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A new Canadian interdisciplinary Ph.D. in computational sciences

William B. Gardner*, Gary Grewal, Deborah Stacey, David A. Calvert, Stefan C. Kremer, Fangju Wang

University of Guelph, Ontario, Canada

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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 Ph.D. 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.

1. Introduction

The School of Computer Science (SoCS) at the University of Guelph is in the process of introducing a new interdisciplinary Ph.D. 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, modeling (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,

* Corresponding author.
E-mail addresses: gardnerw@uoguelph.ca (W.B. Gardner), ggrewal@uoguelph.ca (G. Grewal), dastacey@uoguelph.ca (D. Stacey), dcalvert@uoguelph.ca (D.A. Calvert), skremer@uoguelph.ca (S.C. Kremer), fjwang@uoguelph.ca (F. Wang).

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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" [7]. 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 enrollment, it also discourages undergraduate students from pursuing graduate education. While these results are of concern, they also provide an opportunity for future action" [8]. Our new program is one answer to the future of graduate studies at the Ph.D. 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 Labor 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 [4] 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 [3,6]. Given the interdisciplinary nature of our new Ph.D. 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 Ph.D. 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" [5]. 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 is 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 [1]. 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 Ph.D. 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 Ph.D. 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 Ph.D. program at our university will be able to draw upon a large pool of potential students. Unlike conventional Ph.D. 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 M.Sc. and Ph.D. students in other units within the university and externally, including Engineering, Integrative Biology, Pathobiology, Population Medicine, Economics, Music, Mathematics and Statistics, English and Theater Studies, Environmental Science, Geography, and Psychology. As well, 21 non-SoCS faculty members have participated in our existing, not ostensibly "interdisciplinary," Ph.D.