Beatrice Helen Worsley: Canada's Female Computer Pioneer

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When Beatrice Worsley died in 1972, Canada lost a computer pioneer and a witness to several great moments in computing history. This biography aims to provide insight into Worsley's obscure, but remarkable and all too short, career.

In the past decade, several authors have begun to explore the history of computing in Canada. A special 1994 issue (vol. 16, no. 2, April–June) of the *IEEE Annals of the History of Computing* was dedicated to the theme, and John Vardalas's book, *The Computer Revolution in Canada,* (MIT Press, 2001) examined the development of a Canadian computer industry. When discussions turn to early developments at the University of Toronto, one name that frequently appears is Beatrice Worsley. Although many other computer pioneers still recall her quiet personality, complete accounts of her career and life are more disjoint.

In fact, her experiences and accomplishments were remarkable. During her short career before a fatal heart attack at age 50 in 1972, Worsley built a differential analyzer; was a member of the Cambridge, UK, Mathematical Laboratory, during the first EDSAC run; worked with well-known figures such as Douglas Hartree and Alan Turing for her PhD; published 17 technical papers; cowrote a compiler for the Ferranti Mark I; and taught various computer courses for 20 years at the University of Toronto and Queen's University in Kingston, Ontario.

Worsley was a pioneering computer scientist and the first female in Canada to make significant contributions to the field. This biography will not fully explore the role of gender in the history of computing, but as we shall see, there is little doubt that Worsley's gender had a significant effect on her career.[1]

Beatrice Helen Worsley was born in Queretaro, Mexico, on 18 October 1921, the second child of Joel and Beatrice Marie Worsley. Their first was Charles Robert Worsley, a few years older, born in Atemajac. Joel Worsley had been born in Ashton-Under-Lynn, Manchester, UK, in 1887 to a working-class family. In 1908, he moved to Mexico to work at his wife's family's textile mill in Xia near Oaxaca, which her grandparents had established in the 1850s. Around 1917, the mill was destroyed by rebels, and the family moved to El Salto where Joel rose to general manager of the Rio Grande group's CIMSA mills. Charles and Beatrice were home schooled by their mother, and the children spent many years isolated and physically cut off from the surrounding community for general safety reasons. They learned Spanish, although not fluently.

Early days

In 1929, Joel and his wife left Mexico for Toronto, Canada, primarily for their children's education. In Toronto, Charles attended Upper Canada College, one of the oldest and more prestigious private schools in the country. Beatrice, aged 7, attended Brown Public School until 1934, then attended the private Bishop Strachan School until 1939. Both Worsley children tested well enough to be put in advanced classes.[2]

The Bishop Strachan School was founded in 1867, under the Anglican Church of England, as an alternative to the many Catholic orphanage and finishing schools in Toronto. Originally, students were typically daughters or relatives of clergy, or from the middle-class families of the region. In the 1920s, however, tuition was increased, and the school began catering to the well-to-do. When Worsley was a student in the 1930s, the school's reputation was academics and religion and featured a heavy dose of extracurricular sports, drama, and music. Most teachers were British, hired specifically for a preferred English teaching style.[3]

Two educational tracks were available. The first emphasized religious and domestic training; the second offered a university track program including algebra, geometry, chemistry, and physics. Worsley excelled in the university track, despite the fact that she was the youngest

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in a class of about 30 students. The headmistress during her stay, a Miss E.M. Lowe, noted she was one of the most brilliant pupils ever at the school.[4] Worsley finished middle school in 1937, with awards in math, physics, divinity, English, and general proficiency.

In 1938, she completed junior matriculation, and in 1939 graduated, with honors, senior matriculation; with awards in math, science, and proficiency, and the Governor General's Award for the highest overall grade.[5] Worsley enrolled in the honors course in science at Trinity College, University of Toronto, in September 1939. Her marks earned her a general proficiency entrance award and the Burnside Scholarship in Science from Trinity. She had the number-one rank in most classes that year and was awarded the first Alexander T. Fulton Scholarship in Science. In October 1940, she transferred to the Mathematics and Physics division, specializing in applied mathematics.

Worsley continued to excel academically and to impress the lecturers in courses such as pure and applied mathematics, classical physics, thermodynamics, optics, quantum theory, relativity, and electricity. Because her college years coincided with World War II, her studies included German and ballistics. She finished First Class each year and won the James Scott Scholarship in Mathematics and Physics in her third year. In 1944, she graduated with a bachelor of arts in mathematics and physics.

It's possible that Worsley's interest in computing machines was first sparked during these formative years. Between June and August of 1942, she had worked with mechanical calculators in the Actuarial Department of Manufacturers Life Insurance Company in Toronto. The clerical position would have had little in common with numerical analysis, but the early exposure could have caught her attention in some way.[6] Regardless, by graduation the foundation of Worsley's career was set as an outstanding student, with obvious aptitudes in mathematics and science. Professors later recalled she was one of their best students: gifted, dependable, conscientious, and painstaking in all her work.[7]

But what of Worsley's personality and ambitions? No records at Bishop Strachan exist that suggest she participated in team sports or drama. Later, in the 1944 *Torontonensis* yearbook, the only activity she listed after five years at the University of Toronto was the Math and Physics Society. She did, however, leave no doubt as to what she foresaw in her future: "War service, then advanced study."[8] Indeed, Worsley enlisted as soon after graduation as possible in the Women's Royal Canadian Naval Service (WRCNS), also known as the Wrens. The decision to serve was not unusual, and her brother, who graduated that year with a bachelor of architecture, joined the Royal Canadian Engineers at the same time.

Military service: Wrens

An impression of her personality emerges from the pages of her military application. In a letter to the WRCNS Recruiting Offices in February 1944, seeking an opening in the organization, Worsley expressed a preference for laboratory work or research duties.[9] More details are found in the notes from the recruitment interview later that month. For example, Worsley expressed a fondness for music and piano playing, and an interest in photography. And as the interviewer noted and her references agreed, she had a quiet, pleasant, and composed personality.

Probationary Sub-Lieutenant Beatrice Worsley started service on 5 April 1944 at the HMCS *Conestoga* base in Galt (now Cambridge), Ontario. Galt was the basic training center for Wrens from across Canada, and it included about four weeks of physical training, drills, and lectures on naval customs. For Worsley, this was followed by another four weeks of officer training. After several months of unspecified general duty, she was commissioned and directed to the Special Branch and on 9 September transferred to the Naval Research Establishment (NRE) at Her Majesty's Canadian Ship (HMCS) *Stadacona* in Halifax, Nova Scotia, for harbor defense research.

Although the NRE was a recent creation of the Royal Canadian Navy (RCN), the origins went back to 1940, when the RCN accepted responsibility for degaussing ships, sailing from Canada to Europe, to reduce their magnetic signature and vulnerability to German magnetic mines. Although in principle a straightforward operation, the research, testing, and fine-tuning of existing and experimental techniques fell to a small group of about 50 officers, scientists, and support staff stationed in Halifax. At the peak of this activity, Worsley was one of six Wrens at the NRE. The research and testing of degaussing techniques was the beginning of scientific naval research in Canada, and the NRE's work was crucial to keeping the East Coast harbors clear of enemy mines.[10]

By the time Worsley arrived in Halifax in 1944, many of the degaussing operations had become routine, and the scientists were reduced to handling new or special cases only. Worsley was employed on generalities at first, likely assisting with the onshore data analysis, probably not much different than the lab work she had requested when enlisting. Although experiments were under way at the NRE to develop countermeasures against acoustic mines and torpedoes, she was not a member of that particular group.

With the end of hostilities in 1945, the immediate relevance of the NRE research declined, and by early 1946, most of the staff had left, typically taking advantage of educational opportunities available to veterans. Worsley was one of just a handful who chose to stay on, and the only Wren to do so. In Septem-ber 1945, she was promoted to lieutenant at the same time as she was reassigned to a new project: hull corrosion research. Hull corrosion is a nontrivial problem that affected metal-hulled ships at the time and required regular, expensive dry-dock repairs. The underwater electrochemical effects were not well understood, but scheduling difficulties during the war had prevented most investigations beyond limited visual inspections. With the freeing of ships, earnest research began in late 1945.

As part of the fundamental research section of this project, Worsley performed experiments and consolidated findings on board various test ships and the NRE research minesweeper HMCS *Quinte* (see Figure 1). The project demanded more than 150 days at sea—a record for Wrens' at-sea service—which were often spent during adverse midwinter weather conditions. Worsley's endurance earned her much consideration and respect from the crews, as did her knowledgeable onshore interactions with hull surveyors and specialists. Known to all as "Trixie," she was well able to hold her own. Working at what she herself acknowledged was a man's job, by her actions and manner Worsley well deserved the recognition she earned.[11] In August 1946, she was demobilized.

Graduate studies

In September 1946, Worsley entered graduate studies at the Massachusetts Institute of Technology (MIT) in a one-year master's program of mathematics and physics. This would be the preliminary launching point for her computing career. The challenges she met at the NRE may have prepared her for research, but MIT provided the first exposure to computers.

Her coursework included solid-state physics taught by Laszlo Tisza; a course based on John L. Synge's text, *Principles in Mechanics* (McGraw-Hill, 1942); an applied electronics course on feedback amplifier design; and a function theory course with Henry Wallman, a member of the famed MIT Radiation Laboratory and the supervisor of Worsley's master's thesis.[12]

Figure 1. Worsley at sea on the *Quinte* in midwinter, conducting an experiment under decidedly chilly conditions. (Photo courtesy of Alva Worsley.)

That thesis, *A Mathematical Survey of Computing Devices with an Appendix on Error Analysis of Differential Analyzers*, provides a fascinating snapshot of contemporary computing technology. With the eye of a mathematician, Worsley had combed the literature and compared the features and characteristics of many continuous and discrete computing devices completed, under construction, or planned. In the discrete category, her tables described the Harvard Mark I and II, several IBM calculating machines, a Bell Labs electromechanical computer, the ENIAC, the EDVAC, the Institute for Advanced Study computer at Princeton University, the Whirlwind I and II at MIT, the UK's National Physical Laboratory (or Pilot Automatic Computing Engine) computer, and the University of Cambridge EDSAC. The appendix provided a practical and theoretical analysis of the sources and areas for error reduction in differential analyzers. The research was suggested by Samuel H. Caldwell, of MIT's electrical engineering department, who had helped Vannevar Bush design recent analyzers. In her conclusion, Worsley stated that her mathematical results corresponded well with and confirmed the experiences of analyzer users.[13]

With her advanced degree in hand, Worsley returned to Canada near the end of summer 1947. Never one to share her personal thoughts, she now confided to her family that her future was in computers. She was quickly becoming an expert on the new technology. It's unlikely she was exposed directly to the ongoing Whirlwind research at MIT during her short stay in Boston, but the proximity was enough: The seed had been planted.

Unfortunately, although MIT was a leader in computing technology, Canada had yet to leave the starting blocks. With no immediate employment opportunities in the computer field, Worsley found work in Ottawa at the National Research Council (NRC) of Canada.

After only a few months as an aerodynamics research officer in the mechanical engineering division, she resigned. With the approval of her director, she had negotiated a position at the new, University of Toronto Computation Centre, and by mid-January 1948 joined the Centre as a project assistant.

Computation Centre at Toronto

Toronto was among the few universities in North America to have a computer research and development program in place at the end of the 1940s, and the only one in Canada for a number of years thereafter.[14] Preliminary discussions regarding the Centre had taken place among faculty seeking support from government research agencies throughout 1946 and 1947 that culminated with a relatively small grant from the NRC in September 1947. Funds were provided for two IBM punch card calculators and salaries for two project assistants: Worsley and J. Perham Stanley, a graduate student and former colleague of Worsley through the Math and Physics Society.[15]

Day-to-day management of the Computation Centre was handled by Calvin C. "Kelly" Gotlieb, a physics PhD graduate from the University of Toronto a few years earlier and a member of the Physics Department. After training on the new tabulators, Gotlieb, Worsley, and Stanley tabulated a function for Atomic Energy Canada (AEC) at Chalk River, Ontario. This and similar computing problems simultaneously raised the profile of the fledgling center and helped stimulate interest in relay and electronic computing research in Canada.[16]

Over six weeks during summer 1948, Worsley constructed a differential analyzer using Meccano (a metal construction system designed for building models), based on Douglas Hartree and Arthur Porter's 1935 article.[17] Constructed from about CAD$75 worth of Meccano, the analyzer was minimally modified from the original design but offered slight improvements to the electrical power distribution system, the design of the torque amplifiers, and the output pen support.[18] Unfortunately, there is no information regarding what use, if any, the analyzer was put to or why Worsley built it. Possibly the Centre was looking for an inexpensive computational device in addition to the punch card machinery; if constructed properly, a Meccano analyzer could be put to serious use as Porter explains in a recent article.[19] Work on a second analyzer, or perhaps the original model, was restarted by another student in 1951 at the behest of Gotlieb for teaching purposes.[20]

Under way at the same time was a much more ambitious electronic engineering research project: the design and construction of Canada's first computer, the University of Toronto Electronic Computer Mark I (UTEC). It was a parallel-processing machine designed by a team of professors and graduate students. This was no toy built of spare parts but a prototype worth tens of thousands of dollars to the Canadian Defense Research Board (DRB) and to the NRC, which were sharing the development costs. The project represented an attempt to obtain a single large computing resource to be shared nationally among government, military, and university research groups. The UTEC project ran for a number of years as parts were designed and built locally by hardware specialists at the Computation Centre, who operated independently of the analog and mechanical computing side of the Centre at the time.

By October 1951, the UTEC was nominally operational but plagued by tube failure and mechanical reliability issues. Unfortunately for the team, Wilfrid B. Lewis of AEC had grown impatient for a dependable, full-scale computational machine for Canada. Instead of finishing the UTEC, the influential Lewis urged that the DRB and NRC money would be better spent by purchasing a complete system, specifically a Ferranti Mark I. (He knew that the UK government had canceled an order earlier that year, leaving Ferranti without a buyer.) A decision was forced quickly, against the wishes of the hardware development team, and the University of Toronto ordered the Mark I early in 1952.

Worsley had little to do with the UTEC prototype development. Her career always leaned toward software rather than hardware, and the UTEC was built during a period when she was absent from the Centre because she was on assignment in the UK. However, she did play a unique role when the Ferranti Mark I arrived, by naming it Ferut. (Ferut is an initialism standing for "Ferranti computer at the University of Toronto.") Ferut was installed and gradually made operational over the spring and summer of 1952, and it quickly replaced the UTEC.[21]

EDSAC and Cambridge

Meanwhile, after finishing the Meccano project in 1948, Worsley and Stanley had been sent overseas to learn what they could of the EDSAC at the Cambridge Mathematical Laboratory. (It was not uncommon for researchers to join the lab for a time to help build and test the computer.) The two project assistants arrived to find the EDSAC in a fairly advanced state of construction, and although neither had an engineering background, both helped prepare it for the first run on 6 May 1949.[22] The EDSAC (see Figure 2) was working just in time for a conference on high-speed computing held at Cambridge that June. On the first day, it was demonstrated to the attendees by printing tables of squares and primes. Worsley prepared a report that included a reproduction of the results and a description of the observable physical events and order code routines. This report went into the conference proceedings and subsequently was reprinted in the famed resource for historians of computing, Randall's *The Origins of Computers*.[23] There was no particular glory to this task, and it must have seemed minor at the time, but the report earned Worsley a place in history.

Stanley earned his historical footnote soon after the EDSAC was running when he cowrote a routine with Maurice Wilkes to tabulate the reciprocal of the complex Gamma Function.[24] The extensive tables were published the next year after he returned to Toronto to complete his PhD.[25] The routine possibly represents the first time a machine produced values never before computed by any other means. The event was made historically unique when John von Neumann surprised the lab by visiting unannounced while the routine was running.[26]

Worsley did not return to Canada until 1951 because she had resumed her graduate studies in mathematical physics at Newnham College, University of Cambridge. While helping in the lab, she attended or at least audited a number of courses and lectures. These included several on quantum theory, taught by a collection of well-known figures: Paul Dirac, Sir Lennard-Jones, and Nicholas Kemmer. Perhaps more significant to her career were courses she took on summable series and number theory, with Albert Ingham, and on numerical analysis, led by Douglas Hartree.[27]

Hartree was an important figure at Cambridge with great interest in the EDSAC's potential in solving numerical problems. Many have recalled Hartree's helpfulness and generosity toward others; he certainly collaborated with an unusual number of women for the time, and supervised at least one other Canadian, Charlotte Fischer, before his death in 1958.[28] He likely would have been impressed that Worsley constructed her own Meccano analyzer, and perhaps this is why he chose to supervise her dissertation.

Worsley started writing her dissertation at Cambridge, but in 1951 for some unknown reason she returned to Canada with the text unfinished. She arranged to complete the work with the supervision of Byron A. Griffith, a professor of mathematics at the University of Toronto and a member of the Computation Centre. Worsley wrapped up the writing quickly and was rehired as a staff mathematician at the Centre in July 1951. Hartree approved the dissertation in Cambridge, and Worsley's doctorate was awarded in 1952 after Hartree made a visit to Toronto.[29]

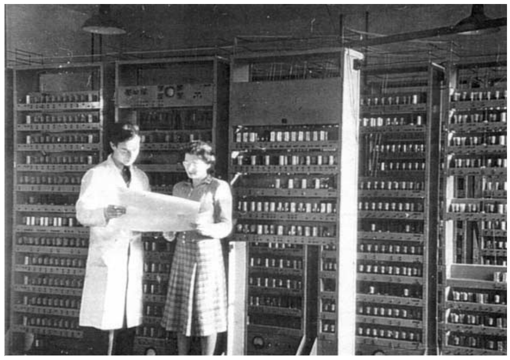

Figure 2. A posed photograph (Worsley is on the right) in front of the EDSAC in Cambridge, circa 1949–1951. (Photo courtesy of Alva Worsley.)

Worsley's dissertation: A review

Worsley's dissertation, *Serial Programming for Real and Idealized Digital Calculating Machines*, is believed to be the first PhD dissertation involving modern computers.[30,31] It was divided into four logical sections, each tackling an academically interesting aspect of digital computing, and offers some early examples of routines used to solve nontrivial scientific problems numerically.

The first section outlined and discussed *Class I* machines, which were defined as digital, automatic, serial, and universal. These criteria were then used in the next few sections of the dissertation to explore three specific machines: the EDSAC, the Manchester Automatic Digital Machine (MADM), and the UTEC. She was clearly familiar with all three and knowledgeable of various idiosyncratic programming practices, but because she included only EDSAC routines in latter sections, the full extent of her exposure to the MADM is unknown. It is also likely that she added the UTEC section after she returned to Toronto.

In the second section of her dissertation, "Idealized Machines," Worsley discussed the potential of universal Turing machines and what sorts of problems could properly be handled. She treated the subject formally and made clear the distinctive limitations and differences between abstract and physical computers.

For the third section, Worsley wrote her own EDSAC routines to solve three scientific problems numerically. The first problem was a determination of the second-order correction to be applied to the value of gravity from pendulum measurements at sea. The problem was considered well suited for the EDSAC because of the magnitude and requirement of many solutions of similar basic forms, and she credits an R.I.B. Cooper for proposing the research. This chapter was later published separately as her first scientific article.[32]

The second problem was an automatic rendition of the Hartree self-consistent field method for the solution of atomic wave equations with exchange. This was suggested by Hartree himself and was of course based on the technique that he had developed for desk calculators. The third question was selected to demonstrate a way in which automatic computations could be used to explore the merits of a method together with variations. Worsley concluded that a Lieberman one-dimensional process compared unfavorably with step-by-step and adjustment methods.

In the fourth and final section of her dissertation, Worsley's experience and command of computing science and technology is unambiguous. On the basis of the first three descriptive, theoretical, and applied sections, Worsley presents an empirical and systematic theory of "axiomatic programming," which could "guide the design of order codes and libraries, based on the proposal of an optimum basic automatic universal digital machine."[33] Although her theory was partially derived from ideas apparently presented by Turing at the 1950 Cambridge summer school on program design of automatic digital computing machines, Worsley did not specify his exact contribution. Possibly, she was elaborating on Turing's preference for simplicity of hardware instructions.[34]

The general problem that Worsley presented was not new. As she explained in her dissertation, Claude Shannon provided a guaranteed way to set up relays to solve logic problems, but faster or more intuitive arrangements were often possible, and work was under way to minimize or otherwise economize the number of relays.[35] This notion could be transferred to electronic computers, but instead of optimizing relays, the problem was to determine which hardware instructions were fundamental and which were supplementary. Her intention was to narrow down a universal set of fundamental order codes to be used by all Class I machines. Designers and engineers could then selectively optimize the execution of the machine code in question to provide better overall throughput. Routines could also be developed and placed in libraries that any programmers could reuse, regardless of the machine they were using.

Worsley broke down potential Class I computer usage into four scenarios or applications: logical and truth calculations, applied mathematical and engineering problems, pure mathematical problems, and payroll or statistical problems. Each was evaluated in terms of order code complexity to determine the minimum number of instructions per case. Her analysis suggested that although the scenarios overlapped, a substantially different set of instructions was necessary in each case.

This invalidated the premise of a universal machine code, which she acknowledged. Although highly specialized computers could be built, general-purpose models represented the foreseeable future, given the cost and unique nature of existing machines. Consequently, computers were destined to occupy a middle ground between the two extremes of scientific computation and data processing. Furthermore, machine and order code design could and would result in infinite variations and not an optimal, universal solution. Worsley returned to this concept later in her career, and she held a long interest in computer libraries and subroutines.

Unsolved mysteries

By the time Worsley finished her assignment at Cambridge, she was one of the most computer-literate women in the world, with practical and theoretical expertise that few could have matched. She was one of the first female academic computer programmers who wrote all her own programs, a point she strongly emphasized in her dissertation. Not only did her time at Cambridge prove that real scientific work could be accomplished with computers (as opposed to Meccano), it undoubtedly solidified her career choice.

However, several mysteries remain from this period. First, it is unknown why she returned to Canada in 1951 without having completed her dissertation. At the time, PhD students registered in Cambridge for three years and then had two years to finish writing; it was not unusual to do this at another location.[36] But why did she leave Cambridge? There were no family-related obligations or known romantic attachments in Toronto encouraging her to return.

Moreover, the Computation Centre in Toronto did not rehire her right away, although her knowledge of UTEC suggests she visited the facility regularly, so her return was probably not related to employment. Money was not likely the issue, because in May 1950 she was awarded a CAD$1,500 Senior Fellowship by the Canadian Federation of University Women. With the Korean War under way, the RCN requested she consider service, but she turned down the opportunity.

Unfortunately, because of her quiet personality and the decades that have since passed, the answer may never be known. No one from the Cambridge lab seems to recall Worsley much beyond that she was a member for awhile.[37] What makes this issue intriguing is an event that occurred 20 years later. After her death in 1972, Worsley's entire estate was bequeathed to the University of Cambridge. A total of £75,000 would form the Lundgren Fund, in honor of one Helge Lundgren.[38] The Lundgren Research Award is presented to PhD students, not ordinarily residents of the UK, who have completed at least four terms and are engaged in research in a scientific subject, including mathematics. All things being equal, preference is given to candidates "working in the Computer Laboratory, or whose research has been interrupted by national service or personal misfortune."[39] The identity of Helge Lundgren remains unknown, as does the motivation for the large donation.

Figure 3. Beatrice Worsley sitting at the Ferut in the University of Toronto's Computation Centre, circa 1952–1958. (Photo courtesy of Alva Worsley.)

Ferut and Transcode

As the Ferut was installed at the Toronto Computation Centre over the spring and summer of 1952, Worsley soon found herself operating the console (see Figure 3). Gotlieb was sent to Manchester to learn what he could from the Ferranti Mark I installed there, but Worsley would have been somewhat familiar with it because it was a copy of the Manchester computer described in her dissertation. While the engineers were getting the Ferut up and running, the Centre staff was faced with the problem of software. Fortunately, because of the contact with Manchester, they had access to the original system software and libraries, and staff members also picked the brains of attendees of the September 1952 Association of Computing Machinery (ACM) conference in Toronto. Once operational, the Ferut was put to use on both scientific research and practical computational problems, from atomic energy equations to St. Lawrence Seaway calculations and insurance tables.

The Ferut was a tricky computer to learn to program, and the staff devised improved input and output routines, debugging tools, and other techniques for their novice programmers. The first year Ferut was on the campus, Gotlieb and Worsley held a small informal course on the proper methods of programming, adapting techniques for their installation along the way. In 1953, they arranged two more formal courses for a wide variety of computer novices, including actuaries, scientists, and gradate students. The lessons contained both theoretical and practical components devoted to machine design, computer logic, and numerical techniques. The attrition rate seems high, however, because just eight of 30 students completed one course.[40] Few could master the Ferut; in the words of one user, it was appallingly difficult to program.[37]

In the fall of 1953, inspired by John Backus's Speedcode system for the IBM 701, a solution to the Ferut's programming difficulty was considered. Speedcode effectively simulated the existence of a reasonably easy to program computer; software ran slower, but programming and debugging times were reduced significantly. If something similar could be done with the Ferut, it would be valuable to the Centre. As the only computing facility in Canada, simplifying the programming cycle for remote users was an important goal. Worsley and J.N. Patterson Hume, an assistant professor from the Physics Department, were assigned to create an automatic coding system for the Ferut. They both had considerable experience with the machine, having authored numerous operating system modifications and subroutines. They dubbed their project Transcode and finished writing the compiler within about a year, taking advantage of every nuance in the hardware.[41]

Transcode was an immediate success. Basic lessons could be taught in two hours, and the calculations could be returned to users in a matter of days, not weeks, although Ferut was considered slow at the time. Articles by Worsley and Hume appeared in both the *Journal of the ACM* and *Physics in Canada* announcing Transcode and describing the new and effective tool for physicists and scientists.[42] By 1958, when the aging Ferut was replaced by an IBM 650, hundreds of faculty and students had been taught Transcode, and the Centre had put it to scientific use on behalf of dozens of research groups across Canada.

Because of the code's simplicity, nearly bug-free programs could be submitted and returned by mail. A direct teletype hookup between Toronto and various Canadian universities was added later to provide a primitive remote operation.[43]

Articles and courses: A paper trail

Worsley's focus and skill lay in adapting scientific problems to be solved using Transcode and the Ferut. This subject area is the focus of most of the 17 technical papers she published between 1952 and 1964. Her first such article described results obtained using Transcode to solve nonlinear second-order differential equations using a Runge-Kutta method, and custom floating-point routines that she developed.[44] Most of the other articles flowed directly out of her Cambridge work on self-consistent field calculations.

In September 1955, the Pure Physics Division of the NRC and the Computer Centre launched a joint project to develop the Hartree-Fock formulations for digital computers and calculate specific atomic wave functions. Working in conjunction with J.F. Hart of the NRC, who coauthored several of the papers, Worsley coded the routines for the Ferut.[45] Hartree consulted on the project until his death in 1958, and the general scheme Worsley used can be found in his 1957 text *The Calculation of Atomic Structures*.[46] The work led to a series of short articles on the wave functions of several elements.[47] In the early 1960s, she coauthored a number of biophysical articles that explored numerical computational techniques available for such research.[48] Although most of the staff at the Centre had advanced scientific degrees, if measured by the number of publications credited, Worsley was by far the most productive member of the Computation Centre in the 1960s.

By 1960, Worsley's career was heading away from research toward teaching. She began teaching noncredit university extension courses in the mid-1950s. They became graduate and undergraduate courses and the load increased when the IBM 650 was installed in 1958 and the Institute of Computer Science was founded at the University of Toronto in 1962.

Detailed records and notes from her courses are available in the archives at Queen's University. One of the earliest was a fourth-year industrial engineering course on programming the IBM 650 and a senior physics course called Programming Digital Computers. The lessons included theoretical and practical exposure to numerical analysis and related programming challenges. Worsley had an excellent reputation as a sharp and knowledgeable lecturer. As the discipline of computer science began to stabilize in the 1960s, the computer-related content of Worsley's courses began trickling downward from graduate levels to third- and second-year studies. When the 650 was replaced by Canada's first IBM 7090 in 1962 and made available to students, she modified her courses to accommodate newer languages and techniques.[49] All the while, Worsley maintained an affiliation with the Physics Department, running first-year tutorial sections for a number of years.[50]

Worsley increased her professional activity year by year as opportunities for women improved. She had been an early member of the ACM and in the 1960s joined special-interest groups on university computing and information retrieval. Worsley also served as the Toronto region correspondent for the *Quarterly Bulletin* of the Computing and Data Processing Society of Canada from 1962 to 1965, as the director of the national executive in 1968 (now renamed the Canadian Information Processing Society), and technical editor for the *Bulletin* from 1970 to 1971.

One of Worsley's long-term interests was subroutine libraries, which she had first written about in conjunction with universal instruction sets in her dissertation. Throughout the 1950s, part of her job as staff mathematician at the Computation Centre was developing and maintaining a variety of low- and high-level subroutines for the Ferut and Transcode. The lessons from these years were sketched out theoretically in a 1959 article, "Blueprint for a Library." As she saw it, the university computing center library requirements were twofold: "a sophisticated coding scheme for staff engaged in research projects and a simplified coding scheme for teaching purposes and student applications."[51] Worsley wrote that the coding scheme should be as flexible as possible yet provide complex mathematical functions and operations. It should also provide direct machine addressing if necessary. Worsley described the second scheme as a subset of the first and available to all programmers. It should provide double- or multiple-length arithmetic, floating-point routines, complex and matrix algebra, and statistical functions. Most importantly, the schemes should be universal and machine independent, within the bounds of the topology of any given computing center.

In some ways, the "Blueprint" article was an updated realization of axiomatic programming. But now Worsley's intention was to abstract above the machine's instruction set, creating in essence a virtual machine. It made possible optimized libraries that every programmer could use and benefit from, regardless of whether one needed procedures for data processing or for numerical analysis functions.

A secondary interest of Worsley's was library automation, which developed through external circumstances. In 1963, the Ontario New University Library Project staff began the task of acquiring and cataloging more than 35,000 new books within three to four years. One of the participants, the University of Toronto Library (UTL), turned to the Institute of Computer Science for assistance.[52] Worsley did not help immediately, but did work at the subcommittee level on the Serials Systems Design project, tying automated serials processing with acquisition, circulation, and catalogue generation.[53] In 1965, the NRC awarded her Grant Number A-2654 for "An Information Retrieval System for Computer Science Literature." The one-year project was to implement a computer system for retrieving references and abstracts from a computer science literature database. Worsley's proposal was based on an earlier paper by Guy J. Groen, a colleague at the Institute of Computer Science at Toronto.[54] The grant was to cover the costs of developing a small prototype using a sample set of data. However, Worsley's participation on both library projects was limited, because she left Toronto permanently before the summer was out to join Queen's University.

The reason for Worsley's departure might be guessed. Although she had a PhD from Cambridge, was a core member of the Computation Centre teaching staff with more publications than anyone else, and had been performing valuable research for the university for over a decade, it was not until 1960 that Worsley was promoted from Computation Centre mathematician to assistant professor of physics. Eventually, when the University of Toronto created a graduate department of computer science in 1964, she was promoted to associate professor of physics and computer science. In comparison to other staff members, the lack of official recognition is conspicuous and is almost certainly because of her gender.

As a result, in 1965 Worsley left Toronto to take a new position at the Computing Centre at Queen's University in Kingston, Ontario. The departure caught her Toronto colleagues off guard, and it would not have been an easy decision for her. At Queen's she would no longer be a professor, but computing advisor to the Computing Centre with teaching duties. Compared to the well-funded, well-equipped, and committed research and teaching program in Toronto, Queen's was a considerable step down. There was no computer science program, and the only computer in evidence was an outdated IBM 1620 in the Civil Engineering Department.

On the other hand, Worsley was lured to Queen's specifically to help launch and manage a new Computer Centre with the 1620. Besides herself, just two people were involved: John Lindsay, with a master's degree from the University of Toronto and several years' industry experience, and Mers Kutt, who had been recruited earlier by Queen's to get computing off the ground.[55] For Worsley, it was a chance to start afresh, and perhaps earn respect the way she had in Halifax: by her merits, regardless of gender. Unfortunately, her career, which had already veered from scientific research, quickly narrowed at Queen's to that of teacher and administrator.

Queen's University: Many hats

A 1967 letter to Worsley from Kutt, the director of computing, outlined her teaching responsibilities at Queen's, which besides lecturing included serving as curriculum advisor and Arts and Science Faculty representative. Worsley was also tasked with providing material for the university calendar, self-education, and drafting reviews for *Communications of the ACM* and *Applied Mechanics Reviews*. In her role as computer science advisor to the computing center, she was to select book and journals for the small library, coordinate the programming staff, act as Queen's computing advisor to local area high-school teachers, arrange seminars, and authorize computer time. Beyond that, she would be the local SHARE user group representative.[56]

Immediately after arriving at Queen's in 1965, Worsley began teaching undergraduate computing courses, which continued until her first sabbatical in 1971. These courses were heavily grounded in numerical analysis, covered programming techniques using Fortran, Watfor, and assembly, and included material on the mathematical principles of computing. Many of her records, notes, and lecture outlines from this period survive in the Queen's University archives.

Much of Worsley's day-to-day work also dealt with the operation and long-range planning for the Computing Centre. Like many other Canadian universities, Queen's had an IBM 1620 installed in the early 1960s. Unlike most, it was not upgraded to an IBM 7040 or 7090 mainframe. By the time Kutt, Worsley, and Lindsay arrived at the Computing Centre, a 7040 no longer made sense economically, and so they held off upgrading until the IBM 360/40 became available in 1966. Queen's was one of the first universities in Canada to announce such a prized acquisition, but geographical isolation and static university bureaucratic structures created a computer-related apathy at Queen's. The field lacked a high profile on campus, and in the early 1960s the mathematics department signaled they were not interested in computing or applied mathematics, although this eventually changed with new faculty recruits. During Worsley's time at the Computing Centre, most of the impetus for computing came from the engineering department, which sought undergraduate training and programmers experienced with numerical techniques.[57]

Worsley worked hard to improve the situation. Without the larger budgets of other universities, computing power was slowly broadened with microcomputers, with three DEC PDP-11s and two PDP-15s and an ancient IBM 360/20 in place by 1971.[58] Lindsay was the programming guru, and Worsley was the librarian. In addition to maintaining routines and programs, she also wrote most of the computer manuals and related documentation.

Queen's administration implicitly expected that by gradually increasing the role of computers, computer science studies would evolve on campus. A master's program at Queen's was created in 1968, together with a new Department of Computing and Information Science. Worsley was a driving force behind the creation of an academic home for computing, and she was again promoted to associate professor.

In September 1971, Beatrice Worsley took a long-deserved sabbatical year at the Department of Applied Analysis and Computer Science at the University of Waterloo. While at Waterloo, she studied assembler coding as it related to computer architecture, which appears to have been an attempt to return to her earlier research interests. However, on Monday, 8 May 1972, while in Waterloo, she suffered a fatal heart attack. Survived by her brother Charles, the funeral was held that Thursday, 11 May, in Toronto, where she was interred in the Mount Pleasant Cemetery.

Conclusion

The parallel career of Grace Murray Hopper is sure to cross the mind of many readers. Hopper and Worsley were apparently acquainted, although casually. Both studied mathematical physics in graduate school, both enlisted in the navy during World War II, and both worked on first-generation computers, although neither was a hardware specialist. Both were professionally active early on, advocating compilers and the value of higher-level languages. Worsley's interest, however, was academic and scientific computing, while Hopper's was business computing and data processing.

Consequently, Worsley helped write Transcode, earning the gratitude of physicists across Canada, while Hopper helped design Cobol, earning accolades from business programmers across the world. Finally, whereas Hopper had an outgoing personality and was a colorful spokesperson for the US Navy and for computer companies, Worsley was virtually the opposite, working quietly in an academic environment. In the words of her sister-in-law, "She was so very quiet and did not talk about her work too much. I guess she realized that it was beyond our comprehension."[59]

"Trixie" Worsley left a fascinating legacy as a computing pioneer. Her natural appreciation for what computers were capable of doing was reflected in a lifelong interest in the development of computer libraries and scientific computation. A skilled mathematician and unquestionably Canada's first female computer scientist, she found a successful calling in a profession dominated by men. Throughout her life, she struggled against this barrier. The strength of her intellect and accomplishments is undeniable, but official recognition has taken too many years.

References and notes

1. The year before her death, Worsley donated a number of her early papers and records, from 1946 to 1959, to the Smithsonian Institution. These items are available through the National Museum of American History. The bulk of the material for this article came from two alternate sources. The first is Worsley's own notes, held at the Queen's University Archives. These boxes contain copies of her publications including theses, notes from high school to graduate school, professional correspondence, her teaching notes from both Toronto and Waterloo, and a great deal of administrative paperwork from her final years at Queen's. The second source is sister-in-law Alva Worsley, who provided a wealth of personal information and contributed the photographs.

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7. I.R. Pounder to M.N. Bedard, Nat’l Research Council, Worsley personnel file.
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