

「海外を拠点とした制御理論研究者のあれこれ」

解 説

## Life-Changing Experience: My Four Years in Toronto's Systems Control Group

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## 1. Leaving Toronto in 2008

On a Greyhound bus leaving Magog, where I spent a week of summer vacation with Murray, I knew I was going to leave Murray, leave Toronto, leave Canada... I didn't remember when was the last time I felt so heartbroken. Murray Wonham was the advisor of my Master's course at the University of Toronto.

## 2. All Started from 2006

Winding the clock back to August 2006, I landed for the first time in Pearson International Airport, Toronto. I was 23, full of dreams about virtually everything, and to start my Master's study at the University of Toronto. I got admission with full scholarship, which not only covered tuition but provided sufficient monthly stipend. Here is my 'secret' of being successful in getting such generous support.

## 3. Secret of Getting Scholarship from North American Graduate Schools

My secret, well, is threefold: doing the mechanics, being dedicated, and having good luck. Let me explain these in order.

- (1) Mechanics: There are certain documents you need to prepare for each application. GPA, TOEFL/IELTS, GRE (if you target graduate schools in the US), Reference Letters, and Personal Statement. Which documents are more important than others? Different professors weigh differently. So no chance to take; just do them all at your best. Personally I spent most time in drafting and proofreading Personal Statement, and least time in Reference Letters (because I was not the person writing them).
- (2) Being dedicated: Preparing the application documents is hard, not to say time-consuming. Starting early is key, and you really have to. For high GPA, you start basically from day 1 of your university life. For TOEFL/IELTS and GRE, I quitted university's soccer club and spent a substantial portion of my third year in preparing these tests. Tests are never my favorites, but you just have to do them. And if you decide to do the tests, why not try doing your best. Finally, writing Personal Statement was

in fact fun. At early 20s, everyone is filled with dreams and full of ambitions. Personal Statement is the document that you can dump them all in, of course in an intelligible and elegant way. All these take great dedication; but no success comes without dedication.

- (3) Having good luck: Yes, a final piece to success is to have good luck (like many other things). Let me explain why. You usually target certain professors or research groups. Now in the year you apply, the professor might be in sabbatical, or already has too many graduate students, or simply doesn't have enough fund to support new students. These can happen; and if these happened, no matter how strong your application is, you don't get to the professor or group you want to. If you make your targets less specific, then there is always funding for good students, somewhere. The above being said, I'd like to stress that luck comes *after* dedication, inasmuch as the application is not merely lottery.

At my time, I had all three above. Apart from getting Admission plus Scholarship from the University of Toronto, I got a few others from universities in the US. I confess that I took some time before I decided, as I suppose many people would do. But soon the hesitation was proved to be unnecessary, and the decision was the best I have ever made, which has since fundamentally changed the trajectory of my life.

## 4. Study in Toronto

The Systems Control Group (SCG) is (at least was) one of the largest centers in the world for control research. Murray Wonham, Edward Davison, and Bruce Francis are among the best known control researchers. All SCG graduate students are mixed together and have their desks in two large offices, the configuration of which encourages communications and vibrant discussions.

For a Master's course each student needs to take five courses. Five might sound very few for Japanese students; these courses are extremely intensive and keep you busy for a whole year. At my level of intellectual ability, three courses per semester is maximum. These courses cover from basics to research oriented topics; well designed homework consolidates one's understanding of the material. Often the final projects are open research problems, solving which would mean you might have got content to write a paper. Of course the lecturers must have spent a great

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deal of time in course preparation. It was a hard time going through the courses, but they well worth one's time.

The five courses I took were Supervisory Control of Discrete-Event Systems I, II, Mathematical Logic, Hybrid Systems, Knowledge Representation and Reasoning. The first two were offered by Murray Wonham, and there is no better place to learn the material than here inasmuch as Murray is the founding father of the theory. Murray's lectures were once a week, three hours each, intensive and insightful. Besides, his lectures were full of subtle jokes; some I got at the spot and laughed out, but many I realized only afterwards and wondered how many other students had realized the subtleties. These two courses pave way from the basics to advanced research topics. Upon finishing these two courses, one is well positioned at targeting research problems in this field.

The Math Logic course was in fact an undergraduate course offered by the Math Department. This course was a must for Murray's students, as he believed that a solid background in math logic was essential for doing research in control, in particular for proving statements. And I totally agree on this point.

Hybrid Systems and Knowledge Representation courses were my choices. The former was offered by SCG as a control course, while the latter offered by the Computer Science Department as an AI course. I chose these two because both were related to discrete-event systems. Hybrid Systems deals with plants (i.e. systems to be controlled) with both continuous and discrete dynamics. Knowledge Representation introduces modeling dynamic systems as logical statements; the collection of these statements is viewed as a "knowledge" database. The framework deals with automatic reasoning in this database to derive answers with regard to imposed queries.

My first year was mostly devoted to courses, leaving little time for research. The only research activity of my first year was to write up a proposal for my Master's research, which was required by SCG. For writing this proposal I reviewed much literature, old and new, in control and in robotics (I shall talk about my research in more details in the next section).

I also audited a few courses which were very helpful. The Control Systems course taught by Bruce Francis was mind-blowing: he explained difficult concepts in a clear and concise way and provided motivation behind the original development. I learned the course before in China, but the level of clarity and sophistication were distinct. In Bruce's course, I learned new insights out of old contents. I particularly liked Bruce's lecture notes, which I am now using in my own teaching of the same course.

Another course I audited from Bruce was his Distributed Control of Robotic Networks. While the course was at the time beyond my full comprehension, it inspired my interest of this topic and led me eventually to pursue my Ph.D. in this direction.

One more course I audited that much impressed me was the Computability and Logic taught by Stephen Cook. Stephen is a recipient of Turing's Award for his work on NP-complete problems, and I remember vividly his notes on constructing various types of Turing machines. His lectures were concise and interesting, but assumed certain Computer Science prerequisites that eluded me before long. Nevertheless my time was well worth for getting a flavor of the scientific studies of Computers from a giant in that field.

To summarize my study in Toronto, it was hard, stressful, and all-consuming. I devoted many evenings and weekends on working out problem sets and projects. Because of all the hard work, however, I learned a great deal of new knowledge that eventually prepared my research and subsequent academic pursue. In particular, the inspiration from those great teachers was priceless.

## 5. Research in Toronto (Master)

Since the very beginning I had been interested in research topics on multi-robot teams. Specially interesting to me was how to effectively coordinate individual robots such that as a team they perform desired tasks specified by the designer.

Murray (as my advisor) let me follow my own prompt, and suggested me of formulating a discrete-event multi-robot control problem, and solving such a problem using discrete-event methods. And this should be the proposal for my Master's research.

Although I got to do what I wanted to, I had tremendous struggle in finding a suitable problem, as multi-robot control had never been studied in the field of discrete-event systems before. Namely this was a completely new problem. That being said, since multi-robot control was the topic of my own interest, I had equally tremendous passion working on it. (This is, in my opinion, an ideal model for any graduate student, and the guideline for supervising my own students.)

Towards this goal, I did a large amount of literature review: robotics, concurrent programming, distributed computing, distributed artificial intelligence, multi-agent cooperative control, and (even) animal group behavior. This process was time-consuming, difficult to understand technical details of different fields, and often discouraging to find yet another unworkable problem. I can recall that for some time I was doubting if I was ever to compose a proposal. Indeed, Murray had the same worry I believe, as he suggested a different problem for me to consider as an alternative. On the other hand, this process was in fact very fruitful. I got to learn some very similar problems having attracted attention from researchers working on different fields, and an entire different set of tools had been employed to address these problems.

The effort paid off, eventually. After a slow start, my research progressed smoothly. After formulating and solving the first basic discrete-event multi-robot

control problem, I went on formulating and solving several extended problems. Some of these extensions were inspired by the literature I reviewed, so you never know when your previous effort might come to help that once you thought to be wasteful. I progressed so rapidly that Murray joked (seriously) that if I was to keep that pace, he would need to grant me a Ph.D.

I got enough results for my Master's thesis and went on organizing the committee for my defense. In SCG, there is no fixed time at which all students do their thesis defense. If your advisor and you think you are ready to go, you can proceed to contact three professors to form the committee for your defense. One professor must come from outside of SCG. For my case I had two from SCG and one outside. Then you need to coordinate a time that all committee members, as well as your advisor, can attend, and that time will be your defense. At least two weeks before the defense you must deliver your thesis to all committee members such that each member has enough time to go through your work.

A defense in SCG consists of a 30-minute presentation, followed by Q & A that has no time limit. Typically each committee member takes 20-30 minutes, which means at least one hour is spent for Q & A. I heard there were cases where Q & A took as long as 2-3 hours. Questions will range from slides to details in your thesis. It is not unusual to be asked to clarify Definition 3.2 on page 42 of your thesis. Each committee member brings along a list of questions that he/she recorded when reading your thesis. It is a lengthy process, but ensures that each approved thesis meets the highest standard.

I scheduled my defense on June 26, 2008 (deliberately one day before my birthday), so that, on the assumption of success, I would have a stress free birthday party. My defense indeed went fairly smoothly; after about 90min I successfully defended my work, and in fact the committee gave me the highest A+ for my thesis work.

Summary for my Master's research in Toronto: Choose a topic of your interest, believe your work, and work hard. Efforts will pay off.

## 6. Early Conference Experiences

I had a couple of conference experiences during my two years in Toronto — a good one and a bad one — both are CDC (IEEE Conference on Decision and Control).

My first CDC was 2007 in New Orleans. It was not my own work, but the work of a previous Ph.D. student (Lei Feng) of Murray who went to Sweden (KTH) for postdoc and couldn't attend the conference. Murray sent me instead. I must say I really enjoyed the conference — meeting people working on similar problems, listening to plenary talks given by famous researchers, and above all making a presentation in front of others (even though it was not my

work). Plus, I took some time off to see New Orleans' French Quarter and Garden District, a bonus to hard work at conference.

The 2007 CDC experience motivated me to submit my own work to the next year's CDC, Cancun, Mexico. I submitted the main results of my Master's research, and was looking forward to meeting famous people again, not to mention the additional luxury of lying down on the picturesque Cancun beach. The publication result was, however, devastating. Not only the paper was rejected, but the reviews were too bad to believe. One reviewer criticized: "what is the meaning of this exercise?" The rejection came just days before I left Toronto, although pointless Murray and I thought some reviewers were rather unfair and prepared a rebuttal letter. We received a long reply from the organizing committee with a degree of sympathy, but the result remained negative.

Though extremely disappointed at the time, I believed in my results and was eager to prove that this was definitely not just an "exercise". Along with Murray's encouragements, we went on for a TAC (IEEE Transactions on Automatic Control) journal paper [1] which was accepted after a few rounds of reviews/revisions. In fact this work set the basis and led eventually to my first book [2].

## 7. Leaving Toronto and Returning

After finishing my defense in June 2008, I decided to leave Toronto but continue my Ph.D. study in Tokyo. This unusual trajectory is for a good reason, which will be explained in Section 9 below. Did (and do) I regret this decision? Yes and no, but certainly, when looking back, this decision added lots of drama in my life.

I spent a week (in July 2008) of summer vacation with Murray in his cottage in Magog, where I learned deep Canadian culture : respect the nature, canoe on the lake, and sense of individual space. Lying down on the deck by Lake Memphremagog, it was as good as (and much quieter than) on the beach of Cancun.

On a Greyhound bus leaving Magog, I was heartbroken. I said to myself, I must come back here again.

In the subsequent three years, I got my Ph.D. in Tokyo Institute of Technology. With no hesitation, I returned to Toronto, returned to the Systems Control Group, and returned to Murray, this time as a postdoc.

## 8. Research in Toronto (Postdoc)

From October 2011, I started my 2-year postdoc work in Toronto. I felt I returned home. Three years have gone; the SCG was much the same, except that the students there were all new to me. In the student discussion room, there was a new ping-pong table, a refreshing activity among not only students but faculty members (Bruce Francis was an active ping-pong player).

I got a nice cubic in the student office (there was no other office just for postdocs). I enjoyed being mixed with many others, just like I was a student there three years ago. Students in SCG liked to discuss academic problems, which is a vibrant environment for research.

As for research topic, I was free to do anything I was interested in, and that was a bonus reason for me to return to Toronto. The big direction, nevertheless, that I wanted to pursue, and this was also Murray's intention, was to extend my Master's research to a much further level. Thus this time, unlike at the beginning of my Master's research, I was able to delve right into research work, with no delay and no learning curve – there was much to do and I knew how to proceed. Before long, I was already writing conference and journal papers on several results newly derived. The start was a smooth sailing.

Apart from research, I sat in Murray's class again (Supervisory Control of Discrete-Event Systems). I didn't need to study or refresh my knowledge on the material. My purpose this time was to learn Murray's teaching skills. I aimed, and determined, to become a professor, in which case I would teach this same course myself. (I do, and I have done so for four years.) I was taking notes, particularly on those words that Murray used to transit from one concept to the next, on the back-the-scene stories he provided on developing an original result, and on his insightful paraphrases for definitions and theorems. These all have become invaluable asset in my own teaching today, and I believe my students benefit from these side notes too. I was also trying to record his subtle jokes. I have to say many of those were something intrinsic to personal characters and hard to imitate. On the other hand, one doesn't need to, and probably shouldn't, mimic everything another person does – otherwise a video lecture would suffice.

In one of Murray's lectures, he mentioned an outstanding open problem in the theory that awaited a solution. I remembered he mentioned the same problem back when I took the course as a student. I guess he mentioned this problem every time he taught the course. The problem was on partial-observation supervisory control: on one hand, the property called observability is algebraically ill-behaved; on the other hand, a stronger property called normality is too conservative. So the question is, does there exist a property in between that is algebraically well-behaved? This time, this problem caught my attention, and I had an idea that might help construct a solution. Prompted by this idea, and motivated by the fact that this outstanding problem hadn't been solved for about 25 years, I set off writing down a solution. This was not at all in the original plan for my postdoc, but I had the freedom to follow my prompt, which I believe every true researcher should deserve.

Murray was extremely thrilled to see this breakthrough. He named the new concept "relative ob-

servability", and we nailed it down to the literature by conference/journal publications.

Towards the end of my postdoc, I believed we had developed a series of solid results that could be put into a framework, and I proposed to Murray to organize our work into a monograph. Murray was very supportive and encouraging. I was only able to finish a structure of the book when I was in Toronto, but I continued afterwards and finally got the book published [2].

During my postdoc in Toronto, I also took over the annual revision work for Murray's lecture notes "Supervisory Control of Discrete-Event Systems". This is the main reference for Murray's course, and each year Murray updated the notes by adding and/or removing certain material. The update had been carried out by the secretary of the SCG, who in fact typed the initial draft. I took the work over from the secretary for two reasons: (i) she was having increasingly more administrative work to do, which often resulted in significant delay of updating the notes; (ii) more importantly she was going to retire. Thus I got all files from the secretary and was able to compile the notes on my own computer. Since then, the annual update had been done by me and this turned out to be more efficient and productive.

Perhaps motivated by our book [2], Murray eventually proposed to also publish his notes. We set off working on this project. Since the notes had been written over a period of two decades, there were numerous details that had to be taken care of, the process of which was honestly painstaking. We had also decided to add new material such as my own work on supervisor localization and relative observability, and at the same time remove certain perhaps obsolete or not-so-relevant material. This work had eventually led to our second book [3].

During my two years in Toronto as a postdoc, I met and had interesting discussions with a few other postdocs and visitors in SCG. One of the visitors was Renyuan Zhang, who was then a Ph.D. student visiting from Xi'an JiaoTong University. He was very interested in extending my work on supervisor localization, and we started collaborating on a few topics that I thought worth developing. This collaboration had dramatically helped progress my own research, because Renyuan was excellent in coding and implementing theoretically designed algorithms. He helped code algorithms for supervisor localization and relative observability (two main results during my postdoc), which would have taken much longer time if I was to do the programming myself. With his codes, I was able to test my theories on big and complex examples, which added significant values to the obtained results. Renyuan, now a professor himself, has since become an indispensable collaborator, and we are working together on exciting topics.

Summary for my postdoc research in Toronto: Choose a free environment, follow your prompt, and open to

collaborations.

## 9. Private life in Toronto

If you are looking only for serious stuff, you can safely skip this section. I believe, however, private life is just as important as ‘non-private’ life; at least for me, my private life in Toronto enriched my experience and changed the trajectory of my life.

Let me wind time once again back to 2006, when I first started my experience in Toronto. My English wasn't bad at that time, but definitely not as fluent and natural as needed for everyday life. I was excited to be in an environment where people around me spoke native English, and I was sure my English was going to improve rapidly. I tried to hang out as much as possible with local fellows, grabbing lunch or hitting a bar, from which I got to learn how to speak English like natives, not to mention the style of life and culture of the locals.

In fact in Toronto you do not have to do what I did. It is a multi-cultural city with immigrants from all over the world and from diverse cultural backgrounds. You can easily find people from where you are from and hang out just with them. Comfortable? Yes. But you are wasting your golden chances of improving your English and opening your eyes to new cultures. You can always stay with people speaking your mother tongue back in your own country. So don't do that in Toronto.

I also went to many events that celebrated a variety of cultures: from St. Patrick Parade to Brazil Festival, from Salsa parties to Pride Parade. I might like some more than some others, but I was open-minded to all.

Above all things I did in my private life in Toronto, the singly most important one was meeting the love of my life. I met my wife at a BBQ party held for new international students, and she was a visiting student from Japan. Life is intriguingly designed: she is from the university that I visited as an exchange student in my fourth year in undergraduate. So we had a lot to talk about, and I found her pretty and intelligent. After a year, however, her term of visiting Toronto came to an end and had to return to Japan. I saw her off at the Pearson International Airport, and said to her that I would find a place in Japan to do my Ph.D.

It's a lie if I say I never considered staying in Toronto for my Ph.D. If I so did, I'm not here writing this article. To tell the truth I had much struggle in making a decision, which I believe anyone in my position would. To put the long story short, I finally decided to follow her and left Toronto. We got married three years later, and returned to Toronto together when I became a postdoc. I would have an entirely different life if I stayed in Toronto, but I'm grateful that I chose the current one that I'm living.

## 10. Final Remarks

In retrospect, I have the following messages for young fellows who are looking for an overseas study/research experience:

- By all means go. You will find a very different experience overseas; good or bad, the experience will no doubt enrich your life in a way that cannot be done if you stay home.
- Choose a place where you can have maximal freedom of selecting your own research topics. In that case you work with maximal passion for topics that you are most interested in.
- Follow your prompt of research ideas. You might discover unexplored areas which could lead to groundbreaking results.
- Choose a multi-cultural city like Toronto. Experience different ways of thinking, embrace different ideas, and be open-minded to others' opinions.
- Finally, work hard. Let's face it – we are not genius. So let's work hard to make up.

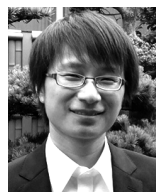
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