11
QC	McGill University	Kry, Paul	Interaction Capture Laboratory	$59 742	14-juin-11
QC	Bishop's University	Allili, Madjid	Ground-Based LIDAR Data for Modeling, Mapping and Assessment of Natural and Man-Made Structures.	$75 896	15-mars-11
ON	University of Waterloo	Wan, Justin	Research Infrastructure for Scientific Computing and Visualization	$94 295	2-nov-10
QC	Concordia University	Glitho, Roch	End-user Service Engineering for Communication Networks	$98 863	2-nov-10
BC	The University of British Columbia	Abolmaesumi, Purang	Advanced Laboratory for Image Guided Therapy and Diagnosis	$125 000	15-juin-10
SK	University of Regina	Zilles, Sandra	Laboratory for Computational Learning Theory (CLeT Lab)	$72 278	15-juin-10
QC	École Polytechnique de Montréal	Pal, Christopher	Key Infrastructure for Scanning, Analyzing and Manipulating 3D Visual Data	$125 000	15-juin-10
MB	University of Manitoba	Irani, Pourang	Collaborative Visual Analytics	$376 790	9-mars-10
QC	Université du Québec à Chicoutimi	Bouchard, Bruno	Laboratoire de recherche sur l'Intelligence Ambiante pour la Reconnaissance d'Activités (LIARA)	$213 174	9-mars-10
AB	University of Calgary	Carpendale, Sheelagh	Multi-Touch Displays for Interactive Information Visualization	$187 876	17-nov-09
BC	The University of British Columbia	Warfield, Andrew	A Distributed Storage Facility for Virtual Machines and Execution Logging	$124 205	17-nov-09
AB	Athabasca University	Lin, Fuhua	Infrastructure for Building 3D Virtual Classrooms	$13 422	17-nov-09
ON	University of Waterloo	Li, Ming	Computing Cluster for Bioinformatics	$114 880	17-nov-09
ON	University of Toronto	Hinton, Geoffrey	Massively parallel computation and massive storage for the application of deep learning to large databases	$37 214	16-juin-09
ON	University of Waterloo	Keshav, Srinivasan	Infrastructure for Research in Tetherless computing	$98 352	16-juin-09
ON	University of Toronto	Fiume, Eugene	Construction of a Centre for Collaborative Interactive Digital Media	$2 400 000	16-juin-09
ON	York University	Jenkin, Michael	Canadian Centre for Field Robotics	$711 696	16-juin-09
QC	McGill University	Liu, Xue	Networked Embedded Systems Laboratory	$60 000	16-juin-09
BC	University of Victoria	Ganti, Sudhakar	Traffic Management support for the High-Speed Data Network Lab	$72 931	31-mars-09
ON	McMaster University	Carette, Jacques	G-ScalE: Gaming Scalability Environment	$258 886	31-mars-09
BC	The University of British Columbia	Hutchinson, Norman	Flexible computing platform for low-level experimentation in computer systems	$95 000	18-nov-08
AB	Athabasca University	Gasevic, Dragan	Infrastructure for Research in Semantic Technologies	$74 918	18-nov-08
SK	University of Saskatchewan	Mandryk, Regan	Human-Computer Interaction Laboratory for Sensing User Context and Adapting User Interfaces	$60 000	18-nov-08
ON	Queen's University	Fichtinger, Gabor	Percutaneous Oncology Intervention Laboratory	$400 000	18-nov-08
ON	The University of Western Ontario	Rogan, Peter	Chromosomal and point mutation discovery and interpretation in the post-genome sequencing era: tools for bioinformatic and genomic analysis	$374 063	18-nov-08
BC	The University of British Columbia	Schötzau, Dominik	Computational Laboratory for Algorithm Development and Visualization	$79 894	18-nov-08
ON	University of Guelph	Stacey, Deborah	Pervasive and Wireless Networking Research Laboratory	$101 804	17-juin-08
BC	The University of British Columbia	Lawrence, Ramon	Distributed Database Laboratory	$99 000	18-mars-08
BC	The University of British Columbia	Meyer, Irmtraud	A computer cluster for comparative genomics	$86 895	18-mars-08
BC	University of Victoria	Gooch, Amy	Colour Science for Computational Photography	$82 437	18-mars-08
BC	The University of British Columbia	Mitchell, Ian	Smart wheelchair testbed for provably safe human-automation interaction	$95 968	18-mars-08
ON	University of Toronto	Ganjali, Yashar	Advanced Packet Switch and Network Laboratory	$120 000	18-mars-08
ON	University of Toronto	Koudas, Nick	Social Information Systems Laboratory	$194 366	18-mars-08
ON	McMaster University	Patriciu, Alexandru	Robotic test bed for soft tissue image guided medical interventions research	$69 317	23-oct-07

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ON	Queen's University	Vertegaal, Roel	Advanced Input and Display Techniques for Transparent Computing Technologies	$397 773	23-oct-07
ON	University of Guelph	Nasser, Nidal	Wireless Computing Laboratory	$114 687	23-oct-07
NS	St. Francis Xavier University	MacCaull, Wendy	Center for Logic and Information	$105 364	23-oct-07
BC	The University of British Columbia	Lucet, Yves	Computer Aided Convex Analysis Laboratory	$62 783	19-juin-07
ON	University of Toronto	Frey, Brendan	Computing Infrastructure for Information Processing and Machine Learning	$174 921	19-juin-07
QC	McGill University	Archambault, Philippe	Innovative rehabilitation techniques to promote recovery and improve upper extremity function in persons with motor deficits	$149 600	19-juin-07
NS	Dalhousie University	Zeh, Norbert	Experimental Evaluation of Algorithms for Massive Data Sets	$118 186	19-juin-07
ON	University of Ontario Institute of Technology	Green, Mark	Laboratory for Advanced User Interfaces and Virtual Reality	$59 607	6-mars-07
BC	University of Victoria	Thomo, Alex	Data Exploration, Integration, and Analysis (DEIA) Laboratory	$57 917	6-mars-07
BC	University of Victoria	Tory, Melanie	Large Screen Visualization Laboratory	$73 942	6-mars-07
SK	University of Saskatchewan	Wu, FangXiang	Computational Bioengineering Laboratory	$60 000	6-mars-07
ON	McMaster University	Maibaum, Thomas	Visual Design and Analysis Laboratory (VIDALAB)	$100 000	6-mars-07
ON	Queen's University	Hassan, Ahmed	Development of an empirical software engineering facility capable of mining software repositories for large long lived industrial and open source projects	$100 000	6-mars-07
ON	University of Ontario Institute of Technology	McGregor, Carolyn	Health Informatics Laboratory	$125 000	6-mars-07
ON	University of Ontario Institute of Technology	Hung, Patrick	Research Center for Mobile Healthcare Service Assurance and Privacy	$54 459	6-mars-07
ON	University of Windsor	Gras, Robin	The Bioinformatics Laboratory	$25 707	6-mars-07
BC	University of Victoria	Pan, Jianping	Infrastructure of laboratory equipment for advanced research in networking (iLEARN)	$174 993	14-nov-06
ON	Ryerson University	Guan, Ling	Centre for Interactive Multimedia Information Mining	$650 000	14-nov-06
BC	The University of British Columbia	Jones, David	Tunable UV and soft X-ray laser source for coherent high-resolution spectroscopy	$374 781	14-nov-06
ON	University Health Network	Jurisica, Igor	Comprehensive systems biology approach to profiling and modeling of cancer; A collaborative infrastructure for integrated translational research.	$4 001 041	14-nov-06
ON	University of Toronto	Jurisica, Igor	Integrative Computational Biology: Towards Intelligent Molecular Medicine	$259 393	14-nov-06
NL	Memorial University of Newfoundland	Pike, David	Resources for Large-Memory Computational Problems in Mathematics and Statistics	$116 456	20-juin-06
ON	University of Toronto	Morris, Quaid	Systems biology through machine learning: adaptive computer programs for denoising, interpreting, and integrating large-scale biological databases	$128 873	20-juin-06
BC	The University of British Columbia	Pai, Dinesh	Laboratory for Sensori-Motor Computation	$112 808	7-mars-06
BC	University of Victoria	Wyvill, Brian	Computer Graphics Research Laboratory	$66 199	7-mars-06
BC	University of Victoria	Tzanetakis, George	Experimental Analysis Retrieval Laboratory for Audio-Based Environments (EARLAUBE)	$42 538	7-mars-06
SK	University of Regina	Chan, Christine	Visualization Infrastructure for Energy Informatics Laboratory	$104 314	7-mars-06
ON	University of Ottawa	Raahemi, Bijan	Knowledge Discovery and Data Mining Laboratory at the School of Management, University of Ottawa	$15 641	7-mars-06
ON	University of Waterloo	Wan, Justin	Resources For Scientifc Computing And Visualization	$132 274	7-mars-06
BC	Simon Fraser University	Tardos, Gabor	Laboratory for Computational Geometry, Complexity and their Applications	$120 000	17-janv-06
ON	University of Ottawa	Shirmohammadi, Shervin	Collaborative Virtual Presense Modeling, Communications, and Applications	$60 832	18-oct-05
ON	University of Toronto	Truong, Kevin	Cross-disciplinary Protein Engineering Laboratory	$150 000	18-oct-05
BC	Simon Fraser University	Vaughan, Richard	Scientific Data Acquisition, Transmission, and Storage (SDATS)	$120 000	18-oct-05
QC	Université du Québec à Montréal	Elbiaze, Halima	On-demand Bandwidth Allocation: Customer-Controlled Optical Network testbed infrastructure	$254 039	18-oct-05
BC	Simon Fraser University	HAMARNEH, Ghassan	Medical Image Analysis Laboratory (MIAL)	$130 000	7-juin-05
BC	The University of British Columbia	Murphy, Kevin	Computational statistics lab	$37 515	7-juin-05
BC	University of Victoria	Coady, Yvonne	The UVicUbiq (University of Victoria Ubiquitous Computing) Lab	$78 500	7-juin-05

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ON	Ryerson University	Okouneva, Galina	Computer Vision in Aerospace Applications Laboratory (CVL)	$41 549	7-juin-05
ON	The University of Western Ontario	Boykov, Yuri	Laboratory for Image-based 3D Modeling Technologies	$218 396	7-juin-05
ON	University of Toronto	Amza, Cristiana	Autonomic Computing Laboratory	$292 551	7-juin-05
NS	Dalhousie University	Blouin, Christian	A Research Laboratory in Evolutionary Algorithms, Computational Biology and Computer Graphics.	$243 112	7-juin-05
NL	Memorial University of Newfoundland	Banzhaf, Wolfgang	Network Analysis Laboratory	$46 880	7-juin-05
ON	University of Waterloo	Leung, Debbie	Infrastructure For Quantum Communications Research	$185 591	6-mai-05
QC	École Polytechnique de Montréal	Antoniol, Giuliano	SOftware Cost-effective Change and Evolution Research (SOCCER) Laboratory	$125 000	18-avr-05
ON	Queen's University	Green, Mark	Characterization of Innovative Infrastructure Materials and Assemblies at Extreme Temperatures	$104 468	8-mars-05
SK	University of Saskatchewan	Stanley, Kevin	Data-driven geometric modeling	$49 800	8-mars-05
ON	Queen's University	Manjikian, Naraig	Malleable, Cost-effective, High-performance Computing Systems	$100 000	8-mars-05
ON	Queen's University	Shatkay, Hagit	Data-intensive Research in Biomedical Computing	$220 000	8-mars-05
QC	Bishop's University	Bentabet, Layachi	Multiple Camera System for Spatiotemporal Modeling of a Changing Environment	$42 821	8-mars-05
QC	McGill University	Pientka, Brigitte	Infrastructure for evolving and verifying complex medical software systems	$157 656	8-mars-05
QC	Université de Montréal	Hamel, Sylvie	Élaboration d'un îlot de visualisation pour l'étude, l'analyse et la comparaison de structures biologiques complexes	$54 198	8-mars-05
QC	Université Laval	Ktari, Béchir	Fiabilité et sécurité des systèmes informatiques	$22 217	8-mars-05
ON	University of Toronto	Chignell, Mark	Knowledge Translation and Quality Improvement in Health Care	$118 595	11-janv-05
SK	University of Regina	Gerhard, David	Rough music and audio digital interaction lab (aRMADILo)	$59 655	19-oct-04
BC	The University of British Columbia	Jones, David	Laboratory for Ultrastable Femtosecond Optics	$149 932	19-oct-04
SK	University of Saskatchewan	Jamali, Nadeem	Hierarchical Peer Grid	$60 000	19-oct-04
QC	Université Laval	Roy, Sébastien	Virtual components and complex signal processing systems laboratory	$206 052	19-oct-04
QC	McGill University	Blanchette, Mathieu	Computing infrastructure for the analysis of non-coding functional regions of the human genome	$89 964	19-oct-04
NB	University of New Brunswick	Ulieru, Mihaela	Laboratory Infrastructure for CRC Research in Adaptive Information Infrastructures	$124 998	19-oct-04
NS	Saint Mary's University	Oore, Sageev	Interactive, High Degree-Of-Freedom Tools for Multimedia Applications	$57 840	19-oct-04
ON	Queen's University	Zulkernine, Mohammad	Dependable Software Systems and Their Evolution	$108 000	19-oct-04
BC	University of Victoria	Neville, Stephen	Development of cyber-security laboratory facility capable of accurate production of background traffic and analysis of real-time adaptive security solutions and metrics for industrial scale networks	$167 914	16-juin-04
ON	University of Waterloo	Keshav, Srinivasan	Infrastructure for Research in Tetheless Computing	$199 335	16-juin-04
ON	Ryerson University	Woungang, Isaac	Distributed Applications and Broadband NEtworks Laboratory (DABNEL)	$47 304	16-juin-04
ON	University of Toronto	Hertzmann, Aaron	Laboratory for Scanning 3D Shape and Physics	$200 000	16-juin-04
QC	Université de Sherbrooke	Deschênes, François	Laboratoire de réalité augmentée et de traitement de la vidéo	$83 626	16-juin-04
NS	Dalhousie University	Milios, Evangelos	Dalhousie DRIVE. Distributed Research Institute and Virtual Environment.	$200 000	16-juin-04
ON	McMaster University	Wu, Xiaolin	Major Equipment for Digital Cinema Research	$353 651	2-mars-04
QC	Université du Québec - École de technologie supérieure	Cheriet, Mohamed	Synchromédia : une infrastructure expérimentale pour létude et lintégration dinterfaces intelligentes de soutien au travail collaboratif	$1 369 701	2-mars-04
QC	Université du Québec à Montréal	Makarenkov, Vladimir	Construction et visualisation d'arbres et de réseaux phylogénétiques	$124 157	2-mars-04
QC	Université du Québec en Outaouais	Missaoui, Rokia	Efficient Processing of Multimedia Data	$511 785	2-mars-04
BC	The University of British Columbia	Schötzau, Dominik	Computational Mathematics Laboratory (CML)	$224 919	10-nov-03
BC	Simon Fraser University	Sahinalp, Cenk	Laboratory for Computational Genomics and Bioinformatics	$120 000	10-oct-03
AB	University of Calgary	Carpendale, Sheelagh	Innovations in VIsualization	$182 020	10-oct-03
BC	The University of British Columbia	Wasserman, Wyeth	Gene Regulation Bioinformatics Laboratory	$124 995	10-oct-03

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ON	University of Ottawa	Peyton, Liam	Intelligent Data Warehouse Laboratory	$319 537	10-oct-03
ON	University of Windsor	Ngom, Alioune	A Research Facility for Pattern Recognition and Data Compression with applications to Bioinformatics, Microarray Data Analysis, Data Storage, Classification and Computer Graphics.	$48 685	10-oct-03
ON	York University	Tsotsos, John	Laboratory for Active and Attentive Vision	$214 904	10-oct-03
QC	Concordia University	Haarslev, Volker	Logical Foundations of the Semantic Web	$91 222	10-oct-03
NS	Dalhousie University	Toms, Elaine	Information Interaction Laboratory	$125 114	10-oct-03
BC	Simon Fraser University	Kirkpatrick, Arthur	Haptic Interfaces Usability Laboratory	$200 000	16-juin-03
BC	University of Victoria	Wu, Kui	Laboratory for Wireless Sensor Networks	$85 863	16-juin-03
ON	McMaster University	Anand, Christopher	Automatic code generation of efficient and probably correct image processing and relational programs	$91 623	16-juin-03
ON	University of Ottawa	Boukerche, Azzedine	PARADISE Research Laboratory: infrastructure for research in PARAllel, Distributed and Interactive Simulation of LargE scale Systems and Mobile Wireless Networking.	$257 306	16-juin-03
ON	University of Waterloo	Storjohann, Arne	Research Computing Infrastructure: Collaborative Computing Facilities for New Researchers in Mathematical and Computer Sciences	$515 588	16-juin-03
QC	McGill University	Wanderley, Marcelo	Quantitative Assessment of Performer-Instrument Interaction: Applications to Gestural Control of Sound Synthesis and to the Design of New Musical Instruments.	$199 660	16-juin-03
NS	Dalhousie University	Keselj, Vlado	Scientific visualization through data mining of electornic commerce and health informatics large scale data sets	$697 094	16-juin-03
NS	Dalhousie University	Selinger, Peter	"Foundations of Computation" Research Laboratory	$72 734	16-juin-03
QC	Bishop's University	Allili, Madjid	Laboratory for Visualization and Computational Topology	$39 595	30-avr-03
BC	University of Victoria	Damian, Daniela	Research facility for the study of advanced collaborative technologies in global software development	$235 545	30-avr-03
QC	Concordia University	Mudur, Sudhir	Advanced Visual Computing Research Laboratory	$107 500	30-avr-03
QC	McGill University	Kienzle, Jörg	Fault-tolerant Massive Multiplayer Gaming Infrastructure	$85 727	30-avr-03
QC	Université de Montréal	Langlais, Philippe	Amélioration de l'infrastructure de calcul au DIRO pour la construction inductive de modèles pour la traduction automatique et l'automatisation du génie logiciel.	$111 483	30-avr-03
QC	Université de Sherbrooke	Giroux, Sylvain	DOMUS : Laboratoire de Domotique et d'informatique Mobile de l'Université de Sherbrooke	$160 000	30-avr-03
QC	Université du Québec en Outaouais	Adi, Kamel	Laboratoire de recherche en sécurité informatique.	$77 420	30-avr-03
AB	University of Alberta	Schuurmans, Dale	Algorithms for Large-Scale Probability Models: Learning, Optimization, Inference, and Search---An Integrated Computing Infrastructure for Data Analysis, Experimentation, and Algorithm Development	$112 054	11-févr-03
ON	Carleton University	Briand, Lionel	The Verification and Validation of Distributed, Object-Oriented Software Systems: Software and Infrastructure for Testing Research	$99 111	11-févr-03
SK	University of Saskatchewan	Schneider, Kevin	BlueWall: An Active Display Wall to Augment the Software Project Room	$60 000	19-déc-02
ON	University of Toronto	Balakrishnan, Ravin	Laboratory for Human-Computer Interaction and Computer Graphics	$397 594	19-déc-02
ON	University of Waterloo	Li, Ming	Information, Complexity, and Bioinformatics - Supporting Large Scale Bioinformatics Computing	$121 353	8-oct-02
ON	University of Waterloo	Aagaard, Mark	A Laboratory for Research in Programmable Hardware for Pervasive Computing	$252 654	8-oct-02
ON	York University	Wildes, Richard	Calibrated Active Vision Laboratory for Stereo and Motion Analysis	$126 440	8-oct-02
AB	University of Alberta	Jagersand, Martin	Laboratory for visualization, monitoring and human interaction with intelligent machines and robots	$300 000	12-sept-02
ON	Carleton University	Nussbaum, Doron	Medical Computing Research Lab	$163 423	12-sept-02
ON	Carleton University	Wainer, Gabriel	Advanced Laboratory for Real-Time Simulation	$152 569	12-sept-02
ON	University of Toronto	Zemel, Richard	Machine Learning and Neural Networks Laboratory	$165 140	12-sept-02
ON	York University	Allison, Robert	Active stereoscopic displays for a laboratory to study depth perception and virtual reality	$206 674	12-sept-02
NS	Dalhousie University	Heywood, Malcolm	Intelligent Infrastructure protection	$118 708	12-sept-02
BC	The University of British Columbia	Heidrich, Wolfgang	3D Geometry Acquisition and Rapid Prototyping Facility	$112 334	18-juin-02

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BC	The University of British Columbia	Maclean, Karon	GEMINI: General Environment for Multimodal Investigation into New Interfaces	$150 000	18-juin-02
ON	University of Ottawa	Turcotte, Marcel	Computing infrastructure supporting new initiatives in bioinformatics, coding, cryptography and combinatorial algorithms	$159 171	18-juin-02
QC	McGill University	Arbel, Tal	Computer Vision, Medical Imaging and Perceptual Modeling Lab	$176 000	18-juin-02
QC	McGill University	Hallett, Michael	Infrastructure for Distributed Information Systems, Data Mining and Bioinformatics	$196 884	18-juin-02
QC	Université du Québec à Montréal	Lounis, Hakim	Développement, déploiement et évaluation de systèmes de grande envergure	$100 921	18-juin-02
AB	University of Calgary	Watrous, John	Quantum Computing Research Group: Equipment for Theory Research Lab	$12 920	23-mai-02
ON	University of Toronto	Hinton, Geoffrey	Compute-server and equipped laboratory for research in machine learning	$243 857	23-mai-02
ON	University of Ottawa	Sankoff, David	University of Ottawa Laboratory for Innovation in Bioinformatics	$215 323	23-mai-02
AB	University of Alberta	Sorenson, Paul	Facility for Study of Effectiveness of Collaborative, Distributed Software Development	$546 350	28-janv-02
SK	University of Saskatchewan	Bunt, Richard	Developing the University of Saskatchewan Research Network (USR-net)	$4 788 837	28-janv-02
SK	University of Saskatchewan	Williamson, Carey	Experimental Laboratory for Internet Systems and Applications (ELISA)	$1 215 482	28-janv-02
ON	The University of Western Ontario	Ma, Bin	Infrastructure for the Study of Patterns in Large Biological Data	$148 897	28-janv-02
AB	University of Alberta	Schaeffer, Jonathan	WestGrid: The Western Canada Research Computing Grid	$11 990 839	28-janv-02
QC	Université du Québec - École de technologie supérieure	Fimbel, Eric	Laboratoire de recherche sur l'ergonomie des environnements de synthèse	$100 894	28-janv-02
ON	University of Ottawa	Felty, Amy	Software Correctness and Safety	$80 198	14-nov-01
ON	University of Waterloo	Baranoski, Gladimir	Computing Infrastructure: A Collaborative Computing Environment for Research in Mathematical and Computer Sciences	$369 584	14-nov-01
ON	The University of Western Ontario	Kari, Lila	Biocomputing Laboratory	$111 128	13-nov-01
ON	Ryerson University	Guan, Ling	Laboratory for Multimedia Processing and Communications: An advanced research facility with state-of-the-art equipment and integrated development environment dedicated to coding, indexing	$124 979	29-oct-01
ON	Trent University	Parker, James	Emotion and Health Research Laboratory	$36 798	29-oct-01
ON	University of Waterloo	Munro, Ian	Computational and Laboratory Infrastructure for the Design of Algorithms and Data Warehousing	$147 622	29-oct-01
ON	Carleton University	Weiss, Michael	Electronic Commerce Infrastructure	$55 474	25-sept-01
ON	University of Windsor	Sodan, Angela	Efficient, Scalable, and Intelligent Scheduling in Heterogeneous Parallel Systems	$66 450	25-sept-01
QC	Université de Montréal	Mignotte, Max	Infrastructure de capture et d'analyse statistique de séquences d'images pour la recherche et le suivi de formes en vision par ordinateur	$79 521	25-sept-01
AB	University of Calgary	Carpendale, Sheelagh	Interactive Visualization Laboratory	$293 260	19-juin-01
ON	Carleton University	Huang, Changcheng	Advanced Optical Network Laboratory	$174 548	19-juin-01
ON	University of Waterloo	Kamel, Mohamed	Cooperative Intelligent Systems Laboratory	$198 684	19-juin-01
QC	McGill University	Vangheluwe, Hans	Modelling Simulation and Adaptive Computation Lab	$132 329	19-juin-01
QC	Université de Montréal	Bengio, Yoshua	Algorithmes d'apprentissage pour grands ensembles de données	$103 465	19-juin-01
QC	Université de Montréal	Brassard, Gilles	Laboratoire d'informatique Théorique et quantique	$102 795	19-juin-01
NS	St. Francis Xavier University	Lin, Man	Applied Computing Laboratory	$52 058	19-juin-01
SK	University of Saskatchewan	Gutwin, Carl	A Research Facility for Investigating Next-Generation Groupware and Pervasive Collaboration	$100 000	22-mai-01
BC	The University of British Columbia	Hoos, Holger	BETA-Lab Computational Infrastructure - A Computing Environment for Bioinformatics and Algorithms Research	$101 000	7-mars-01
QC	Université de Montréal	Roy, Sebastien	Infrastructure de capture et d'analyse d'images pour la recherche en Vision par ordinateur	$151 828	7-mars-01
ON	McMaster University	Shirani, Shahram	Multimedia Processing and Communications Lab	$155 224	5-déc-00
ON	Wilfrid Laurier University	Ahmed, Maher	Symbol Recognition	$38 108	5-déc-00
SK	University of Saskatchewan	Vassileva, Julita	Agent Based Mobile and Ubiquitous Computing Laboratory	$358 275	12-oct-00
BC	Simon Fraser University	Wiese, Kay	Information Networking and Multimedia Centre (InfoNet Media Centre) A Versatile Environment for Multimedia Networking and Applications	$393 349	24-juil-00

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SK	University of Saskatchewan	Kusalik, Anthony	Bioinformatics and Computational Biology Research Laboratory	$363 370	24-juil-00
ON	The University of Western Ontario	Bauer, Michael	SHARC-Net: Shared Hierarchical Academic Research Computing Network	$6 616 620	24-juil-00
ON	University of Toronto	Abdelrahman, Tarek	Scalable and Inexpensive Computing with Clusters of SMPs Interconnected with Low-latency, High-bandwidth Programmable System Area Networks	$100 000	24-juil-00
ON	University of Waterloo	George, Alan	Waterloo Centre for High-Performance Computing	$373 842	24-juil-00
ON	University of Waterloo	Weddell, Grant	Software Technology for Embedded Control Programs: The Effective Evolution of Very Large Legacy Communications Software	$282 026	24-juil-00
AB	University of Alberta	Lu, Paul	Laboratory for Advanced Computer and Network Systems: End-to-End Performance and Availability	$131 236	30-mai-00
MB	University of Manitoba	Toulouse, Michel	Infrastructure supporting research in Heterogenous Distributed Computing	$175 345	30-mai-00
ON	Queen's University	Hassanein, Hossam	RELIABLE AND EFFICIENT SOFTWARE FOR INFORMATION PROCESSING AND EXCHANGE	$288 137	30-mai-00
QC	Université de Montréal	Sahraoui, Houari	Retro ingénierie, ré-ingénierie et amélioration de la qualité du logicel	$140 296	30-mai-00
QC	Université de Sherbrooke	Cherkaoui, Soumaya	Équipement pour la recherche en systèmes à base d'agents intelligents, multimédia et de collaboration	$48 736	30-mai-00
NB	University of New Brunswick	Bremner, David	Laboratory for the Investigation of Discrete Structures	$99 834	30-mai-00
NS	Dalhousie University	Inkpen, Kori	Advanced Groupware Environments for Collaboration	$200 000	30-mai-00
SK	University of Saskatchewan	Gutwin, Carl	A Distributed Information Visualization Laboratory	$99 835	7-oct-99
ON	University of Ottawa	Payeur, Pierre	An Infrastructure for Stereoscopic/3D Computer Vision & Modeling, Video Source & Channel Coding	$200 000	7-oct-99
NL	Memorial University of Newfoundland	Pike, David	Initial Computing Infrastructures and Beowulf Cluster	$75 500	7-oct-99
NB	University of New Brunswick	Bhavsar, Virendrakumar	Advanced Computational Research Laboratory (ACRL)	$163 380	7-oct-99
ON	Queen's University	Ellis, Randy	O.R./2010: Laboratories and Operating Rooms for Computer-Assisted Surgery	$1 891 200	22-juin-99
AB	University of Alberta	Schaeffer, Jonathan	Multimedia Advanced Computational Infrastructure (MACI)	$5 785 713	22-juin-99
ON	University of Toronto	Bilas, Angelos	Cluster Computing: Interconnection Networks, Programming Abstractions, and Applications	$40 000	22-juin-99
QC	McGill University	Siddiqi, Kaleem	The Computation, Visualization and Realization Laboratory	$193 200	22-juin-99
SK	University of Regina	Hamilton, Howard	Institute for Informatics Research	$544 693	30-mars-99
ON	University of Waterloo	Black, James	Improvements to University of Waterloo Network and Cabling Infrastructure in Support of Research	$683 100	30-mars-99
QC	École Polytechnique de Montréal	Cohen, Paul	Infrastructure robotique pour l'émulation d'opérations en milieux naturels hostiles	$355 751	30-mars-99
NS	Dalhousie University	Slonim, Jacob	Centre for advanced research and development in global information networking	$3 120 000	30-mars-99
NB	University of New Brunswick	Evans, Patricia	Distributed Web-based Computing	$27 953	13-oct-98
BC	The University of British Columbia	Murphy, Gail	An experimental Distribution systems facility to support software engineering research	$101 800	6-août-98
ON	The University of Western Ontario	Das, Anindya	Quality of Service Management and Interworking Studies for Distributed Multimedia Systems	$200 000	6-août-98
ON	University of Waterloo	Kontogiannis, Kostas	Computing and Laboratory Infrastructure Enhancements for the Wireless Telecommunications, Power Electronics, and Software Engineering groups	$117 300	6-août-98
QC	McGill University	Clark, James	The Shared Reality Environment	$200 000	6-août-98
QC	Université de Sherbrooke	Frappier, Marc	Spécification formelle des scénarios	$31 880	6-août-98
		TOTAL CS		**$76 316 167**	
		TOTAL FCI		**$4 520 366 817**	
		Percentage ICT/FCI		**1,69%**	

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