A New Canadian Interdisciplinary PhD in Computational Sciences

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Abstract
In response to growing demands of society for experts trained in computational skills applied to various domains, the School of Computer Science at the University of Guelph is creating a new approach to doctoral studies called an Interdisciplinary PhD in Computational Sciences. The program is designed to appeal to candidates with strong backgrounds in either computer science or an application discipline who are not necessarily seeking a traditional academic career. Thesis based, it features minimal course requirements and short duration, with the student's research directed by co-advisors from computer science and the application discipline. The degree program's rationale and special characteristics are described. Related programs in Ontario and reception of this innovative proposal at the institutional level are discussed.

Keywords: interdisciplinary, computational science, computer science, postgraduate studies

1 Introduction

The School of Computer Science (SoCS) at the University of Guelph is in the process of introducing a new interdisciplinary PhD program in computational sciences. The program is targeted at students and professionals who wish to engage in research that links topics of traditional computer science (CS) with some other discipline. This perspective recognizes that by the 21st century there is no other discipline like computer science that intersects virtually every other one in the sciences and humanities. All have been "colonized" by computerization.

Their present successes and future advances depend on more and smarter use of software technology. An interdisciplinary degree offers the potential to break down conventional silos of knowledge, and to train "highly qualified personnel" (HQP, in Canadian academic parlance) who are better able to apply computer-based computational techniques to a wide variety of problem areas. This program will be unique in Canada, and will contain features to make it especially attractive to applicants beyond those intending to pursue an academic career. Some applicants may seek this degree program to obtain more marketable skills, as graduates could expect to work in a variety of fields, not only the single field of their doctoral research, and in a variety of academic and non-academic environments.

Our students will have the opportunity to perform research that bridges CS and at least one other discipline such as, but not limited to, biology, engineering, chemistry, physics, mathematics, statistics, geography, economics, English, history, fine arts, psychology, and population medicine. Research topics are potentially drawn from any discipline on campus with a computational component, such as bioinformatics, computational biology, nanotechnology, modelling (developing and using algorithms to predict how real systems behave), simulation, digital humanities (interactive games and multimedia, digital culture, simulating history), health informatics (for both human and animal care), geomatics, embedded systems, artificial intelligence, human-computer interaction, data mining, and high-performance computing (developing and using parallel programming languages, libraries, and tools to solve complex problems arising in various disciplines).

From the above, it is evident that we take a broad view of "computational sciences". "Computational" and "computation" should not be interpreted as simply "number crunching" or "algorithms," as per convention. Rather, the term is intended in the sense of anything connected with the use of computers, or, colloquially speaking, "Computers AND ___" (fill in the blank). As for the term "science," it is meant in the sense of "the science of applying computers to various problem domains." Thus, unlike conventional degree programs in computational science (see Section 2) that focus primarily on traditional computation and algorithm development in the areas of mathematics, computer science, engineering, chemistry, and physics, our new program aims to be as inclusive as possible as it spans 11 academic units at our university.

This paper first describes in Section 2 our rationale for creating the new program and then its detailed characteristics in Section 3. Section 4 shares the experience of attempting this kind of innovation in our institutional setting. The conclusion in Section 5 summarizes our hopes going forward.

2 Rationale

This degree program is in step with current trends in graduate education, and meets society's present and anticipated future needs. It also leverages our university's competitive advantages and builds on our School's experience with interdisciplinary research and undergraduate education.

2.1 Needs of Society

We agree with Professor Mark Taylor who argues that, "If doctoral education is to remain viable in the twenty-first century, universities must tear down the walls that separate fields, and establish programs that nourish cross-disciplinary investigation and communication. They must design curricula that focus on solving practical problems, like providing people with clean water" (Taylor, 2011). This implies training the next generation of researchers to engage in interdisciplinary collaborations with a focus on solving relevant, real-world problems and developing skills marketable inside and outside of academia.

Furthermore, the report *Pathways Through Graduate School and Into Careers* indicates that, "graduate students lack access to clear, useful career information about the full range of career options available to them, both inside and outside the academy. This shortfall not only affects students during and after their graduate school enrolment, it also discourages undergraduate students from pursuing graduate education. While these results are of concern, they also provide an opportunity for future action" (Wendler, et al., 2012). Our new program is one answer to the future of graduate studies at the PhD level. Not only will it prepare students for a traditional academic career, but it will also fulfill the need for highly trained personnel in business and industry, and it will give them one of the most needed skills for this career: the ability to move more easily between domains and to collaborate with interdisciplinary teams. The need for this skill has been documented in numerous studies in business and industry. In addressing this need, we will be producing a highly sought-after graduate who will contribute on the global scene to the economy and to society.

The U.S. Bureau of Labour and Statistics predicts that over the next decade nearly 3 out of 4 new science, technology, engineering or mathematics jobs in the U.S. are going to be in computing, with many of these jobs requiring specialized skills and training. While these statistics are for the U.S., there is no reason not to expect them to roughly hold for Canada (indeed most of the world) as well. A survey of industrial experts recently undertaken by Canada's Information, Communication, and Technology (ICT) Council (O'Grady, 2011) estimated that the ICT sector alone would be seeking to hire approximately 106,000 new employees over the next five years (2011–2016), and warning that many of these positions may go unfilled, due to "alarming skills and labour shortages." Our program will help fill those needs in Canada. The report also underscored the fact that the job market for ICT had "radically changed," stating that "It is no longer enough to be a technical expert, the industry now needs workers with multi-disciplinary skills" and that "employers are on the hunt for personnel who have specific combinations of IT experience as well as expertise in domains such as e-health, e-finance, and digital media." The report called on universities to "shift to integrated, cross-discipline programs" to ensure that graduates are equipped with the mix of skills employers are looking for. Companies such as Microsoft, Amazon, Facebook, and Google all seek workers with interdisciplinary expertise in communication, visual arts, digital media, and computing (Spradling, Strauch, & Warner, 2008) (Hey, Tansley, & Tolle, 2009). Given the interdisciplinary nature of our new PhD program, SoCS feels well-positioned to expand graduate training in areas where there is strong industry and economic need over the long term.

An attractive feature of our program is that, unlike a conventional PhD in computer science, it can appeal to both computer experts and those working in an application area. Concerning the latter, a 2005 study foresaw some 90 million "end users" of computers in the US alone by 2012. Of those, 13 million would consider themselves "programmers," required to go beyond the use of spreadsheets and databases. Since 13 million far outstrips the 3 million professional software developers expected to be supplied through formal computing education, this potentially creates a large demand for training and support of so-called "end-user programmers" (Scaffidi, Shaw, & Myers, 2005). Many scientists working in the above fields exactly fit this category, and may be eager to expand their computing knowledge and skills through a program such as ours.

What's more, research shows that traditional software engineering techniques are often a poor match for the needs of end-user programmers working in computational science and engineering (CSE). Some reasons cited are the inability to fully specify software requirements in advance of development, and the inapplicability of conventional testing when the software's expected output is largely unknown (Carver, 2012). In response to these challenges, a research area known as software engineering for computational science and engineering (SE-CSE) or end-user software engineering (EUSE) has emerged with the objective of developing tools and methodologies to improve the effectiveness of end-user programmers. Given the rich and varied supply of interdisciplinary case studies that will take place in our new PhD program, students specifically interested in carrying out research in SE-CSE and EUSE will find a natural home.

2.2 Advantages of Guelph and SoCS

The new PhD program leverages Guelph's competitive advantages. The University of Guelph is strategically located within what is called the Golden Horseshoe (western end of Lake Ontario), in close proximity to many major urban centers and astride the important Toronto-Waterloo high-tech corridor. As a result, a unique PhD program at our university will be able to draw upon a large pool of potential students. Unlike conventional PhD programs in CS, which are plentiful in this geographic area, the new program takes an interdisciplinary and applied approach to computation. The University of Guelph is extremely strong in the sciences and humanities, with faculty in these areas enjoying national and international reputations.

Computer Science faculty currently collaborate with colleagues across campus in areas of common interest including computational biology, engineering, health informatics, artificial intelligence, computer-aided design, human-computer interaction, geo-informatics, digital humanities, disease spread modeling, computational epidemiology, data mining in the social sciences, and environmental modeling. This level of collaboration has resulted in over 100 journal articles and peer-reviewed conference papers co-authored with non-SoCS faculty. Current and past faculty members have advised or co-advised significant numbers of MSc and PhD students in other units within the university and externally, including Engineering, Integrative Biology, Pathobiology, Population Medicine, Economics, Music, Mathematics and Statistics, English and Theatre Studies, Environmental Science, Geography, and Psychology. As well, 21 non-SoCS faculty members have participated in our existing, not ostensibly "interdisciplinary," PhD program as advisors/co-advisors and/or advisory committee members 35 times. Concerning our graduate courses, non-SoCS students from 23 different programs have made up over 700 (16%) of the cumulative enrolment. The above demonstrate that SoCS already has the interdisciplinary momentum and experience to successfully launch this degree program.

At the undergraduate level, our Bachelor of Computing (BComp) program has had, from its outset in 2001, a novel interdisciplinary flavour, expressed in the requirement to study credits in an Area of Application close to the quantity needed for a formal minor. Thus, our undergraduate students have always been pushed to broaden their interests beyond their home niche of computer science, and to be on the lookout for opportunities to integrate their growing computer knowledge with some other field of study. Over the years, these areas of application have ranged very widely right across the university, from "obvious" linkages such as business administration, mathematics, and statistics, to the more "remote"—archaeology, music, drama, and many more. This approach helps to solve a modern conundrum: Must these disciplines send out their specialists with domain knowledge for training as programmers and software engineers, or shall computer specialists acquire sufficient domain knowledge to make a contribution? Our BComp program graduates HQP who already possess a critical mass of domain knowledge, so that, if they choose, they can pursue careers at the intersection of computer science and an application area, such as climate modeling, computational biology, and so on. The BComp program has experienced a surge in enrolment of 108%, more than doubling from Fall 2011 to Fall 2013. Its success stems partly from its interdisciplinary nature, and our new PhD program is arguably a natural evolution of the BComp approach.

2.3 Related Programs in Ontario

At present, five other institutions in Ontario offer graduate programs in computational science(s), but we have taken care not to duplicate them. Students at Trent University can purse the MSc or MA degree in Applied Modelling and Quantitative Methods (AMOD). Laurentian University offers the MSc degree in Computational Sciences. Supported by the departments of Computer Science, Biology, Chemistry, Engineering, and Commerce, this multidisciplinary program aims, primarily through course work, to prepare students for the design and use of sophisticated computational methods. Queens University offers a collaborative program in Computational Science and Engineering (QCSE) that leads to the MSc or MASc degree. The primary objective of this program is to provide students with sufficient understanding of the methods, algorithms, and tools of high-performance computing (HPC) that they can effectively apply HPC to scientific problems in their "home" area of expertise. The University of Ontario Institute of Technology (UOIT) offers the MSc and PhD degrees in Modelling and Computational Science. This program is offered by the Faculty of Science in partnership with the School of Energy Systems and Nuclear Science. At the master's level, students can pursue either a course-based or thesis-based option, with research topics derived from the areas of computer science, applied mathematics, physics, and chemistry. At the PhD level, research areas are limited to scientific computing and computational physical sciences with expected completion time of

12 semesters. The School of Computational Engineering and Science at McMaster University offers the MSc, MASc, MEng, and PhD degrees. Both the master's and doctoral programs are multidisciplinary programs that seek to connect the areas of computer science, mathematics, science, and engineering. The graduate programs aim to enable students to be proficient in modern computational methodology, with a heavy emphasis on mathematics and parallel computing. At the PhD level, this is achieved through a rigorous combination of course work and independent research study. Completion time is estimated at 12 semesters.

All five of the above programs support a national trend toward interdisciplinary computing based upon student demand and societal need. However, only two, those of UOIT and McMaster, offer doctoral degrees. Our new program at Guelph would not directly compete with, but complement, the programs offered at McMaster and UOIT. The primary reason for this is that the program at Guelph is constructed to exploit the unique research strengths of Guelph and, therefore, will attract, in many cases, a different type of student. The program at Guelph not only cuts across traditional disciplines like science, mathematics, and engineering, but also business, humanities, arts, and the social sciences. Therefore, in addition to attracting students from the traditional sciences, the program is expected to attract students who wish to pursue interdisciplinary studies in other areas such as veterinary medicine, population medicine, animal/human epidemiology, computational biology, economics, history, music, crop science, geomatics, interactive digital media and environmental modeling, just to name a few. These research areas fall beyond the scope of the areas covered by the two existing PhD programs in the province and, therefore, would go a long way toward making the University of Guelph the destination of choice for doctoral students and professionals wishing to participate in interdisciplinary research that links computer science with one of these disciplines. It would serve as a model for other institutions that wish to pursue a broad, inclusive interdisciplinary graduate research degree that highlights computation.

A secondary argument for the uniqueness of the Guelph program is that both programs at McMaster and UOIT concentrate on providing students with a breadth of computational knowledge. This knowledge is acquired through extensive course work with a focus on computational techniques that can be applied across a set of disciplines. In contrast, the program at Guelph emphasizes study in a single interdisciplinary area. This will result in students having a more specialized background and, potentially, increasing their value as HQP. Moreover, as will be seen below, the program at Guelph requires comparatively little course work, depending on the background of the student, thus allowing students to potentially complete their program in 9 semesters versus 12. The length of the program is critical with regards to attracting students and to providing an ever-increasing pool of HQP for government, industry and academia.

Indirect evidence of demand for a PhD in Computational Sciences can be found from the enrolment numbers at other institutions offering a similar degree. Unfortunately, this data is not usually available to outsiders. However, we were able to learn of 22 interdisciplinary PhD students in one program, and 33 interdisciplinary MSc students in another as of Fall 2012. Our new PhD would be ideally situated for capturing students from the latter program wishing to continue their studies. It is important to remember that the interdisciplinary PhD program at Guelph is more comprehensive than all other programs in the province, allowing for collaborations unique to Guelph.

A final rationale is that a traditional CS PhD program is strongly targeted to the academic job market, which suffers its own cycles from ups and down in university funding. The Taulbee Survey (Zweben & Bizot, 2012) found that of 1782 computer-related doctoral degrees awarded in North America (NA) during 2010-11, only 8% of graduates staying in NA entered conventional tenure track academic jobs in PhD-granting schools, while 19% became postdocs, and 6% took other academic jobs, for a total of 39% heading into academic careers. In contrast, 61% obtained jobs in industry and other non-academic sectors. These statistics serve to underscore the fact that the number of academic jobs for PhDs is currently small compared to those in non-academic positions, with the lopsided postdoc numbers indicating an oversupply of doctorates relative to the academic market. At least some of those 61% represent a pool of candidates who could prefer our non-traditional program over a longer traditional one. And since we are not depending primarily on academic-bound candidates, our PhD in Computational Sciences has the potential to be more stable over time than a conventional program with its typically narrower scope for employment.

3 Program Characteristics

As far as we know, our program is unique in Canada, and contains features to make it especially attractive to applicants beyond those intending to pursue an academic career, as well as to those without a CS credential. These features are summarized as follows:

- **Interdisciplinary Strength:** Faculty from external units are integrated into a single program that is exclusively administered by SoCS. Participants include 11 different academic units spanning 6 colleges (groups of departments and schools), the latter being Ontario Veterinary College, plus the Colleges of Arts, Biological Science, Business and Economics, Physical and Engineering Science, and Social and Applied Human Sciences.
- **Flexible Admission Requirements:** We do not require applicants to have a credential in CS. However, applicants must have demonstrated prior academic excellence by holding a thesis-based master's degree or equivalent independent research experience demonstrated through publications in scholarly journals and/or conferences. They must provide a letter describing their experience using computerized techniques and demonstrating that they have the necessary background to complete the research outlined in their research proposal. Suitable examples could include developing computations using domain-specific software tools or generic computational applications like Matlab, Mathematica, R, Maple, and WEKA.
- **Short Program Duration:** The normal duration is 9 semesters (3 years full time). It is expected that the majority of students will defend their degree by the end of semester 9.
- **Minimal, Flexible Course Requirements:** There are no uniform course requirements save for Research Methodology. However, a student's advisory committee, including co-advisors from CS and the application discipline (AD) may prescribe customized requirements in the form of self-study computational modules in view of the student's insufficient background in computing, as well as specific courses in either CS or the AD to strengthen background knowledge needed for the student's proposed research. Beyond the above, a student is free to take any other courses in CS or the AD according to their own needs and/or the advice of their advisory committee.

Faculty may provide specialized computational, peripheral and sensor equipment relative to the sub-discipline of study. As a member of Compute Canada[*], the university is also able to provide students with high-performance and big-data computing resources. Guelph boasts a number of state-of-the-art laboratories for engineering, the physical sciences, and biological sciences. It also has world class simulators, including an automotive driving simulator.

In terms of funding, domestic students will be offered support for 9 semesters from graduate research assistantships (GRAs), graduate teaching assistantships (GTAs), external scholarships and other university sources. International students will also have access to these funding sources, but many are expected to come pre-funded through special agreements already in place between the University of Guelph and the students' home governments. The latter typically provide full funding for up to 4 years, with the expectation that the student will return to his/her home country following graduation.

[*] Compute Canada is a national level advanced computing platform integrating HPC systems, data storage, high speed networking, and research expertise (http://computecanada.ca).

The following subsections detail specific admission and program requirements.

3.1 Admission Requirements

The interdisciplinary nature of this program allows for a wide range of acceptable preparation for entry into this degree. Entry qualifications fall into two broad categories: those that are primarily based in computation and those primarily in an application area. Admission into this program requires a recognized master's degree with high academic standing in either:

1. The application area to which computation will be applied, or
2. Computer science or a closely related discipline.

Entrants are expected to have substantial experience in either of these areas and will likely have a Bachelor’s degree related to one of the above areas.

In addition to the usual Faculty of Graduate Studies admission requirements, applicants to this program must submit (1) a current CV including publications, and (2) a research proposal including background, research questions, literature review, research methodology, and discussion of intellectual merit and broader impact of the proposed research.

In addition, the applicant must propose names of two faculty members—one in CS and one in the AD—to serve as co-advisors. It is expected that most applicants will already have been in contact with prospective PhD advisors in one or both of the relevant disciplines, who should provide supporting letters. Otherwise, SoCS will use the information to solicit advisors. The advisory committee will be filled out to its minimum size of three members after the student is enrolled.

The co-advisors will evaluate the application and determine if the applicant has sufficient computational background relative to the application area. If not, he or she will be required to take one or more undergraduate or graduate courses and/or one or more online tutorials in the first semester to provide them with the necessary training.

A master's degree is seen as appropriate preparation for entry into this program as it provides the research experience that is necessary to prepare students for doctoral studies. In exceptional circumstances, a student who has completed an honours undergraduate CS degree may apply for direct admission to the PhD program. The successful applicant must have an outstanding academic record, breadth of knowledge, demonstrated research accomplishments, and strong letters of recommendation.

3.2 Program Requirements

Students who enter the program without a recognized degree in CS or a closely related discipline may be required by their advisory committee to take one or more online learning modules. Those tutorials are not taken for credit and, therefore, do not appear on the student’s transcript. The rationale for using online modules is that the students who enter this program without a broad background in computation will need to acquire a set of skills and knowledge from a few, very specific areas of computer science. This will ensure that the learning and testing materials for these modules will be consistent and high quality for all students. The objective of the online tutorials is to provide concentrated, individualized instruction to students in a particular area of computation deemed necessary for performing the proposed research. The focus of each tutorial is narrow, and requires careful reading, analysis, and implementation, rather than broad coverage of a particular subject. Potential module topics include the following:

- **Introductory Programming:** This tutorial provides students with an introduction to programming in a high level scripting language such as Python. It will include the basics of control and data structures, data types, methods for program organization and formatting, and a study of library functions.

- **Operating System Tools:** This tutorial provides an exposure to the standard tools and libraries found in the Linux operating system. Common operations for managing files, directories, and processes will be learned. Developing and executing scripts and batch jobs will be presented, along with useful tools for text editing, text processing, and transferring files will be used.
- **Data Management:** This module presents methods for storing and manipulating large quantities of data on a computer. Topics will include common file formats and types (e.g., comma or tab separated, text, binary), organizing and accessing an SQL database, and using tools such as regular expressions to manipulate data.

All students must participate in the CIS*6890 Graduate Technical Communication and Research Methods course during the first year they are enrolled in the program. This course seeks to help students understand the links between different disciplines, and to appreciate the diverse interpretations and techniques involved in identifying and solving interdisciplinary research problems. Students participating in the PhD program will be required to present two seminars to an interdisciplinary audience, which should also help to develop their communication skills—something that is extremely important when working as part of an interdisciplinary team of researchers.

Students will have completed their course requirements by the end of their first semester and are expected to complete their research proposal and Qualifying Examination (QE) by the end of semester 3. The QE must be completed no later than the final semester of the minimum duration of the degree (5 semesters). The examination is intended to assess the candidate's knowledge and preparation to perform the research necessary for their studies. All candidates will be required to participate in both a written and oral examination related to their research proposal. Candidates who were required to take one or more tutorial modules will write a written test based upon the material from the modules, as part of the written component of the QE. The oral examination consists of a presentation by the candidate followed by questions from the examination committee. A research proposal must be submitted to the QE Committee two weeks prior to examination. This proposal must contain a survey of appropriate background literature, a description of the proposed area of research, a statement describing the merits and scholarly value of the proposed research, and a schedule of the research program that the candidate will follow which includes a sequence of milestones and objectives.

Questions will be based upon the research proposal. They are designed to test the candidate's general knowledge of their broader research area and to test their specific knowledge related to the proposal. Students may be required to take one or more additional undergraduate or graduate courses as a result of the examination if prescribed by the examination committee. A minimum grade of 70% is required for each of the additional courses. The examination committee may also require revision of the research proposal and possibly a second oral examination.

The written component of the QE will consist of questions based upon the proposal and all tutorial modules that the student was required to study. There will be one written test for each required module, given in the two weeks prior to the oral examination component. The outcome of the QE can be one of the following: the student passes the examination, the student is required to restudy one or more modules and repeat those tests, or the student fails the examination.

Students in this program will be required to perform high quality graduate research. They will be responsible for mastering the appropriate literature for their discipline, developing a mature research proposal, and defending their work. The student will be required to research and author a thesis as part of their degree. They will be required to defend their thesis in an oral examination featuring an external examiner

4 Institutional Reception

Since our new program is unique in Canada, it would certainly be taken as unusual at our university. We expected to run into a degree of resistance when endeavouring to "break the mold," and this section describes our experience. But to begin with the positive, we found that many colleagues all over the university strongly welcomed the proposal. We initially contacted faculty members with whom we had earlier collaborated on interdisciplinary research, and obtained over 30 letters of support from 10 different departments.

We were expecting "turf issues" to rear their heads primarily in terms of research funding, i.e., fears from deans that SoCS was attempting to "poach" research dollars from their own colleges. In the event, this concern did not materialize, and the deans proved to be supportive of our proposal.

When it started flowing through the institutional approval process, the program's unique features became subject to criticism for being "different from how we always have done it." There was an assumption that an interdisciplinary PhD combining computer science and discipline B ought to produce graduates who are fully qualified to serve as academics in both disciplines; i.e., they should be getting a kind of double degree based on a union of the requirements of both departments' traditional PhDs, and this would naturally take longer than for a single PhD. We had to explain that our training goal was different, and that our graduates would likely not wish to pursue traditional academic careers in either discipline.

The above projection of a "double PhD" was reflected in skepticism concerning our light course requirements. We responded that there are two scenarios we are trying to avoid creating: The first is where a student with a strong CS background (undergraduate and master's degrees) is required to take several courses in the AD, but due to lack of the undergraduate preparation assumed for those advanced graduate courses, it is difficult or impossible for them to succeed. The same scenario applies to students coming from the AD background but expected to take advanced graduate courses in CS that may even have no connection to their research. This kind of requirement can become a stumbling block and unattractive feature that deters people from applying to the program.

The converse scenario is where CS-background students are compelled to take several CS graduate courses that do not facilitate their research. Again, the scenario also applies within the AD. This kind of requirement will unduly extend their studies. As noted above, they may choose to take more courses, but this would not be a degree requirement.

We also cited precedents at our university for doctoral programs with few or no course requirements, and the point was granted. In general, the varying course requirements for PhD programs at Guelph are in line with the university's degree regulations that state: "The PhD degree is primarily a research degree; for that reason course work commonly comprises a smaller proportion of the student's total program than is the case at the master's level." Furthermore, in the European system, doctoral programs are often all about the dissertation and no courses are required. That arrangement is not viewed as substandard, but as an alternative to the usual North American approach.

It is important to realize that graduates from this program will not be claiming broad competency spanning CS and the AD, but rather expertise in an intersection of CS and the AD. Their special competence will be in applying CS techniques to a subset of the AD. If they are primarily computer scientists, they can potentially utilize the skills gained in this program to branch into different application areas; or if primarily domain experts, they can bring their computational skills to bear on different problems within the AD.

In the end, the program did win Board of Graduate Studies endorsement, and is now coming forward for formal approval by the Senate, the body of elected and appointed delegates responsible for academic governance at our university.

It is not impossible that the program may yet become ensnared in provincial politics, since any "new" program is seen to involve extra government transfers—though it is more accurate to see this program as a replacement for, or revision of, our existing traditional PhD—and this is a time of cutbacks in our province. On the other hand, our present government wishes for Ontario universities to do a better job of differentiating ourselves, and for Guelph to offer a non-traditional PhD certainly fits that objective.

5 Conclusion

We believe that our new interdisciplinary PhD program brings an innovative contribution to postgraduate education, with strong potential to elevate the visibility of computational science at the degree level. Key to institutional acceptance was making the case that there would be strong demand from local, national and international employers for this type of HQP. The world of work in both the private and public sectors is rapidly evolving and requires people who are agile in their thinking and experiences. This interdisciplinary research degree prepares students to look outside of the silos that educational institutions have constructed. With the advent of open data, open source software, flexible and mobile computational environments, and agile institutions, there is a great need for universities to produce PhDs that can not only navigate this landscape but, in fact, design and manage this new economic and social environment.

We recognize that this new degree is not going to suit everyone aiming for postsecondary education beyond the master's level. In particular, someone looking for a traditional CS doctoral program has numerous options to choose from across Canada. Instead, we wish to offer a fresh, purposefully-interdisciplinary research opportunity that is available almost nowhere else.

Finally, in terms of enhancing our local situation, we contend that the new PhD will make more realistic use of our faculty complement in an on-going period of fiscal restraint, by multiplying relationships across the campus and strengthening SoCS' research profile. It will increase funding opportunities for both SoCS and non-SoCS faculty by ensuring that the university has the critical mass necessary and technical expertise required to successfully apply for and receive today's large, interdisciplinary grants (Cassel, 2011). Other institutions may wish to consider a similar approach to "bridging the talent gap" in the years ahead.

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