THE PREMISE OF COMPUTER SCIENCE: ESTABLISHING MODERN COMPUTING AT THE UNIVERSITY OF TORONTO (1945-1964)

by

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Abstract

The Premise of Computer Science: Establishing Modern Computing at the University of Toronto (1945-1964), Doctorate of Philosophy, 2006, Scott M. Campbell, Institute for the History and Philosophy of Science and Technology, University of Toronto

This dissertation explores the introduction and acceptance of electronic computers at the University of Toronto, from the first vague intentions of 1945 to the creation of the first Department of Computer Science in Canada that offered a doctoral degree in 1964.

The story begins shortly after World War II, when a group of professors with an interest in modern computing devices petitioned the university and several federal agencies for funding to build or buy an electronic computer. Though located in Toronto, it was hoped that all Canadian scientists could use the new machine for their computations. There were setbacks, including a failed attempt to design and construct a full-scale electronic computer, and successes, ironically involving older, premodern equipment. In 1952, the first electronic computer in Canada was installed at Toronto, though few knew how to use it. With assistance from programmers at Manchester University, the Toronto computing centre mastered the computer and made it available to the rest of the country.

In the second half of the 1950s, less expensive and more reliable commercial computers appeared on the market and other Canadian organizations began making plans to acquire one of their own. As the Toronto computing centre was self-financed through the sale of computer time and federal grants, the changing environment reduced the national significance of the centre and forced a reevaluation of values. Two interrelated plans were made to regain its fortune: to obtain the most powerful computer in Canada, and establish a new, autonomous academic department dedicated to computing research. Success was elusive until the early 1960s, and neither concluded in the expected manner.

It is not the aim of this project to provide a history of computer science, per se, as the discipline did not coalesce until after most of the events discussed herein. Instead, as the historical literature concerning computer science is still underdeveloped, this pre-history provides both a useful case study and a foundation for further research on the history of computing and computer science in Canada.

Acknowledgements

It goes without saying that writing a dissertation is impossible without the assistance, encouragement, and inspiration of other people. First, I must thank my supervisor Janis Langins, who guided me through the project effortlessly and expressed continued confidence in my newfound abilities as a historian. Committees and other people read various drafts and deserve thanks, for their various corrections, criticisms, and advice. The list includes Calvin "Kelly" Gotlieb, Paul Ceruzzi, Craig Fraser, Bert Hall, and last but not least, Sarah Campbell. Remaining mistakes are all mine, of course.

As I quickly learned when embarking on this project, historians can accomplish very little without archivists and librarians. The University of Toronto archivists were always helpful and enthusiastic, particularly Harold Averill and Marnee Gamble, whose recollection of files proved fortuitous more than once. Other graduate students at the Institute for the History and Philosophy of Science and Technology provided a useful sounding board at times, but more often a chance to blow off steam. My family recieved the same treatment, willingly I assume. Other assistance came from Michael Williams, Keith Smillie, Robert Bruce, and Zbigniew Stachniak.

Finally, I dedicate this text to my wife, Sarah, and our son, William, who was born midway through the writing. As the creative spirits ebbed and flowed, you inspired me onward. I love you for all that you did to make it possible to finish, and for always.

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Introduction

"For some time, there has been at this University a growing interest in modern computing machines."

– University of Toronto Professor V.G. Smith to National Research Council President C.J. Mackenzie, 1946.[1]

In the opening decade of the 21st century it has become ordinary for undergraduate students at Canadian universities to attend class without pen and paper and take notes on their laptop or notebook computers. Typing at their desks they are simultaneously linked via wireless radio to millions of other computer systems and information services; encyclopedias, journal articles, and digitized books are at their fingertips. There is a good chance that in their knapsack they carry a few more electronic devices powered by a microprocessor. A cellular telephone, a digital music player, or palm sized digital organizer would not be unusual.[2]

Yet not six decades ago, there was but one electronic computer located at the University of Toronto to serve the entire country. It filled a room, but could not have stored more than a page of text. It was painfully difficult to use, but twice it was successfully linked to another Canadian university via telegraph lines. Comparing the two very different generations of computer technology is not intended to strike the reader with wonder at the advances in semiconductor miniaturization, software engineering, or networking. It is plain that an electronic computer from 1951 cannot

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[1] Griffith, B.A. to Mackenzie, C.J., 19 February 1946, LAC RG77, Volume 134, File 17–15–1–20.

[2] A single device capable of all three functions is equally likely as of 2006.

be compared favourably to the size of a lap or paper notes. Rather, the purpose of the illustration is to introduce the theme of this dissertation: the role of computers in academia. In particular, this history will explore the introduction and acceptance of modern computing devices at the University of Toronto.

At the end of the Second World War a handful of large-scale computing machines operated around the world, though most were located in the United States.[3] At the Massachusetts Institute of Technology, differential analyzers had been in use for several years. The mechanical Mark I had been running at Harvard since 1944, the Model III and IV incarnations of the Bell Laboratories series of relay calculators had recently been put to use by the United States military, and at Columbia University astronomers and other scientists had been using IBM punched card tabulators with great success since the late 1920s. In Europe, there were similar projects underway, co-opting electromechanical relays and tabulators for computing. Projects that employed electronic components in the designs were also underway on both sides of the Atlantic by 1946. Though the public unveiling of the landmark ENIAC (Electronic Numerical Integrator and Computer) would not happen until February 1946, two machines – the Atanasoff-Berry Computer at Iowa State University and the British code-breaking Colossus – had already demonstrated the potential of electronic approaches. By the end of the 1940s at least a dozen electronic computing projects were underway around the world.

In 1945 Canadians had yet to cross the threshold into that new world, but interest was rising, especially at the University of Toronto. Soon, a permanent home for modern computing was created at the university and given room to grow. Under the auspices of supporting scientific research of national importance, Canada's first computing centre was established as a non-academic division of the University. Roughly

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[3] Many resources describe the social and technological development of computing machines in the mid twentieth century. The most valuable general texts include: Martin Campbell-Kelly and William Aspray, *Computer: A History of the Information Machine*, 1st edition (New York: BasicBooks, 1996); James W. Cortada, *Before the computer: IBM, NCR, Burroughs, and Remington Rand and the industry they created, 1865-1956* (Princeton, N.J.: Princeton University Press, 1993); and Michael R. Williams, *A History of Computing Technology*, 2nd edition (Los Alamitos, Calif.: IEEE Computer Society Press, 1997).

twenty years later, the continued importance of computing was recognized at the university with the creation of the first graduate Department of Computer Science in Canada. The computing centre and computer science department will bookend the chronological start and end of this dissertation, from 1945 to 1964. In the intervening years, various people from on and off campus worked to determined the role of modern computing technology at the University of Toronto. The two decades were surprisingly turbulent. The use and purpose of computers changed dramatically, and no person or technology has a primary place at both the beginning and end of this story. A poorly equipped statistics laboratory with secondhand desktop calculators became the Computation Centre. It acquired the first modern computer in Canada in 1952, and was the only proprietor of substantial computing power in the country for half a decade. When computer technology diffused across the nation in the late 1950s, the Centre lost its unique position and was less relevant as a computer service centre beyond the gates of the University. A critical transition occurred that saw the Computation Centre again claim the most powerful computer in Canada as it was split into two autonomous units: the Institute of Computer Science and the Department of Computer Science. The former was solely responsible for the operational aspects of computing on campus and the latter took command of all academic functions – computer related research and teaching. As these two roles did not exist in 1945 it prompts the primary question of how and why they were established.

The history of computing devices extends further backwards in time than many people suspect.[4] The astrolabe, an astronomical measuring and calculating device, and the abacus – despite popular belief, the abacus is not a Chinese invention – are both ancient mathematical tools thousands of years old. More recent examples of computing devices include Napier's Bones, the slide rule, and Schickard's and Pascal's calculating machines, all seventeenth century inventions. They were followed by

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[4] See William Aspray ed., *Computing Before Computers*, 1st edition (Ames, Iowa: Iowa State University Press, 1990).

two nineteenth century breakthroughs, Babbage's engines and Hollerith's punched cards, which set the stage for rapid technological acceleration in the first half of the twentieth century. One of the more important innovations occurred between the two world wars, when commercial tabulating equipment was converted for use in scientific computing and employed to both military and peaceful ends. The culmination of this long line of development was the electronic behemoths of the late 1940s improving calculation speeds a thousand fold. By the mid century mark the design, construction and operation of these machines commanded half a million dollars or more of military or corporate sponsorship financing. These projects drew a corresponding level of attention and prestige, which made electronic computers one of the most exciting technologies of era. This was the birth of modern computing.

The impression that computers are strictly a twentieth century technology invention can be hard to erase. It is one not necessarily aided by book titles such as *Before the Computer*, *The First Computers*, or *Computing Before Computers*.[5] They rely on the premise that the only computer is a modern one: general-purpose, electronic, and digital. To be fair, the leap from speedy calculator to modern computer was revolutionary. The mid-1940s ferment produced crucial concepts such as stored programs and the eponymous von Neumann architecture, which had far reaching practical and intellectual consequences. Virtually every computer today is a descendant of those developments, and there is nothing wrong with using that particular historical paradigm, if proper context is provided. Yet there were other non-electronic, non-digital, and special-purpose computers whose existence overlapped with that of the modern computer for many years. To obey a rigid and modern definition of the word 'computer' fails to recognize that ENIAC and its brethren had little impact on the daily lives of most scientists and engineers for at least a decade. Instead, these people continued to

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[5] Cortada, *Before the computer: IBM, NCR, Burroughs, and Remington Rand and the industry they created, 1865-1956;* Raúl Rojas and Ulf Hashagen eds., *The First Computers: History and Architectures* (Cambridge, Mass.: MIT Press, 2000), and Aspray, *Computing Before Computers.*

rely on paper and pencil, a desktop calculator, and a library of mathematical tables to carry out calculations. This is an important reminder that until that the second half of the twentieth century, a computer often referred to a human, rather than a material artifact.[6]

A pertinent reason exists to emphasize the human precedence of premodern computing. Any history of modern computing at the University of Toronto that neglects this perspective would miss between three to six years of relevant detail – in this dissertation, the entire first chapter and much of the second. With respect to this introduction's epigraph, as of the mid 1940s the definition of modern computing machines had not yet acquired its contemporary meaning and a reader should not misinterpret those words to exclude non-electronic forms of computation.

When the Department of Computer Science was created at the University of Toronto in 1964, the term computer science was also poorly defined.[7] Though the term

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[6] The original mid-seventeenth century definition, according to the Oxford English Dictionary, was "One who computes; a calculator, reckoner; spec. a person employed to make calculations in an observatory, in surveying, etc." The modern usage, referring to a calculating machine, did not appear until the late nineteenth century. Books emphasizing the human nature of computing include: Martin Campbell-Kelly ed., *The history of mathematical tables: from Sumer to spreadsheets* (Oxford, New York: Oxford University Press, 2003); Mary Croarken, *Early Scientific Computing in Britain* (Oxford (England), New York: Clarendon Press, Oxford University Press, 1990); and David Alan Grier, *When computers were human* (Princeton: Princeton University Press, 2005).

[7] The secondary literature describing the history of computer science is far less complete than that of computer hardware, or even computer software. However, a number of articles have broached the subject. See, for example: Paul E. Ceruzzi, "Electronics Technology and Computer Science, 1940-1975: A Coevolution", *Annals of the History of Computing* 10, no. 04 (1988), 257–275; Michael S. Mahoney, "Computer Science: The Search for a Mathematical Theory", in John Krige and Dominique Pestre eds., *Science in the 20th Century* (Harwood Academic Publishers, 1997), 617–634; Michael S. Mahoney, "Software as Science – Science as Software", in Ulf Hashagen, Reinhard Keil-Slawik and Arthur L. Norberg eds., *History of Computing: Software Issues. International Conference on the History of Computing, ICHC 2000, April 5-7, 2000, Heinz Nixdorf MuseumsForum, Paderborn, Germany* (Berlin: Springer, 2002), 25–48; and Seymour V. Pollack, "The Development of Computer Science", in Seymour V. Pollack ed., *Studies in Computer Science* (Washington, D.C.: Mathematical Association of America, 1982), 1–51. Other works describing the professionalization of computer users exist, but by and large these focus on programmers and less on academic computer scientists operating within a higher educational environment. See Atsushi Akera, "Calculating a Natural World: Scientists, Engineers, and Computers in the United States, 1937-1968", Ph. D thesis, University of Pennsylvania (1998); Nathan L. Ensmenger, "The 'Question of Professionalism' in the Computer Fields", *IEEE Annals of the History of Computing* 24, no. 4 (October-December 2001), 56–74; Nathan Ensmenger and William Aspray, "Software as Labor Process", in Hashagen et al., *History of Computing: Software Issues. International Conference on the History of Computing, ICHC 2000, April 5-7, 2000, Heinz Nixdorf MuseumsForum, Paderborn, Germany*, 139–165; and Thomas Haigh, "The Chromium-Plated Tabulator: Institutionalizing an Electronic Revolution, 1954-1958", *IEEE*

had been first used in 1959, there was as yet no single definition which satisfied anyone calling themself a computer scientist. Across North America, new departments tended to prefer research or teaching they was already familiar with. For example, those schools with a strong electrical engineering tradition leaned in that direction, and a program with a history that emphasized mathematics or numerical analysis would proceed that way. There was no broad consensus regarding the boundaries of the discipline. However, historians have observed that it was common to precede an attempt to define computer science by building an organizational structure within a university that would support the new discipline.[8] Once the framework was in place and computer scientists had some degree of autonomy, they set about deciding what computer science was. And as the reader will discover, when the Department of Computer Science was created at the University of Toronto in 1964, the primary argument relied on organizational benefits, not a clear definition of computer science.

There is no question that the history of computing literature concentrates predominantly on the activities, persons, and technologies of the United States. While the European – particularly British – participation in the 1940s and 1950s is generally acknowledged, other international accomplishments are often forgotten or ignored.[9] To some degree this can be attributed to the dominance of American computer manufacturers such as IBM in the 1960s, but this should not excuse the lack of international perspectives.

That said, there have been a few attempts to document the development of computing in Canada. An entire issue of the *IEEE Annals of the History of Computing* was dedicated to the subject. The articles collectively tell a strong story of Canadian

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Annals of the History of Computing 24, no. 4 (October-December 2001), 75–104. At the end of 1991, the *Annals of the History of Computing* ceased publication, replaced at the opening of 1992 by the *IEEE Annals of the History of Computing*.

[8] Ceruzzi, "Electronics Technology and Computer Science, 1940-1975: A Coevolution", 266.

[9] Historians of computing have begun to recognize this failing. See Paul N. Edwards, "Think Piece: Making History – New Directions in Computer Historiography", *IEEE Annals of the History of Computing* 23 (January 2001), 86–88, and Corinna Schlombs, "Towards International Computing History", *IEEE Annals of the History of Computing* 28, no. 1 (Jan-Mar 2006), 108,107.

achievements contemporary with much of this dissertation: the computing program at the University of Toronto[10]; RESERVEC, the world's first automated airline reservation computer[11]; a transistorized computer built at the behest of the Defence Research Board (DRB)[12]; and the history of Ferranti-Canada, the first company in Canada with a digital computer research and development arm, which existed from the late 1940s to the early 1960s.[13] Ferranti-Canada was responsible for RESERVEC, along with a real-time anti-submarine system, the world's first mail-sorting computer, and the first medium sized time-sharing multiprogrammable computer, the FP-6000. The city of Toronto was also home to the world's first fully computerized traffic control system, designed by KCS Data Control in the late 1950s and implemented the next decade.[14] Of course Canadians continued to make contributions to the field, and recent scholarship suggests that the Canadian Micro Computer Machines MCM/70 of 1973 was the first instance of a personal microcomputer.[15]

Foremost among histories of Canadian computing is John Vardalas' *The Computer Revolution in Canada*.[16] It is in the subtitle, "Building National Technological Competence", that the theme of his book, of Canadians working "to transform the accumulating computer engineering know-how into broad national capability," can be found.[17]

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[10] J.N.P. Hume, "Development of Systems Software for the Ferut Computer at the University of Toronto, 1952 to 1955", *IEEE Annals of the History of Computing* 16, no. 2 (1994), 13–19 and Michael R. Williams, "UTEC and Ferut: The University of Toronto's Computation Centre", *IEEE Annals of the History of Computing* 16, no. 2 (1994), 4–12.

[11] Alan Dornian, "ReserVec: Trans-Canada Air Lines' Computerized Reservation System", *Annals of the History of Computing* 16, no. 02 (1994), 31–42.

[12] Linda Petiot, "Dirty Gertie: The DRTE Computer", *Annals of the History of Computing* 16, no. 02 (1994), 43–52.

[13] John N. Vardalas, "From DATAR to the FP-6000: Technological Change in a Canadian Context", *Annals of the History of Computing* 16, no. 2 (Summer 1994), 20–30.

[14] Josef Kates, interview by Michael R. Williams, 9 June 1992, Transcript provided by Michael R. Williams.

[15] Zbigniew Stachniak, "The Making of the MCM/70 Microcomputer", *IEEE Annals of the History of Computing* 25, no. 3 (April–June 2003), 62–75.

[16] John N. Vardalas, *The Computer Revolution in Canada: Building National Technological Competence* (Cambridge, Mass.: MIT Press, 2001). The book is based on: John N. Vardalas, "Moving up the Learning Curve: The Digital Electronic Revolution in Canada, 1945-1970", Ph.D. thesis, History, University of Ottawa (1998).

[17] Scott M. Campbell, "Review: The Computer Revolution in Canada", *Scientia Canadensis* 27 (2003), 126.

The University of Toronto was the home of the first attempt in Canada to build a digital computer, so it is the starting point for Vardalas. From there, he explores in more depth several of the above stories – the DRB electronics research, the many Ferranti-Canada computing projects, and other computer developments at Sperry Canada and Control Data Corporation. However, as explained later, when the university turned away from designing a computer in 1952 to just using one, Vardalas loses interest in academic computing. Moreover, his external perspective of the University of Toronto treats it as a monolithic entity, but as is shown in chapter 2 of this dissertation, his assumption can be misleading. Regardless, this is the only significant book to treat the history of Canadian computing in a rigorous, academic manner.[18]

This dissertation is partitioned chronologically into chapters that mark major events or shifts in policy or priorities. Chapter 1 tells the story of how a few members of the University of Toronto administration and teaching staff sought to acquire a large, electronic, digital computer in the second half of the 1940s. It explains the epigraph of this introduction and the outcome of the "growing interest" in modern computing. Most computer projects underway in the United States or the United Kingdom were located at a university, but the funding typically came from beyond the campus. This was the case at Toronto – the university could not afford to build or buy a computer and so it turned to the Canadian government for assistance. The chapter explores the arguments used in locating the project in Toronto, revealing that a need for a computing centre had to be created.

The contents of chapter 2 take place between 1948 and 1952. During that time the new Computation Centre at the University of Toronto was established, and the chapter explores how it went about securing computing machinery, and how the various

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[18] Two other texts document the history of Canadian computing, but while both are valuable sources of information and enjoyable reads, they are also journalistic in approach. See Beverly J. Bleackley and Jean La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years* (Agincourt, Canada: The Book Society of Canada Limited, 1982) and David Thomas, *Knights of the New Technology: The Inside Story of Canada's Computer Elite* (Toronto: Key Porter Books, 1983).

technologies were used. There were crucial conflicts among the various organizations involved, particularly with respect to the proper role of a campus-based computing centre. The ambitious people driving the project in Toronto did not always see eye to eye with the federal agencies providing the financing. As a result, the success of the various computing projects launched during this time was mixed. The course of computing at the university was determined by influential outsiders more so than any internal actions.

With the arrival of the first computer in Canada, the Computation Centre did come into its own, as explored in chapter 3. The staff quickly learned how to use the computer in Canada, though an important transfer of technological style (in the form of programming knowledge) from Manchester to Toronto was a necessary first step. A second important advance was the development of TRANSCODE, an automatic programming system that simplified programming tasks immensely for beginners and experts alike.

Finally, the story moves to consider several challenges that the Computation Centre encountered which led to the transformation that created a Department of Computer Science. Chapter 4 begins with an analysis of the computer research and training that went on at the University of Toronto after the arrival of electronic computers. By the end of the 1950s Toronto's monopoly as the owner of the only electronic computer in Canada had expired, as many other universities and organizations could now buy their own. This changed the mission of the Computation Centre. There was concern over whether universities should be in the business of computing at all, or should service organizations take over. Could a computer be more than a tool but also an object of study? The answer to this question is addressed in chapter 5, along with the manner in which the leaders of the Computation Centre hoped to establish a new academic department, despite the lack of a cohesive new discipline to found it.

The concluding chapter summarizes and draws connections to other developments in Canada and abroad. In the mid 1960s there were many disparate views of what computer science should be, what subjects should be taught, and what research directions were valid. There was also no guarantee that computing success in the 1940s would be repeated in the 1960s, as other universities with early computer hardware projects discovered to their detriment. Unlike many, the University of Toronto did manage to maintain a position of leadership with a strong computer science program.

Chapter 1

Bringing Computing to the University of Toronto, 1945–1948

"A first-rate computing centre is needed in Canada . . . "

– University of Toronto Committee on Computing Machines, 1948.[1]

The University of Toronto was poised for change and growth in 1945. President Sidney E. Smith was installed that year, a member of the new guard of administrators who would guide the university though the end of the hectic 1940s and into the more prosperous decade that followed. The Second World War might have generated uncertainty or equivocalness about the future of the university, but these fears would have to be dispelled quickly; the federal government had promised free tuition to a massive cohort of veterans who were expected to double the enrolment. Not that the university had been idle during the war, particularly on the scientific front. A number of Toronto scientists and engineers contributed to various research and development projects, including radar, the proximity fuse, shell propellants and explosives, avia-

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[1] Suggestions Regarding the Responsibilities of the University of Toronto in Connection with the Proposed Computing Centre, January 1948, University of Toronto Archives and Records Management Service (UTARMS) A1968-0007, Box 33, Folder 10.

tion medicine, and even chemical and biological weapons.[2] Much of this work was performed in conjunction or under the supervision of the National Research Council (NRC) and at the end of the war an Advisory Committee on Scientific Research was formed by the president and the Board of Governors of the university to sustain this relationship. Members were appointed "to advise the Board on all matters of scientific research and in fostering co-operation with Federal and Provincial research organizations."[3] One of the functions of the Committee was to evaluate faculty and staff proposals and disburse internal grants to support their scientific research. From this pool of funds modern computing would first emerge at the University of Toronto.

It was Samuel Beatty, dean of the Faculty of Arts and chair of the Department of Mathematics who was responsible. In the fall of 1945, wearing his mathematician's hat, he applied for and received a $1000 travel grant from the University of Toronto's Board of Governors Advisory Committee on Scientific Research.[4] The purpose of the grant was to "visit a number of institutions in the United States to study modern computing machines and their applications in research."[5] To use the grant, he assembled an interdepartmental Committee on Computing Machines, consisting of himself, three additional members from the Department of Mathematics: W.J. Webber (chairman), A.F.C. Stevenson, B.A. Griffith (secretary); and one each from the Department of Physics and Electrical Engineering: C. Barnes and V.G. Smith, respectively. As Beatty explained to President Smith, they hoped to visit the Institute for Advanced Study at Princeton University, the Massachusetts Institute of Technology, and Brown University, to meet with, respectively, John von Neumann, Norbert Wiener, and D.R.G. Richardson.

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[2] Martin L. Friedland, *The University of Toronto: A History* (Toronto: University of Toronto Press, 2002), 352–359.

[3] Advisory Committee on Scientific Research, Extracts from Minutes of the Board of Governors, 22 March 1945, UTARMS A1973–0025, Box 8, Folder 6.

[4] As a senior faculty member Beatty was a member of this committee, but it is apparent that his position did not guarantee a positive response to his request.

[5] S. Beatty to S.E. Smith, 28 November 1945, UTARMS A1968–0007, Box 6, Folder 2.

This was not a portentous start for computing in Toronto. The $1000 grant does not stand out among other recipients. The largest grant went to Professors M.F. Crawford and H.L. Welsh of the Department of Physics, who were awarded $5,000 to purchase a Perkin and Elmer Infrared Spectrometer and auxiliary equipment for ongoing research in Raman spectroscopy.

It is not immediately clear what inspired Beatty to apply for the grant, but the idea did not descend from senior levels of the university. In a late 1945 letter to President Smith, Beatty thanked him on behalf of the mathematics department for the grant, but Smith's response, while polite, showed little interest in the project.[6] Beatty's background as a mathematician was algebraic functions, a subject which does not imply an interest in high-speed computational machinery. Yet his application was explicitly made on behalf of the Department of Mathematics and four of the six committee members he chose were mathematicians. In general, most mathematicians at that time had little use for numerical work, but perhaps Beatty perceived more in the future of computing than mere calculation. With the recent departure of J.L. Synge in 1943, and the subsequent absorption of the Department of Applied Mathematics into the Department of Mathematics it is possible that he was casting about for fertile fields of applied mathematical research.[7]

Did a fellow faculty member put the idea to Beatty, in hopes that as dean his prestige and position on the Board of Governors Advisory Committee on Scientific Research would provide a better chance of success? During World War II, V.G. Smith provided computing assistance to the Mathematical Tables Project of the National Bureau of Standards in the United States.[8] During the final year of the war V.G. Smith,

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[6] S.E. Smith to S. Beatty, 29 November 1945, UTARMS A1968–0007, Box 6, Folder 2.

[7] Synge was an Irish mathematician and physicist, who spent the years 1920–1925 and 1930–1943 at the University of Toronto. In the latter period, he helped form a Department of Applied Mathematics which subsequently collapsed when he left Toronto. Gilbert de Beauregard Robinson, *The Mathematics Department in the University of Toronto, 1827-1978* (Toronto: University of Toronto Press, 1979).

[8] For more on the Mathematical Tables Project, see Grier, *When computers were human*. The exact nature of Smith's contribution is unknown, though it included "computational work of a specialized nature relating to the war effort." The Mathematical Tables Project Director, A.N. Lowan, personally

A.F.C. Stevenson, and L. Infeld carried out research on war problems for the NRC that involved computations substantial enough to necessitate hiring an assistant, and they might have had difficulty recruiting suitably skilled human computers.[9] These associates of Beatty may well have felt that the university needed a greater commitment to computation. B.A. Griffith, another member of the Committee on Computing Machines, admitted later that he was not aware of the project until after Beatty invited him to join, although his career changed the most as a result.[10]

One possible inspiration is the June 1945 meeting of the Canadian Mathematical Congress.[11] It was the initial meeting of the newly formed society, and attracted about 250 participants, including Beatty, who was elected the first president. Several international dignitaries attended, including John von Neumann who gave a talk entitled "High-speed computing devices and Mathematical Analysis", and Douglas Hartree who spoke on solving differential equations numerically using a differential analyzer.[12] As world-renowned mathematicians, it is likely that their talks would have attracted a sizable audience, particularly given the novelty of their experiences with modern computing machinery.

At least two other panels held at the Congress are relevant. During a discussion on applied mathematics W.H. Watson, of the University of Saskatchewan, spoke of a need to develop a national policy for applied mathematics and to support this goal made an explicit call for a national computing centre in Canada.[13] He correctly foresaw that the

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thanked Smith for his efforts. A.N. Lowan to V.G. Smith, 22 February 1943 and 19 March 1943, UTARMS B1999–0025, Box 1, Folder L.

[9] S. Beatty, Apportionment to Scientific Research, for the Period 1 April 1944 to 30 March 1945, 16 February 1946, UTARMS A1968–0007, Box 6, Folder 2.

[10] Byron A. Griffith, "My Early Days in Toronto", *IEEE Annals of the History of Computing* 16, no. 2 (1994), 57.

[11] *Proceedings of the First Canadian Mathematical Congress, Montreal, 1945* (Toronto: The University of Toronto Press, 1946).

[12] Douglas R. Hartree, "The Use of the Differential Analyzer to the Evaluation of Solutions of Partial Differential Equations", in "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945", 327–337.

[13] William H. Watson, "A National Policy for Applied Mathematics", in "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945", 111–113.

NRC, the primary sponsor of the Congress that year, should have an "obvious interest" in supporting such a venture, but offered no ideas as to how and where a centre should be established.[14] V.G. Smith, a future member of Beatty's computer committee, also spoke at the Congress, as part of a panel exploring the peculiarities of engineering mathematics. In describing the computational needs of engineers, he reminded mathematicians that numerical solutions require different approaches that are not analytical, and that expensive and elaborate mechanical analyzers and computers can save a great deal of mental labour.[15]

In all likelihood, it was a combination of many factors behind Beatty's move. There had been no prior attempt to develop large-scale computing expertise in Canada, but as the war drew to a close it was apparent that facilities in the United States and England had proven useful to scientists and engineers. If there was to be a national computing centre, with its strong applied mathematics division the University of Toronto was a logical host, if not the only possibility. Beatty was a well-connected man, with his finger on the pulse of science in Canada; he was probably aware of the Canadian atomic energy project taking place in Montreal and Chalk River, Ontario. High-speed computing had been essential to atomic research in the United States, and Beatty would have known that any self-sustaining Canadian program would demand similar resources if it hoped to keep up internationally.

1.1 Touring the Northeast

The Committee on Computing Machines was assembled by November 1945 and met regularly over the following months to prepare for the tour and discuss computing

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[14] That Watson put forth this position is intriguing: within five years he was Head of Physics at the University of Toronto and throughout most of the 1950s chaired the committees that oversaw computing at Toronto. See page 138.

[15] Victor G. Smith, "Engineering Mathematics", in "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945", 43–50.

activities taking place in the United States. Griffith, as secretary-treasurer of the Committee, corresponded with various facilities to learn more and to arrange a visit in the spring of 1946. From June 10 to July 2 of that year, without Beatty, the group set out by car to visit a dozen laboratories, research groups, and individuals across the Eastern United States.[16] They were joined on the tour by G.W. Hopkins of the NRC, and in their visits to the Boston, Philadelphia, and New York areas by N.L. Kusters, of the NRC Radio and Electrical Engineering Division. The number of destinations had grown from Beatty's initial estimate, but the community of high-speed computing machinery research was socially and geographically small enough that they could visit each major project and acquire a good, if incomplete, impression of the state of the art.[17]

The tour first passed through the Naval Research Laboratories in the Anacostia neighborhood of Washington, D.C., the Pentagon, the Moore School of Electrical Engineering in Philadelphia, Aberdeen Proving Grounds, and Princeton Institute for Advanced Studies. They also visited Eckert and Mauchly's fledgling company in Philadelphia, described by Griffith as "a small UNIVAC research group," but otherwise known as the Eckert-Mauchly Computer Corporation.[18] They drove to New York, to visit Bell Laboratories and IBM headquarters, and to Boston – stopping at Brown University along the way – to spend a few days at Harvard and MIT. On the way home, they stopped in Burlington, Vermont to talk with G.R. Stibitz, principle architect of the Bell Laboratories Relay Calculators.

The main object of their trip was to study the types of machines in operation or under construction, in order to understand their principles of operation. They were

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[16] Griffith, "My Early Days in Toronto", 57.

[17] Griffith has admitted that the committee remained ignorant of European activities in the field for several years. They had no knowledge of the most complex English computing project to date – Colossus – which remained classified until the 1970s. In Germany, Conrad Zuse had been building electromechanical computers since the beginning of the war, but few in North America were aware of him or his work in 1946.

[18] Ibid.

also curious about the types of problems that could be solved, and the manner of solution. Although the itinerary included several special purpose machines designed to solve particular problems, their main interest was general purpose computers capable of a more varied set of calculations. It was an efficient trip, having visited virtually every large-scale computing facility in the Northeast and inspected almost every major computer, both analog and digital. The trip, along with their observations and recommendations, was outlined in a 1946 preliminary report to the University of Toronto Board of Governors Advisory Committee on Scientific Research.[19] A preliminary report describing the trip was also filed by Hopkins to the NRC in July 1946.[20]

The Committee on Computing Machines report began with a description of the difference between analog and digital computing. There are two ways to represent a number with a calculating device. Analog devices establish a directly proportional relationship between the number and a variable physical quantity, such as length, angle, or electrical voltage that is measurable. Digital devices store each digit of the number separately, using a finite arrangement of states that vary by discrete steps. Although digital computers have been the dominant technology for large-scale computation since the 1950s, in 1946 both types were widely used by engineers, scientists, and mathematicians and both had well understood advantages and disadvantages.

Analog computers were most closely associated with MIT, a destination close to the end of their trip, where Vannevar Bush had established a substantial engineering laboratory dedicated to analog techniques in the early 1930s. It was here that he developed a successful type of analog computer known as a differential analyzer to calculate integrals that resisted analytical solution. It descended directly from nineteenth

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[19] Preliminary Report on Modern Computing Machines, 1946, UTARMS B1988–0069, Box 1, Folder 2. The Committee also managed to complete the tour under budget. Of the original $1,000 grant, just $19.67 remained when Beatty submitted his report to the Advisory Committee on Scientific Research in 1946.

[20] J.W. Hopkins, Memorandum to File, Report on Visits in Boston and New York Area in Collaboration with University of Toronto Committee on Computing Machines, 5 July 1946, Library and Archives Canada (LAC) RG77, Volume 134, File 17-15-1-20.

century planimeters, the first mechanical integrating devices. Bush's first model, completed in 1930, could solve an arbitrary differential equation to an accuracy around 1 in 1,000. As these equations are the basic means of describing dynamic behaviour in engineering and physical sciences, an analyzer could be used to tackle many common problems in these subjects.

Douglas Hartree, from Manchester University, visited Bush at MIT in 1933 to study his analyzer. Later that year Hartree and Arthur Porter, his graduate student, constructed a smaller and lighter version of the analyzer from Meccano.[21] It was not as accurate, at 1 in 100, but was used to solve nontrivial differential equations related to calculating atomic structure. To scientists in the United Kingdom it was an extremely inexpensive manner of obtaining useful computing power, and several copies were built that decade. After the successful demonstration of his Meccano model, Hartree managed, not without difficulty, to acquire further funding to build a full-scale version at Manchester University, completed in 1935, the sole large-scale mechanical computer in the country until the outbreak of the War.[22]

D.R.G. Richardson of Brown University also built a differential analyzer, at a cost of approximately $6,000. The parts were manufactured locally, and with five integrator units, was felt to have an accuracy similar to Hartree's Meccano models. Perhaps more important to the Canadian tour group was a chance to inspect the mathematical library at Brown, which was felt to be one of the most complete in the world.[23]

At the beginning of World War II, Bush constructed one final analyzer, a crowning achievement known as the Rockefeller Differential Analyzer (RDA), named in honour of the large donations made by the Rockefeller Foundation to his laboratory. The

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[21] Meccano is a children's construction toy, consisting of perforated metal strips that can be fastened together with nuts and bolts. It was available widely in the United Kingdom and Canada before and after World War II. In the United States a similar product known as Erector was more common.

[22] Mark D. Bowles, "U.S. Technological Enthusiasm and British Technological Skepticism in the Age of the Analog Brain", *IEEE Annals of the History of Computing* 18, no. 4 (October 1996), 5–15.

[23] J.W. Hopkins, Memorandum to File, Report on Visits in Boston and New York Area in Collaboration with University of Toronto Committee on Computing Machines, 5 July 1946, LAC RG77, Volume 134, File 17–15–1–20.

RDA was a massive machine, approximately 100 tons, and much more complex than any other analyzer. It included a number of design changes that improved the overall accuracy of solutions to 1 in 10,000. On rare occasions it was possible to reach 1 in 100,000. It was also simpler to 'program': problems that may have taken days to prepare could now be set in a manner of minutes, improving the overall productivity of the machine considerably. The RDA was used almost exclusively and quite successfully to prepare ballistic firing tables during the war.[24]

This military imperative was a crucial force behind the rapid development of digital computers. The Toronto committee recognized three main types, which they categorized by the main components and archetype machines. The first class used electromechanical counter wheels; the most elaborate implementation was the Harvard Mark I, constructed of accounting machine registers. The second category included machines which used electromagnetic relays, such as the Bell Telephone Laboratories series of relay calculators which employed a bi-quinary numeric representation. In the last category, vacuum tubes were used as the principal element. The ENIAC, designed and built at the Moore School of Electrical Engineering at the University of Pennsylvania, was the best known example. Both the first and last categories of machines typically used a strict decimal notation.

At Harvard, computing research was centred on Howard Aiken, who began his career there as an instructor of applied mathematics.[25] Dissatisfied with existing tabulators used to solve scientific problems, he first proposed in 1937 a modified set of commercial punched-card machines linked together that could automatically calculate and print mathematical tables. He managed to convince IBM to help and between

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[24] Allan G. Bromley, "Analog Computing Devices", in Aspray, *Computing Before Computers*, 156–199; Larry Owens, "Vannevar Bush and the Differential Analyzer: The Text and Context of an Early Computer", *Technology and Culture* 27, no. 1 (January 1986), 63–96; and Williams, *A History of Computing Technology*, 203–207.

[25] For more on the life and work of Aiken, see I. Bernard Cohen, *Howard Aiken: Portrait of a computer pioneer* (Cambridge, MA: MIT Press, 1999), and Gregory W. Welch, Robert V. D. Campbell and I. Bernard Cohen eds., *Makin' Numbers: Howard Aiken and the Computer* (Cambridge, Mass.: MIT Press, 1999).

1939 and 1944 IBM engineers worked with Aiken's plans to build the Automatic Sequence Controlled Calculator (ASCC) at the Endicott, New York plant. They used standard accounting register mechanisms capable of storing one decimal digit each. Most of the construction cost, estimated at just under half a million dollars, was also covered by IBM. Thus, when Aiken failed to acknowledge IBM's assistance publicly, it enraged Thomas J. Watson, chairman of IBM. When the calculator was completed, it was moved to Harvard, but long before the public unveiling on 7 August 1944, it was used by the United States Navy for classified work, including computing blast effects of an atomic bomb. Aiken was not present when the group from Toronto arrived, but Grace Murray Hopper, who later became a famous programmer, gave them a tour as the machine computed Bessel function tables.[26]

When Aiken first approached IBM, the company was not unfamiliar with the use of their equipment for scientific research. Their primary product, Hollerith style tabulating equipment, invented in the late nineteenth century, was first turned to large-scale scientific calculations in the late 1920s and 1930s. In England, L.J. Comrie devised a way to compute the motions of the moon from 1935 to 2000 using commercially available punched card accounting machines. The technique was noticed and brought to the United States by Wallace Eckert at Columbia University. In 1929 IBM agreed to found the Columbia University Statistical Bureau, using standard IBM punched card tabulating and accounting machines. In the 1930s the Bureau was expanded to include more complicated calculations and renamed the Thomas J. Watson Astronomical Computing Bureau.[27]

It appears that the Toronto committee did not visit this already famous organization due to a scheduling conflict. They did visit Columbia College to discuss statistics instruction and laboratories for undergraduate students. Griffith may have borrowed ideas from this stop for the statistics laboratory he was planning at Toronto, but Hop-

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[26] Tour details of each facility are available in Griffith, "My Early Days in Toronto", 57.

[27] Jean Ford Brennan, *The IBM Watson Laboratory at Columbia University: A History* (IBM, 1971).

kins' report suggests that the Columbia College computing equipment they saw was less advanced than what was available in Canada. The Committee on Computing Machines also visited IBM's headquarters in New York, but it is unknown what they saw there. Many scientists were beginning to use IBM office tabulators and multiplying punched card calculators in their work, which the committee may have seen.[28]

Of the second category of computing machines, the central figure was G.R. Stibitz, a researcher at Bell Telephone Laboratories. He first conceived of using telephone relays to build a mechanical calculator in 1937 and designed five of the six Bell Labs Relay Calculators. The first unit, known as the Complex Number Calculator (CNC), was completed in late 1939. It was used by electrical and telephone engineers at Bell to calculate complex number multiplication and division.[29]

After the United States entered the war, Stibitz left Bell Labs to join the National Defence Research Committee where he was responsible for research in the design and use of digital calculators. In 1943 he designed a second machine, known as the Relay Interpolator or Model II. It was intended for the military to solve problems of directing antiaircraft fire but was built at Bell Labs, where he had maintained close ties. The CNC could not handle a prepared sequence of operations but by easily changing the input tapes this second model could be used to solve different interpolations, making it useful for many types of scientific and engineering problems. Stibitz improved upon this technique with his next two machines, again built at Bell Labs. The nearly identical Model III and IV were also known as the Ballistic Computer and Error Detector Mark 22, and were installed for the United States Army at Fort Bliss, Texas in June 1944 and for the United States Navy in Washington, D.C. in March 1945. They were not yet general-purpose machines but were much more flexible than their predecessors. In addition to interpolations they could be used to evaluate a variety of ballistic

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[28] The giant Selective Sequence Electronic Calculator (SSEC), Watson's response to Aiken's attitude regarding the Harvard Mark I, was not operating until early 1948.

[29] Paul E. Ceruzzi, "Number, Please: Computers at Bell Labs", in Paul E. Ceruzzi, *Reckoners: The Prehistory of the Digital Computer* (Westport, Conn.: Greenwood Press, 1983), 73–102

equations, for which they too were used almost exclusively.

When the group from Toronto visited Bell Laboratories, two identical copies of the Model V were under construction, the last machine Stibitz designed. It was a large-scale general-purpose calculator, roughly in the same category as the Harvard Mark I or even the ENIAC, although the latter was much faster at arithmetic. The most significant new feature of the Model V over earlier relay machines was the ability to "branch" on a condition and follow a different sequence of operations depending on a result. This made it considerably more powerful but also more complicated. With over 9000 relays, six times the number in the Bell Laboratories Mark III and IV, and a "rather baroque" arrangement of multiple tape readers and tape loops to handle branching, the 10 ton machine cost around half a million dollars.[30] The two copies were built for the United States government for classified military projects. The first was finished in December, 1946 and installed at the National Advisory Committee on Aeronautics, the predecessor of National Aeronautics and Space Administration (NASA), at Langley Field, Virginia and the second was installed at the Aberdeen Proving Ground in Maryland in August, 1947.[31]

Again, it is uncertain what the Toronto committee witnessed at the Aberdeen Proving Grounds, but they might have been introduced to one of the Pluggable Sequence Relay Calculators (PSRC). These were relay-based machines, but controlled by punched card, unlike Stibitz's designs. They were custom built by IBM at the request of the United States Army, and thanks to careful input and output design, could run almost ten times as fast as a standard electromechanical IBM 602 Calculating Punch machine. Only seven PSRCs were built and they are considered to have been a special purpose war-time machine, not a standard IBM product.[32]

The final type of digital computer used vacuum tubes as the principal component.

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[30] Paul E. Ceruzzi, "Relay Calculators", in Aspray, *Computing Before Computers*, 211.

[31] Williams, *A History of Computing Technology*, 230.

[32] Brian Randell ed., *The Origins of Digital Computers*, 2nd edition (Berlin: Springer-Verlag, 1975), 192 and Williams, *A History of Computing Technology*, 255.

The Electronic Numerical Integrator and Computer (ENIAC) was still a classified military secret when Beatty first proposed the trip, so he may not have been aware of it, but it was publicly dedicated in February 1946. The Toronto committee made their way to the Moore School of Electrical Engineering at the University of Pennsylvania where John Mauchly and J. Presper Eckert had built the computer, starting in 1943. Funded by the United States Army, the project's purpose was to calculate ballistics tables, and although the 18,000 vacuum tubes it used were less reliable than relays, the advantages in arithmetic speed were considerable, on the order of one thousand times faster. By Spring 1945 it was underway, running ballistics programs for the Ballistics Research Laboratory (BRL) at the Aberdeen Proving Grounds as well as scientific calculations for local scientists and atomic energy researchers at Los Alamos. Sometime after the Toronto group visit it was relocated to the Ballistics Laboratory where it ran continuously until 1955, with a number of substantial upgrades.[33]

Following the dedication, an overwhelming number of requests for information flowed to the Moore School. In response, plans were made for a special course over the Summer of 1946 (July 8 to August 31) for any interested party to come and learn directly from their work. Entitled "Theory and Techniques for Design of Electronic Digital Computers" many expected the course to outline the development of the ENIAC, but instead most of the lecturers talked about a new and upcoming computer known as the Electronic Discrete Variable Automatic Computer (EDVAC). None of the Toronto group attended the lectures, but the proceedings were disseminated widely and a worn copy can be found in the University of Toronto library.

Despite the fanfare and its computational speed, ENIAC suffered from a number of shortcomings. Eckert and Mauchly recognized them shortly after construction was launched, too late to change matters. The famous mathematician, John von Neumann, also perceived the problems shortly after he took an interest in the project in

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[33] For example, magnetic core storage was added in 1952. Williams, *A History of Computing Technology*, 282.

1944. First, there was very little of the very fast electronic storage. Of the 18,000 tubes, about half were dedicated to the storage, which was sufficient to hold just 20 numbers, enough for differential equations, but not for partial differential equations. The second problem was that programming ENIAC required a long and laborious method of patch-cords plugged and unplugged into the machine; it could take days to prepare a problem that might run for just a few minutes.

A second machine was proposed to resolve these shortcomings, to be known as EDVAC. The actual inventor of the EDVAC is subject to debate, as many people at the Moore School contributed, but the idea was most formally described in a 1945 Report on the EDVAC, authored by von Neumann.[34] His main interest lay in the logical structure of the machine, rather than the arrangement of the parts, and he quickly grasped the potential and future of the computer project. Great flexibility and power could be had by increasing the storage and by executing programs from storage, rather than from punched cards or tape. Plans were made to build such a machine, but the priority was to finish ENIAC first.[35]

After the war, Mauchly and Eckert resigned their positions at the University of Pennsylvania. A patent dispute had arisen between the two and the university, and they chose to leave, convinced they could build and market their own computer. By the time the Toronto group visited in late June the United States National Bureau of Standards, on behalf of the Census Bureau, had awarded them a study contract to the two, who promptly formed their own company, the Electronic Control Company. The study led eventually to an EDVAC-type machine for the Census Bureau, known as

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[34] John von Neumann, "First Draft of a Report on the EDVAC", Technical report (Philadelphia, Pa.: Moore School of Engineering, University of Pennsylvania, 30 June 1945). The most recent evidence suggests that H.H. Goldstine, an army officer involved in the ENIAC project, wrote much the report, cobbling it together over June 1945, but deferred authorship to von Neumann as the most senior scientist. See David Alan Grier, "From the Editor's Desk", *IEEE Annals of the History of Computing* 26, no. 3 (July-September 2004), 2–3.

[35] ENIAC was modified to made it programmable sometime after 1947. It made the machine slower, but it now took hours and not days to prepare it for a problem. Williams, *A History of Computing Technology*, 283.

the UNIVAC, for Universal Automatic Computer.[36] Griffith recalled that during their trip, the UNIVAC group was experimenting with magnetic tape, but none of them foresaw the future importance of this medium.[37] Von Neumann also walked away from EDVAC after the war, determined to build his own computer at his institutional home, Princeton University's Institute for Advanced Study. When the Toronto group made their way to New Jersey, von Neumann was well into the planning stages, and they found his views on the future of electronic computing inspiring.

It is worth noting at this point the views of Stibitz, who was hired as a consultant in the Spring of 1946 by the National Bureau of Standards to review Eckert and Mauchly's proposal. He had not supported the ENIAC project during the war, and remained unenthusiastic about their plans. Instead, Stibitz encouraged careful study and substantial planning before committing a large amount of money.[38] In the opening talk at the Moore School Lectures, he expressed a particular caution about the cost effectiveness of electronic computers – don't look at them as fun toys, he warned his audience, and ensure that you're getting your money's worth.[39]

1.2 Financing the First Steps

Stibitz's cautionary comment resonated with the foremost recommendation of the Toronto committee's preliminary report: the time was not right for the University of Toronto to acquire a large-scale computing machine. The first problem was that they could not purchase one, as there were none for sale. Eckert and Mauchly had only just left the Moore School to launch their own computer company and were many years

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[36] Nancy Stern, "The Eckert-Mauchly Computers: Conceptual Triumphs, Commercial Tribulations", *Technology & Culture* 23, no. 4 (October 1982), 569–582.

[37] Griffith, "My Early Days in Toronto", 57.

[38] Stern, "The Eckert-Mauchly Computers: Conceptual Triumphs, Commercial Tribulations", 575.

[39] George R. Stibitz, "Introduction to the Course on Electronic Digital Computers", in Martin Campbell-Kelly and Michael R. Williams eds., *The Moore School lectures: Theory and Techniques for Design of Electronic Digital Computers* (Cambridge, Mass., Los Angeles: MIT Press, Tomash Publishers, 1985).

away from a finished product. In 1946, IBM and the other companies that would eventually dominate the computer industry had little interest in manufacturing electronic computers, though their attitudes would change in the next decade. Second, financing a computer development project was far beyond their means in Toronto. Although hard figures are unknown in most cases cited above, the development costs of a large-scale digital computer have been estimated to lie close to half a million dollars. Eckert and Mauchly acknowledged that development costs on the UNIVAC would be around $400,000.[40] In 1945 the largest scientific grant at the University of Toronto was $5,000, one hundredth of this amount. To copy an existing machine was an option, but this too was rejected, given that current designs were obsolete, and that future EDVAC-type computers would be more powerful, and hopefully more affordable, "possibly no more than about $50,000 (approximately 10 to 20 per cent of the cost of the present machines)."[41] It is clear they were willing to ride the wave of research south of the border at this point.

The committee remained excited at the potential of high-speed computing, particularly in problems of applied mathematics that had previously been regarded as insoluble: "There can be little doubt that many important additions to our scientific knowledge will be made."[42] Until the time was right, and the university was prepared to cover the costs, they suggested several means to stimulate interest in computing on campus. First off, the facilities for studying and teaching computational methods needed substantial improvement at both graduate and undergraduate levels. This dovetailed well with a numerical laboratory course that Griffith was developing in the Statistics and Actuarial Science division of the Department of Mathematics. The committee proposed that a small appropriation be set aside by the university to cover this need.

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[40] Stern, "The Eckert-Mauchly Computers: Conceptual Triumphs, Commercial Tribulations", 576-578.
[41] Preliminary Report on Modern Computing Machines, 1946, UTARMS B1988–0069, Box 1, Folder 2.
[42] Preliminary Report on Modern Computing Machines, 1946, UTARMS B1988–0069, Box 1, Folder 2.

Aside from teaching computing techniques it was also felt that professors and graduate students from the departments of Physics and Electrical Engineering could make contributions to "fundamental problems connected with electronic computers - in particular, storage devices, circuits, and methods for the insertion and removal of data."[43] One of the most important lessons that came from von Neumann's widely read *First Draft of a Report on the EDVAC* in 1945 was that electronic computers could be modularized and subdivided into five distinct parts: an arithmetical processor, a central control, storage, input, and output.[44] They might not be able to build an entire computer in Toronto, but they could study the component parts and join the community of high-speed computing research.

Perhaps the greatest benefit from the tour was not any knowledge gained of current high-speed technologies – these were already obsolete – but the contacts the committee established between Toronto and the computing centres in the United States. The last, though not least, recommendation in the report was to maintain these connections and set aside funds for faculty and students to attend conferences and meetings. This was the first and only group in Canada to build such links, and they paid off in the fall of 1946 when the United States Bureau of Ordnance and Harvard University Computation Laboratory made plans to put on a Symposium on Large Scale Digital Calculating Machinery and invited a representative from Toronto; Barnes and Smith would attend the January 1947 symposium.[45] Additional meetings were inevitable, such as the earlier and ultimately more influential Moore School lectures they had missed the previous summer. Of course, it was also hoped that the connection established with the NRC could be maintained, in the hopes of improving the odds of securing funding from the federal agency in the future.

Unfortunately, there were no compelling reasons in Toronto to justify the enor-

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[43] Preliminary Report on Modern Computing Machines, 1946, UTARMS B1988–0069, Box 1, Folder 2.

[44] Von Neumann, "First Draft of a Report on the EDVAC".

[45] J.H. Curtiss, "A Symposium of Large Scale Digital Calculating Machinery", *Mathematical Tables and Other Aids to Computation* 2, no. 18 (April 1947), 229–238.

mous costs of a large-scale computer. The rapid development of electromechanical and electronic computers over the previous few years was a direct result of a wartime need for rapid calculations, most typically shell ballistics tables, atomic research, and cryptography. No significant projects of this type were underway at the University of Toronto during the war or after. Small scale computations done by hand at desk calculators were time-consuming and inconvenient, but these sorts of problems were justifiably ignored by most large computing centres. After MIT launched its own computing program called Project Whirlwind, they adopted a rule of thumb that "any computation which can be completed by hand with an expenditure of less than about three man-months of time, and which won't be repeated sooner than a year, should not be programmed for Whirlwind. We have found by experience that the answer to such problems can usually be obtained quicker by hand."[46]

Aside from the fact that Toronto could not afford a large-scale digital computer and had no use for one, it was not obvious in 1946 if funding high-speed computer research was an appropriate activity for a university. The main impediment was financing, a problem common to both analog and digital approaches. Bush's most advanced differential analyzer, the RDA, cost half a million dollars to build, which was covered through donations from the Rockefeller Foundation. Hartree and Porter's frugal Meccano model was an exception to the rule of expensive computers, but in practice it was a limited technology. Of the digital machines Toronto was aware of, most were located and designed at a university, but paid for by the United States federal government or military, or a private corporation. Despite the title, IBM had built and paid for the construction of Harvard Mark I; in knowledgeable circles it was known by its other title, the IBM Automatic Sequence Controlled Calculator. Less known is that prior to approaching IBM, Aiken had been unable to attract interest from members of

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[46] P.M. Morse, "On the Use of Digital Computers", *Physics Today* (Oct 1956), 21, as cited in Larry Owens, "Where Are We Going, Phil Morse? Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957", *IEEE Annals of the History of Computing* 18, no. 4 (October 1996), 36.

Harvard's physics lab, and struck out with his first choice of industrial sponsor, the Monroe Calculating Machine Company.[47] Construction of the Harvard Mark II was underway in 1946 and paid for by the United States Navy. IBM was of course the sponsor of Columbia University's Watson Scientific Computing Laboratory, supplying it with the newest IBM equipment and resources to hire the best staff in order to make it one of the top computing organizations in the world.[48]

The Bell Labs relay computers are one of the only examples of a post-war digital computer developed outside of a university. The first model of 1939 was within the realm of a modest university research laboratory, but the next four models were the product of a military-industrial collaboration, driven by wartime computational needs.

The ENIAC was a sparkling success for the University of Pennsylvania, home of the Moore School, site of ongoing construction of the EDVAC, and the world's first lecture series on modern computing machinery. The university was widely acknowledged as a leader in the field. Yet again, these two machines were military property, developed explicitly as a part of the war effort – the Moore School simply hosted the work. In a patent dispute after the war, the university was forced to admit that it was not entitled to the benefits of the project, as it had been funded entirely by the government.[49]

However, the principal figures involved with the design of EDVAC had cut their affiliations with the project, leaving the Moore School to complete it several years later than expected with a much less experienced team, plagued by constant turnover in leadership and poor morale.[50] Eckert and Mauchly left academia to enter the commercial world and begin work on UNIVAC, but it is without question that this leap would

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[47] Campbell-Kelly and Aspray, *Computer: A History of the Information Machine*, 70.

[48] Brennan, *The IBM Watson Laboratory at Columbia University: A History*.

[49] Stern, "The Eckert-Mauchly Computers: Conceptual Triumphs, Commercial Tribulations", 571–572.

[50] Williams, *A History of Computing Technology*, 349.

have fallen flat without continued government support, through the Census Bureau, the National Bureau of Standards and other government and military agencies.[51] Von Neumann returned to the Institute for Advanced Study (IAS) to build his own computer, but it took all his considerable prestige to attract the necessary funding. The IAS was not accustomed or set up for this sort of applied research and engineering, and in the end roughly three quarters of the funding was external: RCA provided $100,000 and rest flowed from the government, through the Office of Naval Research, Army Ordnance, and Atomic Energy Commission.[52] In Toronto, the Committee on Computing Machines could only hope that as the American groups continued their work the cost to copy or design a computer in Toronto would eventually fall within their financial reach.

Until then, the committee turned to promotion and advocacy. Beatty summarized their report for the Board of Governor's Advisory Committee on Scientific Research, and communicated their excitement to the board: "it now appears practicable to solve, by numerical methods most mathematical problems arising from scientific research."[53] He suggested to the Board of Governors that although the university did not need a large-scale computer – yet – it was a perfect time to stimulate interest with a small computing centre.

Beatty did not make clear in his summary to the University of Toronto Board of Governors what was meant by small, but a followup proposal prepared by the Committee on Computing Machines was more forthcoming. It proposed a computing centre at the University of Toronto, with an estimated start-up costs of nearly $100,000 with an annual budget of $40,000. This would permit the Committee to hire between ten to twelve staff members, equip them with desktop calculators, rent standard IBM business tabulators and computing equipment, create a small library of standard ref-

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[51] Stern, "The Eckert-Mauchly Computers: Conceptual Triumphs, Commercial Tribulations", 574.

[52] William Aspray, *John von Neumann and the Origins of Modern Computing* (Cambridge, Mass.: MIT Press, 1990), 50–54.

[53] Report on Scientific Research for 1945–1946, UTARMS A1968–0007, Box 6, Folder 2.

erence works and mathematical tables, and acquire two large-scale computers: a small differential analyzer, to be constructed locally for around ten to fifteen thousand dollars, and "One modern electronic computing system. To be built at a cost not to exceed $75,000."[54] In the margins of a copy in the University of Toronto Archives, an honest although unidentified reader has written "(probably low)"; in fact, $400,000 to $500,000 was closer to reality.

This was not the small centre Beatty hinted at to the board. However, as a way to bootstrap the program without such a vast investment, the computing committee presented a more reasonable plan. For $6,500, it proposed to rent some calculating equipment from IBM, hire two junior assistants to operate it, purchase two desktop calculators and a selection of books and other computational aids, and establish a travelling fund to maintain contact with computing groups in the United States and attend meetings. Most importantly, the equipment would be more than sufficient to attempt numerical solutions of several research problems within the university, such as computing special navigational tables for air navigation, as suggested by the Department of Astronomy. The committee was confident that many other computations would present themselves and the machines would not sit idle, but could not or did not provide further examples of this. If after a year or two the preliminary investment had proven itself then the question of expanding and upgrading to a larger computer could be reconsidered.

In December 1946 Griffith forwarded the plan to the President Smith, who agreed to meet with the Committee later in the academic term to discuss the proposal.[55] The March 3, 1947 meeting produced a flurry of letters from President Smith, who was apprehensive about several issues. The most obvious difficulty was the level of investment proposed. As he confided to Beatty, who did not attend the meeting, "the

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[54] Preliminary Plans for a Proposed Computing Centre at the University of Toronto, January 1947, UTARMS B1988–0069, Box 1, Folder 2.

[55] B.A. Griffith and S.E. Smith and response, 27 December 1946 and 15 January 1947, UTARMS A1968–0007, Box 17, Folder 2.

ultimate cost in the amount of $100,000 for equipment and an annual budget of about $40,000 scares me. It is one thing to try and find $6,500 for next year; but there must be answered the question: 'Where do we go from there?"'[56] Moreover, he was not happy with the casual attitude of the Committee in establishing a new administrative unit on campus, which suggested attaching the computing centre to the Department of Mathematics but running it independently.

President Smith then turned to Lieutenant-Colonel W.E. Phillips, Chairman of the University of Toronto Board of Governors, whose support was necessary for such a venture, and asked if he felt the university should take the lead high-speed computing in Canada.[57] As noted above, it was not clear that universities should be funding computer research. The committee explained that one could not expect computing centre staff members to have time for teaching, much less personal research, in order to maintain the expected continuous operation of the proposed computational facilities. If that were the case, what benefits could the University of Toronto expect as an early adopter? Was this a field with an academic future, or one that might best be tackled by industry or government? Did it make sense for a university to house the project, or was computing more properly a service, to be used by university researchers but best located outside traditional academia? There were no easy answers to these questions.

Finally, President Smith wrote to C.J. Mackenzie, President of the National Research Council, outlining the work of the committee and their proposal, detailing the immediate and ongoing costs of their two proposals, the small bootstrap plan, and the version requiring hundreds of thousands of dollars. Were there other similar projects in Canada? Was there even a need for such a project? He seemed convinced that the more modest preliminary plan would be of great assistance to several research projects within the university, and that this would be good enough for now. It is clear that Smith was casting about for a solution to the financial hurdle placed before him:

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[56] S.E. Smith to S. Beatty, 25 March 1947, UTARMS A1968–0007, Box 17, Folder 2.

[57] S.E. Smith to W.E. Phillips, 25 March 1947, UTARMS A1968–0007, Box 17, Folder 2.

"I am somewhat staggered by the prospect of such a large investment, and I am wondering whether it should not be inaugurated by the National Research Council or by some other government agency."[58]

Mackenzie's response on April 2 failed to fully answer Smith's questions: "... like you, I have not been able to reach a firm conviction as to just how such a centre would work and where, in the interests of Canada, it should be located."[59] He clearly recognized the importance of computing to science and that universities were not necessarily the ideal home for computing centres. There was great potential for scientific research, but the benefits of designing and building computers were uncertain and the sums involved were larger than the pockets of even the most wealthy universities in the United States. He cited the example of IBM's sponsorship at Columbia University and the plans of Sir Charles Darwin at the National Physical Laboratory, who hoped to create a national computing centre funded by the government but operationally tied to scientific research at universities in Great Britain.[60] Noting the lack of an equivalent mathematical division at the National Research Council, he admitted that they had already hesitated about creating their own computing centre. Mackenzie clearly felt that Canadian university researchers would probably originate the most interesting and vital problems for computing machines. Therefore, from a national standpoint of the NRC, the best approach was a co-operative government-university project. As to where it should be located and who should pay for it, his response was less helpful. In his opinion, without sufficient evidence that all universities in Canada felt a similar need for a computing centre, the National Research Council was not in a position to create one. Yet if no university undertook such a project, the NRC would probably take responsibility and step in to sponsor a national centre. Of course, "everyone would be delighted if the University of Toronto would undertake such a project, as

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[58] S.E. Smith to C.J. Mackenzie, 25 March 1947, UTARMS A1968–0007, Box 17, Folder 2.

[59] C.J. Mackenzie to S.E. Smith, 2 April 1947, UTARMS A1968–0007, Box 17, Folder 2.

[60] For more information on computing at the National Physical Laboratory, see Croarken, *Early Scientific Computing in Britain.*

there is no questioning the outstanding competence of the mathematical group at your institution" and everyone, including the NRC, would likely make good use of it.[61]

Despite the ambiguity, Smith interpreted the letter positively: it assured him that a computing centre was probably needed in Canada, and that although the NRC was in no position to create one, the agency might be convinced to help pay for one. He referred Mackenzie's response back to the Committee on Computing Machines, adding that it should consider a co-operative arrangement with the NRC.[62] As far as Smith and the Board of Governors were concerned, involving the NRC was the best course of action.[63] Gratified at the interest from Mackenzie, the committee quickly reworked the $6,500 proposal for submission to the NRC. Couched with a more national perspective, the proposed activities did not change, merely the context. On behalf of the country, the University of Toronto would undertake to create a small computing centre, modestly equipped, staffed by two graduate students. If it could "produce men trained in machine methods of computation and competent to aid in establishing a first-rate computational centre at Toronto or elsewhere", then after two or three years perhaps an investment in a large-scale high-speed computer should be considered.[64] If the experiment failed, or another Canadian computing centre was established, the equipment would revert to the national government. With this small preliminary plan, the Committee had established a wedge with which they hoped to lever the necessary funds from federal coffers.

In June, Beatty forwarded the proposal to Mackenzie, asking for financial support

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[61] C.J. Mackenzie to S.E. Smith, 2 April 1947, UTARMS A1968–0007, Box 17, Folder 2. Mackenzie might also have been influenced by the NRC report after the 1946 tour, which ended with the advice that computing machinery was in a state of flux and any solid plans "should be suspended until the results of at least the pilot version of Professor von Neumann's machine are to hand." J.W. Hopkins, Memorandum to File, Report on Visits in Boston and New York Area in Collaboration with University of Toronto Committee on Computing Machines, 5 July 1946, LAC RG77, Volume 134, File 17–15–1–20.

[62] S.E. Smith to S. Beatty, 7 April 1947, UTARMS A1968–0007, Box 17, Folder 2.

[63] Advisory Committee on Scientific Research, meeting minutes, 29 April 1947, UTARMS A1968–0007, Box 37, Folder 7.

[64] On the Establishment of a Small Computing Centre at the University of Toronto, April 1947, UTARMS A1968–0007, Box 17, Folder 2.

from the NRC. At the same time, Beatty warned Smith that he had no strong interest in the field himself, but in order to secure the most favourable response, he had cautiously written the proposal to take as much responsibility for the project as possible, and keep it within the Department of Mathematics.[65] Mackenzie replied quickly and all but guaranteed that when the NRC standing council on assisted research met in September 1947, it would support their project.[66] As promised Beatty was awarded a $6,500 grant in September for "The Initiation of a Computational Centre" to cover the preliminary proposal for one year.[67] Beatty immediately ordered a Madas Calculating Machine, but the bulk of the grant was earmarked for a more powerful calculator that Griffith chose the year before. In 1946 he had met with sales representatives from IBM and selected an IBM 602 Calculating Punch, together with a 405 Accounting Machine and 031 Punch.[68] Beatty signed the rental contract in December 1947, although delivery was not expected until at least April 1948.[69] The next step was to find two junior staff members to operate the machines, a task also delayed until the next year.

However, while waiting for a federal grant, members of the committee had not been idle. In 1946, Griffith and Stevenson were each granted $600 to hire assistants with computational training for individual projects, "Some Statistical problems and their application to Industrial and Medical Research" and "The Hartree Method applied to diatomic molecules".[70] Neither were able to locate anyone with the necessary skills that year, suggesting that with respect to computational research and training, Toronto had nowhere to go but up.[71]

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[65] S. Beatty to S.E. Smith, 19 June 1947, UTARMS A1968–0007, Box 17, Folder 2.

[66] C.J. Mackenzie to S. Beatty, 25 June 1947, UTARMS A1968–0007, Box 17, Folder 2.

[67] S. Beatty to R.E. Spence, 13 November 1947, UTARMS A1973–0025, Box 80, Folder 5.

[68] Griffith, "My Early Days in Toronto", 58. This was a common scientific computing combination. Around this time, Northrop hooked a similar 603 multiplier and 405 accounting machine together, a successful precursor configuration of the popular IBM Card-Programmed Electronic Calculator (CPC). Emerson W. Pugh, *Building IBM: Shaping an Industry and Its Technology* (Cambridge, Mass.: The MIT Press, 1995), 152–155.

[69] International Business Machines Company, Limited, Agreement for Electric Accounting Machine Service in Canada, 5 December 1947, UTARMS A1973–0025, Box 72, Folder 5.

[70] Application for grants in aid of research 1946–1947, UTARMS A1968–0007, Box 22, Folder 1.

[71] Report on Scientific Research for 1946–1947, UTARMS A1968–0007, Box 22, Folder 2.

That same year, Stevenson, Infeld, Griffith, and Beatty applied for $900 towards the "purchase of a computing machine". Although Infeld was not on the computing committee he was not far from the problems of computation. In the last year of the war, the NRC had paid the expenses for Infeld, Stevenson and Smith to do war-related research and to hire assistants to perform the necessary computations.[72] The previous year Infeld had received $600 from the Advisory Committee on Scientific Research to hire another assistant "to carry out computational work in connection with research in nebulae."[73]

The $900 was used to purchase two calculators, a Friden ST-10 calculator for $630 and a second unspecified electric adding machine, perhaps a Marchant.[74] The ST-10 was an mechanical calculator designed in the late 1930s, capable of the four major arithmetical operations and commonly used by scientists for numerical work.[75] Joining these were a Monroe calculator and a few older machines found around campus, probably Millionaires that were resurrected by Griffith. Desk calculators were in short supply following the war, and he cast a wide search as far as the DRB, hoping to locate surplus machines from War Assets.[76] Assembled together, the calculators were used to create a statistical laboratory in the Department of Mathematics, in a University College room next to Beatty's office.[77] This laboratory was put to use in the fall of 1947 as Griffith launched an undergraduate and graduate statistics course in collaboration

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[72] S. Beatty, Apportionment to Scientific Research, for the Period 1 April 1944 to 30 March 1945, 16 February 1946, UTARMS A1968–0007, Box 6, Folder 2.

[73] Grants in Aid of Research From Scientific Research Fund, 22 November 1945, UTARMS A1968–0007, Box 6, Folder 2. Although less relevant, Infeld also supervised T.E. Hull's 1949 dissertation. Hull left Toronto that same year but returned in the mid 1960s and played an influential role then. See page 295.

[74] Report on Scientific Research for 1946–1947, UTARMS A1968–0007, Box 22, Folder 2.

[75] George C. Chase, "History of mechanical computing machinery", in *Proceedings of the 1952 ACM national meeting (Pittsburgh)* (ACM Press, 1952), 1–28.

[76] B.A. Griffith to O.M. Solandt, 14 October 1947, UTARMS B1988–0069, Box 1, Folder 2.

[77] Keith W. Smillie, "The Computer and Me: Desk Calculators" ⟨URL: `http://www.cs.ualberta.ca/~smillie/ComputerAndMe/Part08.html`⟩ – visited on 3 March 2004. Gotlieb recalls that there were eight machines at one point, from about four different manufacturers. He used the laboratory when he taught a numerical analysis course a few years later. Calvin C. Gotlieb, conversation with author, Toronto, 10 April 2006.

with the Statistics and Actuarial Science division of the Department of Mathematics.[78] This was part of the committee's initial recommendation in 1946 to increase the visibility of computing methods on campus, or as Griffith put it, "spark an interest in numerical computation for a few bright students."[79]

As of late 1947, the Committee on Computing Machines could point to Griffith's lab and the NRC grant as their first steps, but to establish a permanent computing centre and eventually acquire a modern computer, more support would be needed. S.P. Eagleson, the General Secretary of the NRC, assured Griffith that if satisfactory progress was made, additional funding from the NRC was probable, though not guaranteed.[80] The committee made sure that the university could cover any incident costs for the next year if the grant was cancelled, but continued to explore other avenues of support.[81] Around October 1947, V.G. Smith met with the head of the Defence Research Board (DRB), Omond Solandt, who expressed interest in the computing project.[82] Griffith followed up with a letter to Solandt in mid October, describing the short history of their group, explicitly seeking out cooperation with the DRB in establishing a Canadian computing centre. Griffith forwarded copies of the first proposal written after the tour of the United States and the second proposal outlining their plans for a computing centre. He chose to frame the relative lack of progress by the committee and the truncated preliminary plan in terms of the rapid changes in the field, not the staggering costs. However, the committee had simplified their goals. It hoped to train people in the operation of the IBM 602, conduct research on electronic components for a computing machine, and maintain its contacts with other computing projects in the United States and the United Kingdom. Any computational work

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[78] Griffith, "My Early Days in Toronto", 59-60.

[79] See Ibid., 58, and page 26

[80] S.P. Eagleson to B.A. Griffith, 24 October 1947, UTARMS A1973–0025, Box 72, Folder 5.

[81] S. Beatty to S.E. Smith, 13 November 1947, UTARMS A1968–0007, Box 33, Folder 10.

[82] Their meeting does not appear to have been specifically arranged to discuss computing. The DRB was formed at the end of the Second World War, to consolidate the many war-time defence research programs.

that was carried out would be for research problems, "so that, in a modest way, even this preliminary program may have some worthwhile results." The committee was still looking for a rich patron to support the project and apparently quite willing to accommodate the potential demands of an external group such as the DRB: "We shall welcome any suggestions or advice from you and your associates, in the hope that developments here will be geared to suit your requirements."[83]

The DRB's response did not arrive until late November but immediately opened the door to assistance, "financially and otherwise, in the development of an electronic digital computer for such a centre."[84] More importantly, it proposed a long-term agreement, rather than year to year grants, to best provide the necessary stability for the large-scale project.

A joint meeting was proposed between representatives of the Committee on Computing Machines from University of Toronto, the NRC, and the DRB to discuss a tripartite funding agreement to establish a computing centre at Toronto. The meeting was arranged for 9 January 1948, and took place in Ottawa. In Griffith's notes prepared for the meeting, he outlined a five year plan with three primary objectives for the centre. First, only research problems sufficiently important or extraordinary would be considered, to prevent a flood of work. Second, students would be trained at the centre to carry out much of the computational work, the range of which had been expanded to include government projects and industrial firms. That is, Griffith was again willing to expand the centre's potential usefulness and importance to his sponsors. Finally, the staff members would be responsible for training, but also research on outstanding problems in applied mathematics and the design of computing systems.[85]

To accomplished these goals, Griffith set forth a number of requisites. First, he projected a permanent staff of about fifteen, speculating that their interests would

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[83] B.A. Griffith to O.M. Solandt, 14 October 1947, UTARMS B1988–0069, Box 1, Folder 2.

[84] E.G. Cullwick to B.A. Griffith, 27 November 1947, UTARMS B1988–0069, Box 1, Folder 2.

[85] Notes regarding the establishment of a computing centre at Toronto, 9 January 1948, UTARMS A1968–0007, Box 33, Folder 10.

be divided almost equally among electronics, statistics and computation, applied scientific mathematics (physics and chemistry), and applied engineering mathematics. Second, the estimated costs rose to a more realistic level, with a $500,000 to $600,000 capital expenditure to cover an electronic computer and a 120,000 cubic foot building to house the project. This desire to obtain their own building represents the first attempt to carve out some physical autonomy on campus. Similarly, on the administrative side the Committee expected that the computing centre would eventually exist as an independent department. Until then, it would continue to be run as an arms-length division of the Department of Mathematics, directly supervised by an interdisciplinary committee.

The DRB response to the meeting was positive, though still disappointing for the Committee.[86] Rather than the $50,000 annual budget and half million dollar capital grant, a $20,000 annual grant for the next five years was offered. This grant also had to cover the salary and expenses of an electronics research engineer. This entire support package was also conditional – in addition to the assistance from the DRB and NRC, the computing centre must be supported by the university. This ensured that the university held a fair share of the responsibilities, but also eliminated an awkward situation regarding federal involvement in what might have appeared to be provincial affairs. As a result of the 1867 British North America Act, education in Canada, including post-secondary levels, was intended to be the exclusive domain of the provincial legislatures.[87] The University of Toronto was historically known as 'the provincial university', and Griffith was apprehensive about even the perception of federal interference. In reality, both large and small federal grants were not uncommon, and President Smith, with his long experience at Toronto and the University of Manitoba, was far more confident of the autonomy of a university with respect to provincial gov-

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[86] E.G. Cullwick to B.A. Griffith, 12 February 1948, UTARMS B1988–0069, Box 1, Folder 2.
[87] British North America Act, 1 July 1867, section 93: "Education".

ernments.[88] He reassured Griffith that the proposed deal with Ottawa would be of no great concern to the Ontario Parliament.

Consequently, Griffith drew up a short list of the suggested responsibilities of the university. First and foremost was accommodations. Temporary space was expected in the Physics and Electrical buildings for numerical work, electronics research, and the construction of a differential analyzer. For the future, he suggested that the Physics Building could be expanded, as part of the post-war university construction campaign, to house the electronics research and the astronomy department.[89] President Smith quickly and unapologetically dismissed this notion, pointing out that nearly $1,000,000 had been recently put into an extension to the Physics Building and the remaining campaign was intended to support the humanities and social sciences.[90] Instead, they would have to make do with the temporary accommodations.

With this and other minor issues settled in Toronto, Griffith and Beatty travelled to Ottawa that April to meet with Mackenzie, Solandt and E.L. Davies (vice-chairman of the DRB) to discuss the proposal. This group agreed that "a first-rate computation centre is needed in Canada and . . . the logical site for the proposed centre is the University of Toronto in view of the advantages to be gained by association with strong departments of Mathematics, Physics, and Engineering."[91] Beatty and Griffith returned to Toronto with a $30,000 award for the next year to officially create the Computation Centre; $20,000 would come from the DRB, and Mackenzie increased the NRC award to $10,000.[92] Further funds were not guaranteed, but the present money was targeted at hiring research staff, improving upon their existing computational research, launching an electronic research program under V.G. Smith in collaboration with the Depart-

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[88] S.E. Smith to B.A. Griffith, 7 January 1948, UTARMS A1968–0007, Box 33, Folder 10.

[89] Suggestions Regarding the Responsibilities of the University of Toronto in Connection with the Proposed Computing Centre, January 1948, UTARMS A1968–0007, Box 33, Folder 10.

[90] S.E. Smith to B.A. Griffith, 29 March 1948, UTARMS B1988–0069, Box 1, Folder 2.

[91] Progress Report on the Proposed Computing Centre at the University of Toronto, 1948, UTARMS B1988–0069, Box 1, Folder 2.

[92] Additional note, B.A. Griffith, 10 June 1948, UTARMS B1988–0069, Box 1, Folder 2.

ment of Physics, and beginning to build a differential analyzer and a relay computer. Records of the time do not include any detailed plans regarding these last two projects, but it was estimated that constructing an analyzer might cost ten to fifteen thousand dollars, and as will be shown below the committee was contemplating acquiring a Bell Labs relay machine. The long term goal for the Computation Centre was to be fully operational within five years or less, "with the possible exception of the electronic computer."[93] As will be shown in the next chapter, over the next five years, this last caveat was tested in ways unanticipated by all parties to the agreement.

1.3 Creating a Computing Centre

Roughly two and a half years had passed from the time that the Committee on Computing Machines was assembled to the time that the NRC and DRB agreed to sponsor the primary costs of a national Computation Centre at the University of Toronto. During that period, the field of computing machinery had witnessed a number of significant events.

Already alluded to were the two conferences held dedicated to modern computing machinery. The first, the Moore School Lectures at the University of Pennsylvania, were held over the summer of 1946 and dedicated mainly to discussing EDVAC type computers.[94] The second, the Harvard Symposium on Large Scale Computing Machinery in January 1947, was a much larger meeting and more inclusive towards other non-EDVAC types of computing machinery.[95] These were North American events, but attracted a few international participants and were important for the exchange and diffusion of information in the new field.

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[93] Progress Report on the Proposed Computing Centre at the University of Toronto, 1948, UTARMS B1988–0069, Box 1, Folder 2.

[94] Campbell-Kelly and Williams, *The Moore School lectures: Theory and Techniques for Design of Electronic Digital Computers*.

[95] Curtiss, "A Symposium of Large Scale Digital Calculating Machinery", 229–238.

Ironically, on the hardware front, progress was more rapid in England than North America. The EDVAC project nearly fell apart when the leaders who had collaborated on ENIAC and designed EDVAC abandoned the project for their own enterprises: Eckert and Mauchly left academia to build the UNIVAC, as von Neumann returned to Princeton's Institute for Advanced Study with Goldstine to build their own machine. None of the three projects were near completion by mid 1948, but at Manchester University, a prototype system known as "the Baby" ran the world's first stored-program on 21 June 1948. This event came to have great relevance in Toronto, but not until 1952.[96] The University of Cambridge Electronic Delay Storage Automatic Calculator (EDSAC), often described as the first practical stored-program computer capable of real work, was still under construction at the time. It did not run until May 1949, but well before the three major American projects were finished.

By mid 1948, mechanical computer technology was disappearing in favour of all-electronic designs. At Harvard, Aiken had finished the electromechanical Mark II in 1947 and was building the partially electronic Mark III. The final computer of the series, the Mark IV, would be all electronic. The ultra-reliable Bell Telephone Laboratory relay computers had already reached the end of the line. Adding contemporary programmability features had made them remarkably complex, even baroque, and the final version, the Model VI, was near completion by the end of 1948.[97] The most visible evidence of the transition from mechanical to electronic components was IBM's Selective Sequence Electronic Calculator (SSEC), a motley machine possessing both electromechanical relays and vacuum tubes. Built in total secrecy, the SSEC was installed in January 1948 at IBM's New York headquarters and famously operated in full view of the public, but clearly represented a half-way point between old and new technologies. For many designers, vacuum tubes were a superior switching element, and F.C. Williams's cathode ray tubes were a fast and flexible storage device. Com-

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[96] See section 3.2 in chapter 3.

[97] See page 72.

monly known as Williams tubes, the Manchester Mark I prototype was built to test the storage technology. Because the tubes could be used for both serial and parallel storage, they were later used in many other important computers, including the Ferranti Mark I, von Neumann's IAS computer, and the IBM 701 and 702, IBM's first commercial electronic computers. Perhaps the most significant electronic technology to come out of post-war years was the December 1947 invention of the transistor by Bardeen, Brattain, and Shockely from Bell Laboratories. It had no immediate impact on computing, but was a harbinger of things to come.

Relatively speaking, the Committee on Computing Machines was remarkably ignorant of these events considering the size of the award they had just received. Following the 1946 tour, the two conferences were the only significant entry points they had into the field. Copies of the proceedings from the Moore School Lectures found their way to Toronto in 1948, which almost certainly influenced the direction their electronics research would take. Two of the committee members, C. Barnes and V.G. Smith, had attended the Harvard Symposium without presenting any research, because, of course, no research was underway in Toronto. Following the symposium Smith had considered a private project to design circuitry to convert numbers between binary and decimal, but had yet to begin.[98] No one on the Committee had any knowledge of the developments in England such as the Baby, or of Williams tubes, or of the EDSAC. Smith appears to be the only member of the committee connected with other North American computer research projects, corresponding with former students at Harvard, the Moore School, and MIT. Unfortunately, his contacts were mostly low level technicians and engineers, not project leaders, and their limited conversations avoided useful details of computer design and construction.[99] Despite the opportunity to form links during the 1946 tour, by mid 1948 Toronto was still on the outside of the rather small group of research laboratories undertaking computer projects.

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[98] V.G. Smith to M. Rubinoff, 26 February 1947, UTARMS B1999-0025, Box 4, Folder R.

[99] See page 93.

Virtually all of the Committee's activity during the previous two and half years had been directed towards the creation of the Computation Centre, rather than the development of an electronic computer. The Committee had been driven that far by the mathematicians, who outnumbered the scientists and engineers combined, and whose primary interest was computation rather than computing machines. V.G. Smith, the sole engineer, described the situation in a letter to another engineer: "The fact that the Department of Mathematics started this makes for the emphasis on the calculation and the use of the machine rather than on its development. I am sure that some of them would have been satisfied to buy an electronic computer complete. Of course I recognize that use is the ultimate object, but the development will be lots of fun, and we shall know better how to improve and modify a machine of our own design."[100] One advantage of this approach was that it made the entire project easier to sell. Comparatively, the benefits of a computing centre were more obvious than those of developing an electronic computer.

For the mathematician Griffith, the most active member of the committee until 1948, a computing centre was an expansion of the numerical and statistics laboratory he was assembling at the same time. Stocked with mechanical calculators and libraries of mathematical tables, such labs were common at many universities in the immediate years before widespread electronic computing. They were often embedded within science, mathematics, engineering departments, and may have included research or teaching numerical methods as a responsibility.[101] For example, at Cambridge, the University Mathematical Laboratory opened in 1937 as a "well-equipped computing centre where Cambridge scientists carried out their own computation."[102] Ten years later, the mission had evolved to include a course on practical computation for un-

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[100] V.G. Smith to M. Rubinoff, 15 April 1948, UTARMS B1999–0025, Box 4, Folder R.

[101] Paul S. Dwyer, "The Use of Desk Calculators", in Preston C. Hammer ed., *The Computing Laboratory in the University* (Madison, WI: The University of Wisconsin Press, 1957), 79–84.

[102] Croarken, *Early Scientific Computing in Britain*, 113.

dergraduates and the development of EDSAC.[103] Similar examples can be found at Columbia University, home of the Watson Scientific Computing Laboratory and the earlier Thomas J. Watson Astronomical Computing Bureau or at MIT's Computation Center in the Division of Industrial Cooperation.[104] In Canada, there was similar activity outside of Toronto at the University of Alberta, where its history of computer science has been traced to a 1950s statistics laboratory which "used small Monroe calculators which were cranked by hand, and there were only one or two electric desk-calculators in the whole [mathematics] department, of rather old-fashioned type."[105] Numerical and statistical laboratories were important prototypes for early computing centres, as a place where faculty and students alike could work towards better numerical results by machine assistance.

Strangely, when the Committee on Computing Machines proposed creating a computing centre in Toronto, it had difficulty identifying a specific and legitimate need, beyond Griffith's teaching plans. Obviously, it could provide a home for a modern electronic computer down the road. The potential was enormous: the speeds brought many problems previously insoluble by analytical or numerical means to within range of numerical methods. As the committee's first report exclaimed: "the importance of this in such fields as theoretical aerodynamics can scarcely be estimated."[106] While this statement was certainly true, the aerodynamic engineers at the University of Toronto took little interest in the computing centre until 1951. The massive scientific and technological effort during World War II had demanded an massive computational response, but after the war, the Committee looked across the University of Toronto and the rest of Canada and could not see an equally obvious imperative. Without one, an electronic computer was far too costly, and as a result, the Committee was casting

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[103] Croarken, *Early Scientific Computing in Britain*, 114-115.

[104] William Aspray, "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s", *IEEE Annals of the History of Computing* 22, no. 3 (July 2000), 42–87.

[105] Keith W. Smillie, "The Department of Computing Science: The First Twenty-Five Years", Technical report TR91-01 (Department of Computer Science, University of Alberta, February 1991), 6.

[106] Preliminary Report on Modern Computing Machines, 1946, UTARMS B1988–0069, Box 1, Folder 2.

about with a solution in search of an important problem, rather than the more rational reverse.

The preliminary plan for a computing centre was written immediately after the 1946 tour. It included a vague list of possible uses: problems in aeronautics, mathematical physics, statistics, engineering, astronomy, and ballistics.[107] By April 1947, a more specific list was contained in the first training proposal sent to the NRC. Four problems were described: navigational tables for the Department of Astronomy, statistical analysis for the Department of Biology, calculation related to quantum mechanical problems, and research into new methods of solving simultaneous linear equations.[108] As noted, they were "real problems which deserve some attention", that also covered a range of numerical methods. It is likely that the breadth of list was intended to demonstrate an ability to tackle any problem, but what it reveals is aimlessness. Nothing on the list immediately stands out as significant, deserving of a computing centre. As an afterthought, an equally unspecific promise was made to prepare standard function tables and interpolation procedures, "if time permits."

The quantum mechanical problem was the only problem from this list to have been suggested by a source outside of the university. An analysis of the first twenty-one problems that were submitted to the Computation Centre by the end of 1948 reveals difficulties in finding such problems.[109] Seven originated outside of the University of Toronto, but from only two sources: one from the RCAF Institute of Aviation Medicine and six – including the quantum mechanical problem – emerged from the NRC's nuclear research program at Chalk River. Of the remaining fourteen problems submitted by faculty members of the University of Toronto, just four were not suggested by a member of the Department of Physics: one electronics problem was abandoned, two

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[107] Preliminary Plans for a Proposed Computing Centre at the University of Toronto, January 1947, UTARMS B1988–0069, Box 1, Folder 2.

[108] Training Program in Computation at the University of Toronto 1947–1948, April 1947, UTARMS A1968–0007, Box 17, Folder 2.

[109] Two of the twenty-one problems were abandoned before completion, but have been included in the count.

were from the Department of Astronomy (including the navigational tables), and the last was a small problem from the Department of Aeronautical Engineering. Despite the Committee on Computing Machine's earlier remark, aerodynamics played a minor role at the Computation Centre and this was the only aerodynamic problem until 1951.[110]

The relationship between the Computation Centre and the atomic energy project was far more significant.[111] In early 1948, as the NRC and DRB were considering long-term financial support, the Committee on Computing Machine's took pains to point out the quantum mechanical calculations "of interest to the Atomic Energy Project at Chalk River."[112] This was part of a strategy to appeal to a national conscience, or perhaps just national pride. In the first report, the committee declared the time was not right to obtain a large-scale computer and offered a number of suggestions that might create more favourable conditions. However, the advice applied exclusively to the University of Toronto. When it became clear that the university was in no position to finance these activities independently, a new tack was chosen: the new computing centre should be "organized so as to take care of the computational needs of scientific research in Canada".[113] The claimed advantage was that Canada's computational problems would no longer be treated as insoluble, solved imperfectly or at the cost of tedious months or years of effort, or soluble only at similar facilities in the United States or England. Calculations to be performed on behalf of the much more impor-

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[110] See Computation Problems, January 1957, UTARMS B1988–0069, Box 1, Folder 3, Problems 19, 54, and 72. Gotlieb maintained a log of what appears to be most scientific problems tackled by the Computation Centre between 1947 and 1957. Some gaps in the listing can be filled by cross referencing the log with Computation Centre progress reports filed between 1948 and 1952. However, there are considerably fewer problems listed following the arrival of Ferut, and the lack of regular and detailed progress reports at this time makes it difficult to ascertain the completeness. It is clear that with respect to Ferut, teaching problems are not included on the list, nor were several private problems completed by faculty or students. Most likely, the list is restricted to service work post 1952.

[111] The role played by Chalk River also increased with time as shown in the following chapter.

[112] Progress Report on the Proposed Computing Centre at the University of Toronto, 1948, UTARMS B1988–0069, Box 1, Folder 2.

[113] Preliminary Plans for a Proposed Computing Centre at the University of Toronto, January 1947, UTARMS B1988–0069, Box 1, Folder 2.

tant atomic research at Chalk River was the trump card, played deliberately to entreat federal support.

There is no doubt that the atomic energy research was of national importance and that it needed computing assistance: "some theoretical investigations which are desirable for a better understanding of the pile and associated experiments are not attempted because of the present limitations of computing resources."[114] That the Committee was unaware of this for so long exposes the lack of clear focus for the Committee and the computing effort at Toronto. The first quantum mechanical problem was proposed in January 1947, but there is no evidence that it was tackled earnestly until at least February 1948. The Committee on Computing Machines was ignorant of the needs or the importance of Chalk River, or both. The majority of the atomic energy computations were not sent to Toronto until after Griffith visited the project over the summer of 1948, which may help to explain the delay. Yet without these problems, the proposed national computing centre shrinks quickly to a local statistics laboratory with federal funding but no federal necessity. Regardless of the worthiness of the other mandates – research and instruction in numerical methods and digital electronics – the justification offered for a national computing centre was remarkably thin. For the time being, the needs of the atomic research were insufficient to require an electronic computer.

In retrospect, it is difficult not to question the judgement of the NRC and DRB when the two agencies decided to fund the creation of the Computation Centre at the University of Toronto, with a mandate that went beyond numerical computing to include electronics research and development. The Committee on Computing Machines was having a hard time justifying the former, let alone the latter. From the NRC's point of view, why not provide the Atomic Energy Project with their own computing power? The IBM equipment Griffith had selected for Toronto could have been

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[114] W.H. Watson to E.C. Bullard, 24 September 1948, UTARMS B1988–0069, Box 1, Folder 2.

installed in Chalk River just as easily, though it would have been underused and unavailable to the rest of the country.

If the goal of the two federal agencies was to produce an electronic computer, other questions arise. The University of Toronto was not the only possible site with this capability, merely the most aggressive applicant. As the president of the NRC noted, the strength of the applied mathematical division made it a logical place to house a computing centre, but it did not follow that it was the best location to design and build an electronic computer.[115] Another historian has called into question the suitability of the university, pointing out that the NRC or the DRB were perhaps better qualified to carry out the electronics research.[116] Yet there was an unwillingness by the NRC to tackle the project. B.G. Ballard, head of the NRC's Radio and Electrical Engineering Division, wrote in April 1948: "We do not feel that it would be profitable for us to undertake the development of an electronic computer at the NRC but we feel that we could justify a computing machine in the laboratory for work in this district."[117]

At the time, Griffith suggested that to benefit the country, it was better to locate a computing centre at the University of Toronto rather than a federal agency. Any knowledge gained during the course of things would spread faster and farther via graduates entering the business world and teaching others. A university would also generate a wider variety of problems, a proposition Mackenzie had agreed with. This was more likely to generate new and unusual problems to solve, a better use of the investment.[118]

Ultimately, the best reason for the NRC and DRB to sponsor the computing centre in Toronto was that no alternatives were available. Many people in both federal agen-

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[115] The next chapter will explore how this misunderstanding affected the Computation Centre.

[116] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 24.

[117] B.G. Ballard to D.R. Hartree, 30 April 1948, LAC RG77, Volume 52, File 17–28B–1. It is unclear what 'district' Ballard was referring to; it may have been the Ottawa region, the NRC, or merely his department. In any case, electronic computer development was of less concern than the opportunity to use one.

[118] Griffith, "My Early Days in Toronto", 6.

cies felt that computers were going to be essential for scientific research and without one Canada would fall behind. These same people typically had little to no experience with large-scale electronic computers, but believed that "Canada should have an electronic computer to enable her to pursue her own research program independent of foreign countries," and "until Canada is equipped with a suitable computing centre, she will be obliged to rely upon foreign aid for many of the designs which require large-scale calculations. If it is agreed that Canada should be independent in this respect, then the time has arrived to initiate a computer centre in Canada."[119] With the DRB and NRC unsettled at the notion of doing without, pushing ahead in Toronto without any reasonable alternatives eliminated the insecurities.

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[119] Quoted in Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 22.

Chapter 2

Building the Computation Centre, 1948–1952

"Huge Pushbutton Brain to be Built at U. of T."

– Globe and Mail headline, 18 May 1949.[1]

If the University of Toronto was on the outside of the modern computer community at the beginning of 1948, then by the end of the the year it had quickly moved inside. Flush with grants from the National Research Council and the Defence Research Board, the Committee on Computing Machines expanded its activity dramatically that year along no less than five fronts. The IBM calculators were scheduled to arrive later that year and training on the equipment was underway. Two projects were established to build a differential analyzer and a relay computer. These were all stop-gap measures, intended to get the new computing centre going until the electronics research in progress paid off and a digital computer could be built. In the meantime, until a punched card calculator, analyzer, relay computer, or electronic computer was available, the new computing centre would handle all requests using desktop calculators

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[1] "Huge Pushbutton Brain to be Built at U. of T.", *Globe and Mail* (May 18 1949), 5.

in the new statistics laboratory.

This was a tall order for any computing centre, let alone one just off the ground. In time, the folly of attempting too much would be clear, but 1948 must have been exciting, if not also a little hectic. However, with three new hardware projects, a necessary shift was also taking place that would affect the leadership and direction of the Computation Centre for the next fourteen years.

2.1 The Rise of the Department of Physics

The end of the 1940s witnessed an important take-over of computing activity. Until then, a computer was a person who computed, often aided by a calculating machine to reduce their mental labour. These manual machines were generally limited to the four fundamental arithmetic operations and to the abilities of the operator.[2] In the 1830s Charles Babbage envisioned a sophisticated machine that automated many of the human computer's steps, but over a century passed before his ideas were fully implemented. The first such automatic digital computers were built using electromechanical relays by people largely unconcerned with a systematic implementation. Having successfully demonstrated the concept, vacuum tubes and other electronics were considered as alternative components. Vacuum tubes offered significantly faster operating than relays speeds but many people perceived them to be less reliable. For example, each of the Bell Labs Model's III through VI could multiply two 5 digit numbers in about 1 second; the ENIAC, completed around the same time as the Model V, could do the same in 0.002 seconds.[3] However, tubes were a relatively new technol-

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[2] Distributing computations among other human computers was another technique, such as with the many table projects of previous centuries. See Campbell-Kelly, *The history of mathematical tables: from Sumer to spreadsheets.*

[3] See Franz L. Alt, "A Bell Telephone Laboratories' computing machine", in Brian Randell ed., *The Origins of Digital Computers*, 3rd edition (Berlin: Springer-Verlag, 1982), 287; E.G. Andrews, "Telephone Switching and the Early Bell Laboratories Computers", *Annals of the History of Computing* 4, no. 1 (1982), 17; and Herman H. Goldstine and Adele Goldstine, "The Electronic Numerical Integrator and Computer", *Mathematical Tables and other Aids to Computation* 2, no. 15 (1946), 99.

ogy that failed, often to spectacular effect, whereas relays were well-understood and considered more reliable. Camps formed around relays and vacuum tubes because the community, as computer historian Paul Ceruzzi has explained, lacked consensus "on what a digital computer ought to look like."[4] Von Neumann's 1945 EDVAC Report broke the bottleneck, giving computer designers a logical architecture that was not tied to a particular technology. When a computer could be constructed using relays or tubes or anything else, then the superior speed of vacuum tubes became the deciding factor. Electronic technology took over computing, although the transition was not immediate and a number of inelegant hybrids were built.[5]

It is unclear how well the Committee on Computing Machines understood the implications of the EDVAC report. An electronics research project was started in Toronto, but there were also plans to build a relay computer. The NRC and DRB initially agreed to this strategy, but the former was not entirely happy with the leadership in Toronto. In June 1948, C.J. Mackenzie, president of the NRC, made it clear to President Smith that he was not paying close enough attention to the computing project. In particular, Mackenzie was concerned that important departments were not sufficiently represented by the project and that Griffith was not the right man to be leading things.[6] Smith apologized, admitting that he had been directing his attention to the supersonics laboratory for the Department of Aerophysics in the School of Applied Science and Engineering.[7] He agreed that someone other than Griffith with more imagination and vision was needed, and that physics and engineering needed better representation on the project.

The solution came in the person of E.C. Bullard, who had recently been lured away

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[4] Ceruzzi, "Electronics Technology and Computer Science, 1940-1975: A Coevolution", 260.

[5] See page 42 for several examples.

[6] S.E. Smith to C.J. Mackenzie, 8 June 1948, UTARMS A1968–0007, Box 57, Folder 8.

[7] With good reason: the DRB was taking interest in the lab and awarded it a $350,000 grant to establish the new University of Toronto Institute of Aerophysics. Richard White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000* (Toronto: Faculty of Applied Science and Engineering, University of Toronto, 2000), 166.

from the Cavendish Laboratory after a long search to find a new chair of the Department of Physics at the University of Toronto.[8] Bullard was a geophysicist originally from Cambridge and a Fellow of the Royal Society who had distinguished himself during the war on anti-magnetic and anti-acoustic mine work before moving into Operations Research for the Navy.[9] In September, President Smith wrote to Mackenzie, happily confirming that that Bullard had also accepted chairmanship of the Committee on Computing Machines and would be supervising the various computing projects from now on.[10]

Bullard's first task was to locate a hands-on director of the computing centre to operate things. It was important to find someone balanced in both mathematics and engineering. Computational experience could no longer be the sole criteria, though it would be important so that they could manage the operation of the IBM punched card equipment. Just as important would be someone knowledgeable in the wider field of computing machines with electronics skills and the ability to supervise the electronics research and the construction of the relay computer and the differential analyzer. Finally, it was just as crucial to find a personality that would engender confidence from the DRB, which had recently confirmed a $20,000 grant for the project, and was watching Bullard closely.[11]

Over the summer of 1948 Bullard corresponded with Griffith, who was at Chalk River at the time, to discuss their options.[12] A number of high-profile names were considered including G.R. Stibitz, inventor of the Bell Labs relay calculators, and Bengt Carlson, a Canadian who had directed the Atomic Energy Project's computing staff

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[8] That one early meeting of the search committee took place at Chalk River suggests that the significance of the position went far beyond the campus gates. Confidential, Summary of Candidates for Post of Chair of Physics, 12 March 1946, UTARMS A1968–0007, Box 63, Folder 1.

[9] D.P. McKenzie, "Edward Crisp Bullard. 21 September 1907-3 April 1980", *Biographical Memoirs of Fellows of the Royal Society* 33 (December 1987), 66–98.

[10] S.E. Smith to C.J. Mackenzie, 16 September 1948, UTARMS A1968–0007, Box 57, Folder 8.

[11] O.M. Solandt to E.C. Bullard, 19 July 1948, UTARMS B1988–0069, Box 1, Folder 2.

[12] Correspondence between B.A. Griffith and E.C. Bullard, 26 July 1948 and 30 July 1948, UTARMS B1988–0069, Box 1, Folder 2.

in Montreal and Chalk River and was now performing the same work at Los Alamos. Stibitz turned down an offer from Griffith, preferring his consulting work, and it is unknown if anybody approached Carlson. Two other obvious candidates were Morris Rubinoff and Calvin C. "Kelly" Gotlieb, both recent graduates of the university who had worked together during the war on a proximity fuse project for the military, completing their Ph.D's along the way.[13] Rubinoff had since spent time at Harvard's Computation Laboratory and von Neumann's computer group at Princeton's Institute for Advanced Study Computer.[14] Gotlieb had stayed in Toronto and had just been hired as a lecturer in the physics department. Griffith dismissed them both as lacking "sufficient mathematical background – or rather, theoretical 'know-how.'"[15] Bullard was unconvinced, and in late August wrote to John von Neumann for advice on a suitable director.[16] He asked von Neumann for his opinion of Rubinoff, though Bullard was doubtful himself: "I cannot quite see him as director."[17] Von Neumann agreed, remarking that he was an excellent engineer but did not see in him the same qualifications as a mathematician, "and the man you want for the directorship should, I suppose, have a good grounding in mathematics."[18] Sensitive to the the preference for a Canadian, he suggested several other potential experienced candidates including J. Carson Mark, acting head of the theoretical division of the atomic energy laboratory at Los Alamos.[19]

As much as Bullard may have wished such an experienced man, a major limitation

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[13] For the story of the international proximity fuse project, see R.B. Baldwin, *The Deadly Fuze* (San Rafael, Ca.: Presidio Press, 1980).

[14] Short resume of M .Rubinoff, 1950, UTARMS B1999–0025, Box 4, Folder R.

[15] Correspondence between B.A. Griffith and E.C. Bullard, 26 July 1948 and 30 July 1948, UTARMS B1988–0069, Box 1, Folder 2.

[16] The two had spent time together in London in 1943 while Bullard worked for the Naval Operations Research. Bullard also wrote to Norbert Wiener, but there is no record of a response in the University of Toronto Archives.

[17] E.C. Bullard to J. von Neumann, 27 August 1948, UTARMS B1988–0069, Box 1, Folder 2.

[18] J. von Neumann to E.C. Bullard, 17 September 1948, UTARMS B1988–0069, Box 1, Folder 2.

[19] J.C. Mark had received his Ph.D. in mathematics at the University of Toronto in 1939, and taught at the University of Manitoba until joining the Manhattan Project in 1945. He remained at Los Alamos for the rest of his career. "Los Alamos National Laboratory: History: Staff Biographies: J. Carson Mark" ⟨URL: `http://www.lanl.gov/history/people/J_Mark.shtml`⟩ – visited on 10 April 2006.

was money. The federal award was intended to cover research assistants and in any case could not hope to cover the salary of someone such as Stibitz. Instead, Bullard decided to put Gotlieb in charge as the Acting Director. Explaining his decision to von Neumann, he noted that if things went well for a few years, they could confidently promote him to Director. From Bullard's point of view as chair of Physics, it also helped avoid the risk of losing Gotlieb and saved some salary money in the early years of the project.[20] Gotlieb stayed at the University of Toronto for the remainder of his career and is now known as the 'grandfather' of computer science in Canada.

Born 27 March 1921 in Toronto, Gotlieb attended Harbord Collegiate high school, excelling in the academic stream. With a small scholarship, he was able to enter the University of Toronto in 1938, majoring in Mathematics, Physics and Chemistry. Graduating in 1942, he was turned down for graduate school at Toronto in chemistry and rejected for military service as an artillery officer, but thanks to E.F. Burton, chair of the Department of Physics, was directed into a group working on proximity fuses. After a brief period working in England at the University of Bristol, he returned to Canada to continue the work, where the project was administered by the NRC and later by Canadian Armament Research and Development Establishment (CARDE) of the DRB.[21] With M. Rubinoff, P.E. Pashler, R.W. McKay – who all contributed a great deal to computing over the following decades – the team improved the design and operation of proximity fuses. Much of the work included trajectory equations, done by Runge-Kutta differential equations on desktop calculators.[22] Along the way, Gotlieb finished his M.A. in Physics in 1944, and following the war, Gotlieb, Pashler and Rubinoff were permitted in 1947 to write up different aspects of their work as classified Ph.D.s and to publish unclassified versions later.[23]

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[20] E.C. Bullard to J. von Neumann, 24 September 1948, UTARMS B1988–0069, Box 1, Folder 2.

[21] C.C. Gotlieb to Department of Labour, 10 November 1948, UTARMS B2002–0003, Box 2, Folder 1.

[22] Calvin C. Gotlieb, interview by Henry S. Tropp, Computer Oral History Collection, transcript of tape recording, 29 July 1971, UTARMS B2002–0003, Box 8, Folder 1.

[23] Calvin C. Gotlieb, "Problems connected with the trajectory of a yawing shell", Ph.D. thesis, Physics, University of Toronto (1947); P.E. Pashler, "The determination of the forces on a shell in flight by a radio

In the fall of 1947, with his Ph.D. in hand, Gotlieb began lecturing in the physics department, and the following February the DRB attempted to recruit him back to CARDE. More comfortable at the university, he turned down a permanent position but expressed interest in a summer job; University of Toronto lecturers were paid only during the school year and were responsible for their own income during the summer months. Without waiting for a response and at the urging of the famous University of Toronto physicist Leopeld Infeld, Gotlieb also wrote to W.H. Watson at Chalk River, then the Head of the Theoretical Physics Branch of the Atomic Energy Project, and asked for a summer position. Gotlieb mentioned to Watson that as a recent research problem he had been rebuilding a mass spectrometer, possibly at the behest of Bullard.[24] Watson passed the application to the Director, W.B. Lewis, who responded to Gotlieb that they could not hire him, due to the large number of applications received that year and limited spaces. The DRB did eventually offer him summer employment at CARDE, in Valcartier, Quebec, but by that time Griffith had hired Gotlieb temporarily for the summer to assist with the computing group.[25] His assignment was to visit a number of computing centres in the United States, in connection with the plans to build the relay-computer. Later that year, Bullard selected Gotlieb as the Acting Director of the Computation Centre.

It would be inaccurate to suggest that the Department of Physics controlled the Computation Centre, though Bullard was chairing the oversight committee and Gotlieb ran things on the ground. The Computation Centre existed as an independent organization within the university until 1962, answerable to an interdisciplinary oversight committee appointed by the president of the university, and to a joint NRC and DRB committee. In part, the relationship between the computing centre and the

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method", Ph.D. thesis, Physics, University of Toronto (1947); and Morris Rubinoff, "A new method of measuring the angular motion of a spinning projectile in flight", Ph.D. thesis, Physics, University of Toronto (1946).

[24] C.C. Gotlieb to Defence Research Board, 27 April 1948, UTARMS B2002–0003, Box 2, Folder 1.

[25] Additional note, B.A. Griffith, 10 June 1948, UTARMS B1988–0069, Box 1, Folder 2.

physics department was one of convenience. When the first of the IBM punched card equipment arrived at the university in the fall of 1948, many months delayed, it was installed in the physics building, even though Beatty's name was on the contract, Griffith had ordered the equipment and his statistical laboratory was housed next to Beatty's office. The computing centre offices had been relocated earlier that year to the physics department. This was probably the only affiliated department with space to spare at the time, having just undergone a one million dollar expansion. The mathematics department offices were already scattered across campus and the engineering facilities were overwhelmed by the post-war enrolment boom.[26] It is noteworthy that as the Centre grew, the physics department did submit the greatest number of problems.[27]

Indeed, 1948 and the arrival of Bullard marked the withdrawal of the near exclusive control by the mathematicians of the computing centre. The DRB award in early 1948 launched the electronics research, relay-computer and differential analyzer construction, all of which was expected to take place in the physics building. Although mathematicians had instigated the computing centre, Griffith had admitted that C. Barnes and V.G. Smith were much more knowledgeable members of the committee when it came to building computer machinery.[28] The two had represented Toronto at the Symposium on Large Scale Digital Calculating Machinery at Harvard, rather than a mathematician.[29] V.G. Smith was also perhaps best connected to other computing projects at the time, corresponding with former students at Harvard, the Moore School, MIT, and on the west coast.[30] In general, most mathematicians were simply not interested in modern computing machinery or methods. Griffith was an exception. He gave a talk at the 1951 meeting of the Canadian Mathematical Congress

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[26] Friedland, *The University of Toronto: A History*, 373.

[27] See table 2.1.

[28] Griffith, "My Early Days in Toronto", 60.

[29] S. Beatty to S.E. Smith, 11 December 1946, UTARMS A1968–0007, Box 17, Folder 2.

[30] See page 93 for more of Smith's correspondence with students and his connections to other projects.

on these subjects but the response lacked any enthusiasm and as he put it, his words had "little lasting effect."[31]

2.2 The Mathematical Side of the Computation Centre

It should not be surprising that operations within the Computation Centre effectively split into two mutually exclusive groups: the mathematical side and the electronics side. The first was responsible for actual computation, the second was given the task of developing an electronic digital computer. The next three sections will describe the activities of the former.

2.2.1 Desktop and Punch-card Success

After Griffith had chosen to rent the IBM calculator he started looking for operators, but until the end of 1947 his search ran dry. His ideal candidate was a recent mathematics or science graduate or graduate student willing to attend IBM training sessions and operate the IBM 602. One stalling point appears to have been salary. No one on the Committee had any idea if $200 a month was too high or too low to attract the right person. For comparison, Beatty appealed to the University Accounting Office, which apparently used similar though less sophisticated tabulating machines[32] It was not unusual to find punched card machines and tabulators at a college or university, particularly within the bureaucratic structures. A well known book of the time, *Practical Applications of the Punched Card Method in Colleges and Universities* described uses for punched card machinery in registrar's offices and other university business and administrative units.[33].

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[31] Griffith, "My Early Days in Toronto", 51.

[32] S. Beatty to R.E. Spence, 24 November 1947, UTARMS A1973–0025, Box 79, Folder 2.

[33] George Walter Baehne ed., *Practical Applications of the Punched Card Method in Colleges and Universities* (Morningside Heights, New York: Columbia University Press, 1935).

In December, Griffith finally located two junior assistants to handle the job: James P. Stanley and Beatrice H. "Trixie" Worsley, who both began work 15 January 1948, at the starting salary of $200 per month.[34] The two previously knew each other from the campus Math and Physics Society. Stanley, born in 1926 at Trail, British Columbia had finished his B.A. in Mathematics and Physics at the University of Toronto in 1946. He was just finishing his M.A. at Toronto when he was hired.[35] Worsley was born in Queretaro, Mexico in 1921, and had moved with her family to Toronto in 1929, where she attended Bishop Strachan School. In 1939 she entered the University of Toronto, switching to the Mathematics and Physics program her second year and graduating one year ahead of Stanley. After a year and a half of service as a Wren in the Women's Royal Canadian Naval Service (WRCNS), including a stretch of sea-going scientific research, she finished a one year master's program of mathematics and physics at MIT, where she was first exposed to large-scale digital computing. Her thesis: "A Mathematical Survey of Computing Devices with an Appendix on Error Analysis of Differential Analyzers" provided a fascinating snapshot of mechanical and electronic computer and demonstrated her wide knowledge of the field. She returned to Canada in late 1947 and after a few months working in the mechanical engineering division of the NRC in Ottawa, she returned to Toronto to join the computing project.[36] Given her work at MIT, it is entirely possible that at this point Worsley knew as much or more about existing computing machinery than the rest of the Committee on Computing Machines and her colleague.

Worsley and Stanley were sent to the IBM Service Bureau to complete training on the IBM 602 Calculating Punch and 405 Accounting Machine. The latter was IBM's

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[34] Progress Report on the Proposed Computing Centre at the University of Toronto, 1948, UTARMS B1988–0069, Box 1, Folder 2 This was increased later that year to $250 and $225, respectively. S. Beatty to G.L. Court, 4 November 1948, UTARMS B1988–0069, Box 1, Folder 2.

[35] Programme of the Final Oral Examination, James Perham Stanley, 15 May 1951, UTARMS B1988–0069, Box 3, Folder 30.

[36] Scott M. Campbell, "Beatrice Helen Worsley: Canada's Female Computer Pioneer", *IEEE Annals of the History of Computing* 25, no. 3 (Oct-Dec 2003), 51–54.

high-end tabulator, their flagship product from its introduction in 1934 until after the war. The equipment was not expected to arrive at the university for several months, but in the meantime they had access to similar machines in the Service Bureau. The 405 arrived in March 1948 with a 601 Multiplying Punch, a product first introduced in 1931. The 601 was replaced in July 1949 by an IBM 602A, also known as "the 602 that worked."[37] Worsley and Stanley were also expected to pursue their own study and research into computing methods and report back to the committee. Stanley, for example, gave a seminar surveying numerical methods of integrating differential equations.[38]

The delays with IBM held up the two computing problems that were underway in the spring of 1948. The special navigational tables for the Department of Astronomy first mentioned in April 1947 were prepared for the machines, but obtaining actual results proved more difficult: "work is progressing at the IBM Service Bureau, as conditions permit."[39] The tables were not completed until March 1950.

The second problem was the quantum mechanical calculation for the Atomic Energy Project, also first mentioned in 1947. Though not especially noteworthy when the project first got off the ground this computation became the first major success for the Computation Centre, leading to three scientific publications and a great boost of support from Chalk River. The problem, suggested by L.G. Elliott, H. Coish, and W.H. Watson, was to simplify for computational purposes Hulme's formulae for the internal conversion of γ-radiation in the K and L shells, eventually focusing on the L_1-shell. Griffith supervised the process, verifying the simplifications done by Stanley, who spent eight weeks tabulating to five-places the values on a Friden ST-10.[40] The

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[37] Computation Centre, Progress Report as of October 1, 1949, LAC RG77, Volume 52, File 17–28B–1. The primary computational difference between the 601 and 602 was that the 602 could divide.

[38] Progress Report on the Proposed Computing Centre at the University of Toronto, 1948, UTARMS B1988–0069, Box 1, Folder 2.

[39] Progress Report on the Proposed Computing Centre at the University of Toronto, 1948, UTARMS B1988–0069, Box 1, Folder 2.

[40] Byron A. Griffith and James P. Stanley, "On the Numerical Calculation of the Internal Conversion in the K-Shell; the Electric Dipole Case", *Physical Review* 75, no. 3 (Feb. 1949), 534–535, and James P.

work was expanded by H.S. Gellman who used the IBM 602 to handle the remaining hypergeometric functions.[41]

Griffith had hired Harvey S. Gellman that year, after Stanley and Worsley. Born in Poland in 1924, Gellman immigrated to Toronto with his parents in 1928 and attended Central Technical High School. This was not a normal route to university, and he left after three years to work in an electrical manufacturing plant to help the family finances. There, he discovered he had enjoyed his studies more than he had appreciated and returned to high school. From there he enrolled in the University of Toronto in the Mathematics and Physics program. After graduating in 1947, he took a job as a physicist working with radium at the Eldorado Mining and Refinery at Port Hope, about 100 km east of Toronto. Again, longing for more stimulating work, he returned to the university, but now married, he needed a postgraduate position that paid a living wage.[42] Sometime in first half of 1948 Gellman heard of the computing project and approached Griffith, his former professor, to ask for a job.[43] The original NRC grant application allowed for just two employees, Stanley and Worsley, but with the DRB grant Griffith was able to hire Gellman to assist Stanley with the ongoing internal conversion calculations.[44]

Stanley and Gellman's work was crucial to the initial success of the Computation Centre. Their publications in the *Canadian Journal of Research* specifically mentioned the Computation Centre of the University of Toronto, not the Department of Mathematics or Physics. As the first widely available scientific article to mention the Centre this was sure to catch the eye of physicists across Canada. As W.H. Watson put it

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Stanley, "On the Numerical Calculation of the Internal Conversion in the K-Shell – The Electric Dipole Case", *Canadian Journal of Research, Section A* 27 (1949), 17–25.

[41] Harvey Gellman, Byron A. Griffith and James P. Stanley, "Internal Conversion in the L1-Shell", *Physical Review* 80, no. 5 (1950), 866–874.

[42] Marina Strauss, "Harvey Gellman: 1924-2003", *The Globe and Mail* (10 May 2003), F11, and Harvey S. Gellman, interview by Michael R. Williams, 9 June 1992, Transcript provided by Michael R. Williams.

[43] Around the same time he was also offered a job to teach mathematics in the Engineering Faculty, but upon the advice of Dean Beatty, another former professor and mentor, he went for the computing job, reasoning that a teaching job was always available.

[44] Griffith, "My Early Days in Toronto", 58.

in a letter to Gotlieb that fall: "I incline to the view that is is important both for the Canadian Government and for the University of Toronto that the work done in the Computation Centre which is not classified should be given the widest possible publicity consistent with its value to scientific and technical workers, in order that we may build up a well founded prestige for the centre."[45] Classified work done for the DRB or the Atomic Energy Project was not uncommon. To permit, as Watson put it, the widest possible publicity, when problems were submitted the computations were structured such that the resulting tables would be applicable in other fields.[46] Watson's enthusiasm and support, as Head of the Theoretical Physics Branch at Chalk River, was important as his positive experience helped justify to the NRC and DRB that their investment was sound. The computations were vital to the work at Chalk River, and the work had been conducted in Canada by Canadians, not exported to a computing centre in the United States or England.

An important test came in October 1948. Just as Stanley finished the calculations, Watson informed Toronto that the Oak Ridge Laboratory in the United States wanted to conduct similar and more thorough internal conversion calculations for different atomic weights. The work was to be handled at Harvard on the Mark I, but Watson felt that Toronto could handle the work.[47] Through the ensuing negotiations, he wrote to Griffith that the Computation Centre would likely be responsible for the L_1-shell calculations, and if the Mark I was not used they would be asked to take up as much of the work as they could handle.[48] Not only was the Computing Centre judged capable of useful work, but used as a bargaining chip in Chalk River's dealings with their United States counterparts, underlining again the national significance of having a Canadian computing centre.

The internal conversion calculations also offered Toronto a chance to contribute on

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[45] W.H. Watson to C.C. Gotlieb, 6 November 1948, UTARMS B1988–0069, Box 1, Folder 2.

[46] W.H. Watson to C.C. Gotlieb, 21 October 1948, UTARMS B1988–0069, Box 1, Folder 2.

[47] W.H. Watson to B.A. Griffith, 13 October 1948, UTARMS B1988–0069, Box 1, Folder 2.

[48] W.H. Watson to C.C. Gotlieb, 15 November 1948, UTARMS B1988–0069, Box 1, Folder 2.

the international stage to the growing field of scientific computation. In 1949 Gellman and Gotlieb attended an IBM organized conference on scientific computing in Endicott, New York. The second such conference in as many years, it had little to do with electronic computing and a great deal to do with getting IBM's 600-series punched card calculators to do serious scientific work. Gellman presented their work on hypergeometric functions, but in contrast to the three other papers in the Canadian scientific journals which focused on the mathematical simplification of Hulme's formulae, here he focused on the techniques he had used to solve them on the IBM 602.[49] This was the first time that the Computation Centre was able to participate within the scientific computing community, a respectable achievement in less than a year. It helped establish credibility and a reputation for the Computation Centre.

In the fall of 1948 both Stanley and Worsley left for Cambridge University to continue their Ph.D. studies, and to learn what they could of the EDSAC, which was nearing completion.[50] Gellman stayed in Toronto and continued to direct efforts with the IBM 602 and working with Acting Director Gotlieb, who hired various undergraduates and professional human computers to assist their work.[51] They actively sought out problems that would both test the centre and attract interest from government and industrial researchers.[52] By the time the Computation Centre had an electronic digital computer by the end of 1952, over one hundred scientific, engineering, and mathematical problems were completed using the IBM equipment, supported by the desk calculators.

Despite the intentions of the Committee on Computing Machines, when the Computation Centre operated with the punched card machinery it remained primarily a

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[49] Harvey Gellman, "The Calculation of Complex Hypergeometric Functions with the IBM Type 602 - a Calculation Punch", in *Proceedings of the International Business Machines Seminar* (IBM, December 1949), 161–168.

[50] See page 122.

[51] C.C. Gotlieb to W.H. Barton, 14 May 1949, UTARMS B1988–0069, Box 1, Folder 2.

[52] Calvin C. Gotlieb, interview by Michael R. Williams, 29 April 1992, Transcript provided by Michael R. Williams.

[53] Computation Problems, January 1957, UTARMS B1988–0069, Box 1, Folder 3.

Table 2.1: Computation Centre Problems, 1947–1952 [53]

	1947	1948	1949	1950	1951	1952
Chalk River, DRB, NRC	1	5	1	4	1	4
University of Toronto						
Physics	0	10	5	2	6	5
Mathematics	0	0	1	2	2	5
Engineering	0	1	0	7	6	2
Computation Centre	0	1	1	3	2	1
Other	0	2	0	1	3	0
Other Universities	0	0	0	3	5	6
Others	0	0	0	4	5	9
Total Problems	1	19	8	26	30	32

local computing centre. As can be seen in Table 2.1, in every year but 1952, more than half of the problems submitted were from members of the University of Toronto, and of those, the Department of Physics was the most prolific. Of course, these figures can only approximate the actual computational work expended. Inevitably some problems take longer to complete than others, and unfortunately, the relevant historical data is incomplete.[54] However, there is a distinctly rising trend of a more problems submitted by outside organizations. This could correspond to an increased awareness of the Centre, thanks to Gotlieb's judicious self-promotion, or an increased demand for computational services. In either case, shortly after an electronic computer replaced the IBM equipment, the external use of the Centre's computing resources skyrocketed (see Table 4.2).

In 1951, the Computation Centre made ready to replace its two leased IBM 602As with a single IBM 604 Electronic Calculating Punch.[55] Like the 602A, it was programmable via plug-board, and processed punched cards. Unlike the 602A, instead of electromechanical innards, it used modular vacuum tube based circuitry and as a

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[54] Completion dates and details concerning delays are not available for all problems. Despite the availability of the much faster IBM 602, desktop calculators remained in use well into the 1950s. In May 1951, it was noted that problems had been taking on average 12 weeks. Computation Centre Committee meeting minutes, 1 May 1951, UTARMS B1988–0069, Box 1, Folder 3.

[55] Computation Centre Committee meeting minutes, 5 October 1951, UTARMS B1988–0069, Box 1, Folder 2. A second 602A had been added to the Centre at some point in the past two years.

result was considerably faster. Introduced in 1948, it was a phenomenally successful machine; 5,600 were produced and installed in its lifetime.[56] The 604 would allow the Computation Centre to expand its busy operations until an electronic computer was ready.

2.2.2 Relay Computer

The second major project underway in the Computation Centre in fall of 1948 was to build a relay computer, by copying one rather than designing one. Surprisingly, the Centre appears to have ignored the advice contained in the Committee on Computing Machines' first report: "all existing machines are obsolescent in the sense that no copies of the large machines will be made in the future," and: "The group is . . . not in favour of copying an existing machine."[57] The only available explanation is that with the large award from the NRC and DRB it was hoped that a large-scale relay based machine could be assembled quickly until the electronics research could produce a computer. A full year of planning went into this effort, but in the end the project was cancelled by the DRB in 1949 without a tool having been lifted.

The first mention of the project does not make clear what machine was to be cloned, though there were many designs to choose from, including the post-war Bell Laboratories models, the older but still functioning Harvard Mark I, or even IBM's PSRCs that the Committee on Computing Machines may or may not have seen at the Aberdeen Proving Grounds in 1946. For an unknown reason, these better known machines in the United States seem to have been rebuffed initially in favour of a British computer. The Committee put C. Barnes, a physics professor, in charge of the project and in May 1948 he attempted to obtain a copy of a classified report from the Ministry of Supply in England written by E.J. Petherick entitled: "A small sequence controlled calculator".

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[56] Pugh, *Building IBM: Shaping an Industry and Its Technology*, 151–152.

[57] Preliminary Report on Modern Computing Machines, 1946, UTARMS B1988–0069, Box 1, Folder 2.

The report described a relay computer built at the Royal Airforce Establishment (RAE) Farnborough by Petherick and S.H. Hollingdale that came to be known as RASCAL (RAE Sequence Calculator). Intended for processing supersonic wind tunnel instrumentation data, the special purpose computer was never finished, even after relays were replaced with electronics.[58] It is not known how Barnes knew of the RASCAL, as the rest of the Committee remained ignorant of most British computing activity until Douglas Hartree visited Toronto from Cambridge in October 1948.[59] The report was classified, so Barnes' request had to go through the NRC but it was turned down in June 1948.[60]

Around this time Gotlieb was brought aboard to oversee temporarily the relay project as the plans changed to construct a copy of the Bell Laboratories Model IV, modified to include features found in the Model V. Griffith put Gotlieb in contact with Stibitz and arranged for Gotlieb to visit him in Vermont in late July for the two to discuss the Bell Labs machines.[61] On Gotlieb's second trip of the summer, he spent about a week at Bell Labs absorbing all he could from E.G. Andrews, the experienced systems engineer who had helped build the relay computers with Stibitz since the Complex Number Computer. By late August, it became clear that Bell Labs would not be able to supply adequate manufacturing information and the proposed modifications were too troublesome. However, a sixth and final relay machine was under construction when Gotlieb was visiting Andrews. The X-75320 Network Computer or Model VI was intended strictly for internal use at Bell, unlike the earlier military ver-

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[58] E.J. Petherick, "Advance Notes on RASCAL", in Martin Campbell-Kelly and Michael R. Williams eds., *The Early British Computer Conferences* (Cambridge, Mass., Los Angeles: MIT Press, Tomash Publishers, 1989), 255–264.

[59] As Barnes' field of study was ultrasonics, he may have heard of RASCAL in the course of his primary research or contact with colleagues.

[60] C. Barnes to R.A. Kennedy, 29 June 1948, UTARMS B1988–0069, Box 1, Folder 2.

[61] G.R. Stibitz to B.A. Griffith, 12 June 1948, UTARMS B1988–0069, Box 1, Folder 2. Although Stibitz had left Bell after the war, he remained heavily involved in their computing projects as a consultant. It is possible, though unlikely, that the plan to build a copy of a Bell Labs machine was motivated by a desire to attract Stibitz to Toronto as director of the Computation Centre. Gotlieb was still a temporary employee at this time.

sions. It was smaller and simpler than the Model V; its designers felt that the greater complexity of the Model V was unnecessary.[62] Andrews was willing to share the complete Model VI schematics with Toronto when the machine was finished, and Gotlieb convinced the committee to wait and build a copy then.[63]

A favourite anecdote of Gotlieb's is that when he returned to Toronto, he brought with him a large quantity of blueprints that Andrews supplied but hit trouble at the border. The blueprints were marked confidential and when Gotlieb refused to show them to the customs agents they refused to let him pass. Unsure what to do, they eventually allowed him through when agreed to pay a $25 duty determined by the weight of his parcel.[64]

It was understood that the schematics and any operating advice from Bell Labs would not be free, but subject to some sort of fee, though nothing was formalized over the summer. Unfortunately, no progress could be made in Toronto until Bell Labs could finalize some sort of agreement. The committee hoped that the process could be simplified by making arrangements through Northern Electric Company Limited, as the Canadian representative of Bell Telephone Laboratories, but by late October nobody could agree on a price. In retrospect, the problem is understandable as this was a one of a kind machine that was not designed with manufacturing or sales in mind.[65] In contrast, it is worth noting that von Neumann's engineering team at the Institute for Advanced Study (IAS) was willing to share any and all insight and information with other interested parties, in the general interests of science.[66] With one week re-

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[62] Martin Campbell-Kelly, "Punched Card Machinery", in Aspray, *Computing Before Computers*, 14.

[63] E.G. Andrews to C.C. Gotlieb, 20 September 1948, UTARMS B1988–0069, Box 1, Folder 2.

[64] Calvin C. Gotlieb, interview by Michael R. Williams, 29 April 1992, Transcript provided by Michael R. Williams.

[65] Northern Electric Company to C.C. Gotlieb, 29 October 1948, UTARMS B1988–0069, Box 1, Folder 2.

[66] Because of this policy, there were many copies and close derivatives made of the IAS computer including but not limited to: JOHNIAC, of the RAND Corporation; MANIAC (Mathematical Analyzer Numerical Integrator And Computer) of the Los Alamos Scientific Laboratory; ORDVAC (Ordnance Variable Automatic Computer), built by the University of Illinois for the Ballistics Research Laboratory; ILLIAC (Illinois Automatic Computer), a copy of the ORDVAC used by the University of Illinois; and SILLIAC (Sydney ILLIAC) of Australia's University of Sydney.

maining until the end of 1948 Northern Electric finally worked out the details with their counterparts in the United States: in exchange for a licensing fee of $25,000, Bell Labs would provide the University of Toronto with all the necessary technical information to construct and operate a Model VI relay computer. The proposed agreement did not include any of the parts, such as relays, condensers, and teletype equipment, and any assistance with on-site construction would be subject to additional fees.[67]

This fee was much higher than expected, and at a Committee on Computing Machines meeting 6 January 1949, the future of the project was first on the agenda. The committee decided to push ahead with the following justification: it was considered impractical to design their own relay machine within a reasonable period and the Model VI offered "the best hope of obtaining a versatile calculating machine in a short time, and in view of the long development which lies behind the computer, the license request is not unreasonable."[68] Unfortunately, the license fee drove the overall estimate to $70,000, considerably more than the NRC or the DRB had promised to that point. The committee remained surprisingly optimistic that such funding would be forthcoming, and that construction would begin immediately after the Defence Research Board or the National Research Council agreed to meet the additional costs.[69] This was not the case. At a March 16 joint meeting in Ottawa, attended by President Mackenzie of the NRC and E.L. Davies, vice-chairman of the DRB, Bullard and Gotlieb, it was decided not to go ahead with the relay computer. Instead, the Computation Centre was to forge ahead on the electronics research and accelerate their plans for construction of a high-speed computer. To pay for this push, the total federal grant was increased to about $50,000, with the DRB covering around $30,000 and the NRC the remaining $20,000.[70]

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[67] L.P. Stiles to E.C. Bullard, 23 December 1948, UTARMS B1988–0069, Box 1, Folder 2.

[68] C.C. Gotlieb to L.P. Stiles, 26 January 1949, UTARMS B1988–0069, Box 1, Folder 2.

[69] Committee on Computing Machines, meeting minutes, 6 January 1949, UTARMS B1988–0069, Box 1, Folder 2.

[70] W.H. Barton to E.C. Bullard, 22 April 1949, UTARMS B1988–0069, Box 1, Folder 2.

The exact reasons behind this decision to terminate the relay computer project are unknown, but the event is pivotal in the history of computing at Toronto, and by extension the rest of Canada. At such an early juncture the choice of one style of large-scale digital computing over another could easily have led to a far different outcome. As historian William Aspray has shown, early entry to academic computing did not guarantee a later advantage. Many schools with digital computer programs in the late 1940s failed to nurse these seeds into powerful computer science programs in the 1960s, and other late-blooming schools managed to rise to the top.[71] Toronto's entry into large-scale digital computing was delayed four more years until late 1952, by way of a dramatically different route than planned in early 1949. The successful construction and operation of the relay computer would have produced and propagated certain technical skills, and for reasons explored below could have also delayed the arrival of an electronic computer beyond 1952, changing the history of the Computation Centre considerably.

To explain why the relay computer project was abandoned, one historian has suggested that before the Ottawa meeting in March 1949, von Neumann may have convinced Bullard "of the future of electronics and the folly of constructing the relay-based computer", who then persuaded the NRC and DRB to reject it.[72] Yet in a reply from Bullard to von Neumann a few weeks after the Ottawa meeting he stated that although they no longer planned to build their own relay computer they still wanted to buy a complete model, "if we can get one for a reasonable price and within reasonable time".[73] It's not clear where they hoped to find such a bargain, as Andrews had informed Gotlieb the previous year that Bell Labs was in no position to manufacture copies for anyone.[74] Yet the Computation Centre was not ready to reject the technol-

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[71] Aspray, "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s", 42–87.

[72] Williams, "UTEC and Ferut: The University of Toronto's Computation Centre", 7.

[73] E.C. Bullard to J. von Neumann, 29 March 1949, UTARMS B1988–0069, Box 1, Folder 2.

[74] E.G. Andrews to C.C. Gotlieb, 20 September 1948, UTARMS B1988–0069, Box 1, Folder 2.

ogy as obsolete and intended to obtain a copy. But even this changed approach was dropped entirely a few weeks later when the DRB made clear that any and all attempts to acquire a relay computer were to be abandoned immediately. Davies rebuked the end-run around the March 16 decision, and in no uncertain terms made clear that the increased annual grant was to be used solely to sustain the computational side of the project until the electronics team was ready to build a high-speed computer. At that time, the government grant would be increased to cover the construction costs. If there were other plans in Toronto, somebody there had misunderstood.[75] Further evidence that the DRB decided to cancel the project can be found in correspondence between Gotlieb and Northern Electric before and after the decision. Although Gotlieb was not senior enough at the time to dispel all historical doubt, his letters convey his impression that the DRB, as the primary benefactor, had made the decision and had killed the Computation Centre's plans.[76]

What is clear is that in Toronto, even under Bullard, there were non-trivial disagreements with the NRC and DRB about the future of computing. This will be a recurring theme throughout the rest of this chapter, but for the moment consider the following questions: why was the Computation Centre so determined to pursue the relay technology? Was this plan 'folly', as Williams suggested? Historically, by 1949 the shift away from electromagnetic towards electronic components was well underway. The Bell Labs Model VI was the last major relay machine, though it was not finished until well after the first EDSAC runs in May 1949. Yet the United States Army and Navy each had three relay computers operating at the time, relying nearly exclusively on them, implying that the technology was not dead yet. Moreover, *all* of the Bell labs machines except the original 1940 Complex Number Calculator were still in

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[75] W.H. Barton to E.C. Bullard, 22 April 1949, UTARMS B1988–0069, Box 1, Folder 2.

[76] See: C.C. Gotlieb to L.P. Stiles, 26 January 1949, UTARMS B1988–0069, Box 1, Folder 2; and C.C. Gotlieb to E.T. Downs, 6 May 1949, UTARMS B1988–0069, Box 1, Folder 2. Gotlieb has also recalled a meeting in Ottawa where he was taken aside privately by Mackenzie, who explained that the NRC did not lack confidence in the Computation Centre, merely that of relay computer technology.

use in 1958, three years after the much faster ENIAC was dismantled and as the next generation of even faster transistorized computers were appearing.[77] Had Toronto successfully completed a copy of the Model VI in 1949, there is little reason to doubt that it too might have been operating ten years later, nor that this might have affected the arrival of a modern computing device. Looking beyond speed comparisons can help explain the longevity of relay computers and why Bullard and the Committee on Computing Machines were so willing to pursue the technology.

Arithmetical speed cannot and should not be used to accurately judge the overall quickness of a computer. One must also consider input and output, locating and loading subroutines from storage, and various other delays that have nothing to do with calculation. It turns out that the Bell Labs relay machines perform very well under such criteria. First and foremost, they are recognized for their remarkable reliability. Guided by years of Bell Labs experience designing telephone circuits that had to operate continuously without fail, the computers that emerged from the same base of knowledge and technology were exceedingly dependable. In general, electromagnetic relays are usually reliable mechanical devices but prone to occasional failure should, for example, a piece of dust become stuck between the contacts. But unlike vacuum tubes, which are subject to a more permanent blowout-type failure, a relay can often recover silently. Dust could fall loose without any indication that anything went wrong in the first place.[78] To combat this problem the Bell Labs engineers developed "self-checking and second-trial functions" that helped guarantee reliable telephone networks, features then reused in their computers.[79] Every model after the first used a bi-quinary numerical system to represent decimal digits. A special checking circuit that could then detect if a relay was stuck or otherwise malfunctioning and automat-

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[77] Andrews, "Telephone Switching and the Early Bell Laboratories Computers", 13–16. The ENIAC remained in use until October 1955. The transistorized Philco TRANSAC S-2000 was marketed in 1958, though the first deliveries were in January 1960. Paul E. Ceruzzi, *A history of modern computing* (Cambridge, Mass.: MIT Press, 1998), 65.

[78] Ceruzzi, "Number, Please: Computers at Bell Labs", 73–102.

[79] Andrews, "Telephone Switching and the Early Bell Laboratories Computers", 18.

ically re-attempt the operation, rendering harmless the dust problem. More elaborate checking features were added to subsequent models to the point that "through 1951 only two errors were reported from machine faults in Models III through VI."[80] In practice, this meant an operator could load a number of programs late in the day to run all night or all weekend with the expectation that things would finish and be ready in the morning, without a single failure. Stoppages for maintenance or repair were rare; the Model V or VI could easily run for 167 out of 168 possible hours per week, an astounding feat utterly unmatched by any electronic computer of the era.[81] The Committee on Computing Machines was clearly dazzled by the reliability of the Bell Labs computers in its 1946 reports.

Reliability was perhaps the most important general feature that persuaded the Committee, but other factors could have contributed. Historian John Vardalas has noted several possibilities in his treatment of this same material. Compared to electronic computers, a relay computer "was easier to design, build, and maintain", consumed less power, did not require a climate controlled environment, required less maintenance, and took up no more space.[82] In terms of digital capacity – the maximum length of numbers used for calculation – one could make the argument that the Bell Labs relay machines were inferior to other computers. It used seven decimal digit numbers, compared to 23 digits on the Harvard Mark I, and ten on both the Harvard Mark II and ENIAC. However, this limitation is partially mitigated by the fact that the Bell Labs Model V was the first automatic computing machine to use a floating decimal point, rather than fixed. This simplified scientific programming considerably.[83] The Bell Labs machines offered a great deal of versatility, and correspondingly quick and cheap solutions to many scientific computations, as the United States Army and

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[80] Andrews, "Telephone Switching and the Early Bell Laboratories Computers", 18.

[81] E.G. Andrews and H.W. Bode, "Use of the Relay Digital Computer", *Annals of the History of Computing* 4, no. 1 (1982), 2.

[82] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 25.

[83] Alt, "A Bell Telephone Laboratories' computing machine", 266. The Harvard Mark II, which followed the Model V chronologically, was also a floating-point machine.

Navy knew well.

Even when a specific comparison was carried out between a relay and electronic computer, one does not come out better than the other. The United States Army Aberdeen Proving Grounds employed both the ENIAC and a Bell Labs Model V. As F. Alt reported in 1948, operators there had learned that the two computers "represent two extremes;" because of the speed difference ENIAC was suitable for long, simple problems and the Model V was best for short but complex problems.[84] However, ENIAC did not have much numerical storage and so problems requiring considerable storage were better on the Model V. Finally, the nature of ENIAC's vacuum tube technology and long setup times dictated long continuous runs, whereas the Model V tolerated short "on-and-off" problems.[85] Despite its position at one end of the spectrum, there is little reason to believe that a copy of the Model VI would have been computationally inappropriate for the Computation Centre during its first years. Of the four problems put forward in 1948 by the Committee for Computing Machines, all were solved eventually with the IBM 602, implying that that the Model VI would have worked just as well. The same can also be said of the other fifteen problems submitted before the relay project was cancelled in 1949. Despite the high license fee demanded by Bell Labs, a copy of the Model VI would have been a good bargain in Toronto at no higher than one third of the cost of an electronic computer.[86]

Then why did the DRB cancel the project? More important than the problems that were computed are those that were never submitted. In particular, there is no record of a computation request from the DRB until March 1950, one full year after it ordered the relay project shut down.[87] Thus it is unlikely that computational capability had anything to do with the DRB decision. Instead, it makes more sense that the DRB was

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[84] Alt, "A Bell Telephone Laboratories' computing machine".

[85] Ibid., 292.

[86] Bell engineers felt that the Model III and IV represented a better balance of price and performance than later Models. Ceruzzi, *Reckoners: The Prehistory of the Digital Computer*, 95.

[87] Computation Problems, January 1957, UTARMS B1988–0069, Box 1, Folder 3, Problem 39.

simply more interested in accelerating the electronics research program than copying an existing – if useful – computer. Further evidence for this can be found in the DRB's first response to Griffith's enquiries in November 1947: it was not Solandt who replied, but E.G. Cullwick, director of the Electrical Research Division, on behalf of the DRB Electronics Advisory Committee. He makes clear that the proposed computing centre would "undoubtedly be of value to the Defence Research Board," but emphasizes that any assistance would be directed towards "the development of an electronic digital computer for such a centre."[88] As Vardalas has recognized, pushing ahead on this front was a valuable move to the Canadian military: "Digital electronics was just starting to appear at the very frontier of weapon-system research. Designing and building computers was thus a useful vehicle for fostering a national capacity in digital circuit design."[89] Unfortunately, there was little contact between the Computation Centre and the DRB regarding electronic computer design; when the DRB did build its own machine – the DRTE Computer – later in the 1950s, there were no communications with the University of Toronto.[90]

But it was not just the members of the Computation Centre who were disappointed by the DRB's decision. At the NRC, where the primary motivating factor in sponsoring a computing centre was computational, there were concerns that cancelling the relay computer would leave a large gap in the capabilities of the Computation Centre, a fear later proved groundless. N.L. Kusters, of the NRC's Radio and Electrical Engineering Division, who had accompanied the representatives of the Committee on Computing Machines on much of the 1946 tour, drafted a memo in June 1949 with his observations regarding the cancelled relay machine. He did agree with the original and balanced plans to locate a computing centre in Toronto and put to work imme-

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[88] E.G. Cullwick to B.A. Griffith, 27 November 1947, UTARMS B1988–0069, Box 1, Folder 2.

[89] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 26.

[90] Calvin C. Gotlieb, "Early Computer Developments in Canada", interview by Ted Paull and John N. Vardalas, National Museum of Science and Technology, transcript of tape recording, 14 August 1984, UTARMS B2002–0003, Box 1, Folder 17.

diately the IBM equipment and a relay computer concurrent with the long-term development of an electronic digital computer. Removing the relay computer from this equation upset the balance, putting the original plan in question. The Computation Centre appeared to have been given "the job of developing a large scale electronic digital calculator rather than the job of operating Canada's computing centre."[91] While qualified to handle the latter, Kusters held serious doubts about its qualifications regarding the former. The change in plans also threw the future of large-scale computing in Canada in the air; without a relay computer imminent and an electronic computer years away, it left the Computation Centre with the modest IBM 602 calculator to service a nation's computing needs for an unknown number of years.

This then, is the denouement of the relay computer decision: the most appropriate comparison is not to an electronic machine, but the lowly IBM 602. Either the DRB was willing to take the risk that the electromechanical punched card calculator would do until an electronic computer – now on an accelerated program – could be built, or the DRB did not care about computations.[92] Regardless of the factors behind the decision, the IBM 602 was not to be sniffed at. Hundreds of of the 600-series calculators were used in North America for scientific computing, and IBM sponsored several conferences in order to distribute the collective knowledge and experience. In Toronto, IBM also offered training and the use of their Service Bureau until the equipment was delivered to the university. It is not clear if Bell Labs was able, willing, or interested in matching any of these activities. Certainly, in Toronto, Gellman and Stanley put their IBM 602 to work with excellent results almost immediately, followed by several successful years of operations under Gotlieb. And though a relay computer might have been the most flexible and immediate option for large-scale computing in Toronto, in

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[91] N.L. Kusters to B.G. Ballard, Memorandum, Re: Computing Centre at Toronto University, 13 June 1949, LAC RG77, Volume 134, File 17–15–1–20.

[92] One possibility that would cancel this analysis is that the DRB work was classified and never included in the list of problems solved. This can be discounted because DRB requests do appear on the list eventually and because several progress reports sent to the DRB included annual lists of problems completed that do not differ from the 'official' list.

the early years there was insufficient computational demand to justify the costs, when the IBM 602 would do just as well.

Finally, there is little evidence that anyone in Toronto was qualified to build and operate a copy of a relay computer, at least not without removing people from the electronics research. Gotlieb likely had the necessary mathematical skills to run one, but probably lacked the engineering know-how. The technicians and engineers employed on the electronics side might have been capable, but as Bullard admitted to von Neumann after it was cancelled, "we shall only be making one thing at a time. I think we were in some danger of biting off more than we could chew on the constructional side."[93] Vardalas suggests that the Computation Centre may have been seduced by large-scale electronic computing and did not mind dropping the electromechanical option, but both were pursued vigorously enough to dispel that notion.[94] The prestige of a hundred-thousand dollar computer would be a feather in the university's cap, even if a half-million dollar electronic one was somewhere in the future too.

2.2.3 Analog Computing

The relay computer project was not the only one at the time that the Computation Centre failed to pursue to completion. Their attempts to acquire an analog computer were marginally more successful, but despite estimates that a differential analyzer would cost $10,000 or more, the project was never taken seriously and only $75 was ever spent on it. Given the absence of analog computers today in all but the most specialized applications, it hardly seems worth noting a project that was paid for by petty cash and built from tinker toys. However, it was the first computer built at the University of Toronto, and a careful examination of the story casts a useful light on the computing agenda at the time.

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[93] E.C. Bullard to J. von Neumann, 29 March 1949, UTARMS B1988–0069, Box 1, Folder 2.

[94] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 26.

The Committee on Computing Machine's preliminary report distinguished between analog and digital computing, but just half a page was dedicated to analog technology (of four total) and none of the eight recommendations made by the committee referred to it directly. In the first budget proposal tabled a few months later, $10,000 to $15,000 was allocated to a differential analyzer, compared to $75,000 for an electronic computer, and a further $14,000 for lesser digital equipment. That analog was disregarded in favour of digital may not appear an unusual decision, but in 1946 it was not necessarily obvious that one technology was superior to the other, or that one had to chose between them at all. Analog and digital computers had well-defined roles that did not necessarily overlap. Yet had the University of Toronto contemplated entering the computing world just four or five years later, analog would never have been considered. The two year delay from first proposal to first funding was enough to interrupt things, and provides an opportunity to explore how the committee and the technology changed.

Digital computing technology did replace analog, but the causes are not always well understood. As historian Larry Owens has pointed out, many people have assumed incorrectly that it was a simply a matter of speed and convenience: digital was faster and general purpose, and therefore better than analog.[95] But computational speed is tricky to judge, even between digital computers. Although a straightforward comparison of arithmetic speeds between a vacuum tube computer like ENIAC and a relay based computer like the Bell Labs Model V would give the former a substantial theoretical advantage, the practical in-the-field experience would put the two on similar footing. On the one hand, ENIAC's vacuum tubes operated hundreds of times faster than the relays of an electromechanical calculator, but preparing it to run a program could take days of plugging and unplugging cables. On the other hand, preparing paper tape programs for the Bell Labs Model V required effectively zero

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[95] Owens, "Where Are We Going, Phil Morse? Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957", 34–41.

time. The machine was extremely reliable and new programs could be written while old ones were running. When one job was finished, it took almost no time to load the new tape. With respect to the speeds of analog and digital computers, the two do not operate on the same principles, which makes a theoretical comparison of arithmetic operations impossible. However, a relative test of speeds, which demanded of each to solve the same scientific problem, would have been equivocal due to similar differences between setup and output time, or handling minor variations of a problem. Factors like these depended more on the implementation of a machine rather that its type. As Owens puts it, that many people ascribe the decline of analog to slower speed is likely explained by way of the electronic triumph over mechanical in the digital realm, a notion that was then applied to mechanical analog devices.

The other advantage dismissed by Owens is that an electronic digital computer offered a more flexible machine than a differential analyzer, and therefore was more useful. However, once setup to solve a class of problems, analyzers were also easy to adjust in small ways to explore variations. This was particularly useful during a design or testing phase of a problem. Analyzers tended to offer better insight into the overall problem being solved, because they provide a direct physical representation of a problem. Vannevar Bush, inventor of the differential analyzer, described at least one uneducated analyzer operator at MIT who had self-taught himself the concept of integrals to sufficient depth that he could discuss them with trained mathematicians in the lab.[96] To solve a differential equation numerically with a mid 1940s digital computer required a step-by-step algorithm that had little to do with the original curve, and could rarely be so easily modified to explore the problem.

However, it must be said that analyzers were limited to the types of problems that could be solved. Analog computations must be carried out by specific mechanisms; components suitable for sine functions can not be reused for logarithms. In contrast,

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[96] Owens, "Where Are We Going, Phil Morse? Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957", 39.

although digital devices are quite 'dumb', a digital number could represent any value, trigonometric, logarithmic, or otherwise. As a result, and as the preliminary report by the Committee on Computing Machines correctly stated, "Any problem which can be solved with the aid of a differential analyzer, can probably be solved using a digital machine."[97] The reverse was not generally true – analyzers were not suitable for statistical calculations, readily handled digitally. Consequently, analyzers could be considered less flexible than digital computers.[98]

That the Committee on Computing Machines never took analog computing seriously does not appear to have been caused by great concerns over speed or flexibility. In fact, the report readily acknowledged that certain problems were better suited to one type of machine or the other. For instance, a differential analyzer was ideal under the specific computational circumstances that require solving the same differential equation again and again, such as ballistics trajectory tables. However, the demand for such a scenario was not obvious at the University of Toronto, and the committee was desperate to avoid the appearance of a computing centre with no meaningful work. On its first 1946 list of possible areas suitable for the centre, several might have been appropriate for analog solution, such as ballistics and aeronautics, but no actual problems appeared. All of the first four problems – navigation tables, statistical analysis, quantum mechanics, and solving linear equations – that were tackled by the centre were best solved by digital means. Even the NRC report that followed the tour earlier that year admitted that an analog computer would be inefficiently employed at Toronto.[99] There was just one known request in the first few years that specifically

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[97] Preliminary Report on Modern Computing Machines, 1946, UTARMS B1988–0069, Box 1, Folder 2.

[98] The most famous electronic digital computer of the time, the ENIAC, was originally known as the 'Electronic Difference Analyzer' and intended to solve differential equations for ballistic tables, until general-purpose calculation features were added and it was changed to Electronic and Numerical Integrator and Computer. Randell, *The Origins of Digital Computers*, 298.

[99] J.W. Hopkins, Memorandum to File, Report on Visits in Boston and New York Area in Collaboration with University of Toronto Committee on Computing Machines, 5 July 1946, LAC RG77, Volume 134, File 17–15–1–20. At this point, it has not been confirmed if an analyzer or analog computer found significant use for Canadian scientific research before, during or after World War II. Ballistics research at the NRC was not nearly as intensive as at the Aberdeen Proving Grounds, one of the heaviest users

asked for an analog solution. In 1949, an enquiry from the DRB's CARDE arrived asking for help with some "nasty differential equations," that the letter-writer knew could "be solved by some of the analogue type computing machines," but perhaps not easily with a digital machine.[100] Griffith reassured his correspondent that the IBM 602 was up to the task.[101]

The only significant disadvantage cited in any of the committee reports was accuracy: digital computers could represent numbers with unlimited accuracy, but analyzers were restricted to the physical mechanisms in use. This claim is only partially correct. In principle, as the report noted, "the desired accuracy can be obtained by adjoining sufficient elements." A digital computer stores each digit of a number separately up to maximum length, known as the word length, which determines the largest number the computer can manipulate arithmetically. This acts as a limit to the accuracy of the machine. A ten digit decimal machine cannot represent a integer larger than 9,999,999,999, or 1 in 1,000,000,000. A computer with a longer word length will be more accurate, but a specific computer's word length cannot be changed as it is a fundamental aspect of the hardware design. With clever programming, it is possible to simulate a longer word, but this comes at the cost of much slower computations and increased program complexity. For these reasons, multiple word arithmetic, as it was known, should be avoided. It was possible to improve the accuracy of a differential analyzer, but Bush's Rockefeller Differential Analyzer (RDA) was widely considered the most advanced analyzer possible, with an accuracy of 1 in 10,000; the highly precise parts precision to make significant improvements were considered prohibitively expensive to obtain.[102]

However, digital computers suffered a additional flaw worth noting: many num-

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of the RDA. It is not known if an analyzer was ever used seriously at the Atomic Energy Program, the Dominion Observatory, or the aeronautical engineering department at the University of Toronto.

[100] N. Mendelsohn to B.A. Griffith, 17 August 1949, UTARMS B1988–0069, Box 1, Folder 2.

[101] B.A. Griffith to N. Mendelsohn, 22 August 1949, UTARMS B1988–0069, Box 1, Folder 2.

[102] See page 18.

bers cannot be represented accurately with a digital computer or in binary. Consider the fraction $\frac{2}{3}$ or the irrational constant π. In decimal form, they can be written as 0.6666...or 3.1415..., and the dots indicate that the 6s will repeat indefinitely or that the remaining digits of π are infinite. Because these can represented by physical properties, an analog computer can easily handle both of these numbers to within the tolerances of the mechanisms in use. A human can also correctly interpret the dots, but a digital computer cannot store or compute infinitely long numbers. Instead it is restricted to its word length, unless as mentioned above, the user chooses to extend it programmatically. In that case, a number arbitrarily long can be represented with multiple words, with the noted drawbacks. Eventually, the result of a mathematical operation will exceed the chosen length, and the least significant digits must be truncated and the result rounded. The product of multiplication is typically longer than the multiplier and multiplicand, for example, and could overflow the word length. This may seem like an untroublesome issue, but a side-effect can occur during long, repeated operations – the kind that modern high-speed computers excelled at. Frequent overflows and rounding can generate errors that might seem insignificant but taken as a whole can render a wildly incorrect result that is easy to spot, or subtle ones that are not. The recognition and study of these classes of problems helped rejuvenate the field of numerical analysis in the 1950s.[103] Ultimately, the Committee's accuracy criticism remains valid: while analog computers would always be held to the accuracy of the physical components, various clever means could be employed to improve digital accuracy to any desired limit.[104]

Despite the overall lack of interest, a differential analyzer was built in Toronto, though all evidence suggests it was never used.[105] The project was led by Beatrice

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[103] Stephen Nash ed., *A History of Scientific Computing* (New York: ACM Press, 1990).

[104] It is striking that the electronic computer that was built in Toronto between 1948 to 1952 had a word length of 12 bits – not inherently more accurate than Bush's RDA.

[105] A photograph of what is most likely this analyzer can be seen in "Machines Short-Circuit Complex Calculations", *Globe and Mail* (December 15 1951), 4.

Worsley, perhaps the most knowledgeable member of the Computation Centre regarding the principles and design of analyzers, having completed a relevant master's thesis at MIT the previous year. The appendix of her thesis described the theoretical and practical aspects related to the reduction of errors when using differential analyzers. Working with assistance from several machinists in the Department of Physics, she built her analyzer over six weeks during the summer of 1948.[106]

That is was completed in such a short time offers a clue as to the size and complexity of the computer. Worsley based her analyzer closely on a 1933 model built by D. Hartree and A. Porter at Manchester.[107] Like Hartree's, hers was built mostly from Meccano, the children's construction toy set. Not including wood, labour, and the electric motor, she needed only seventy-five dollars' worth of parts, making it substantially less expensive than the initial ten to fifteen thousand dollars Griffith had budgeted for a small differential analyzer. Worsley's three integrator design differed slightly from Hartree's with smaller torque amplifiers, and slight improvements to the electrical power distribution system, and better output pen support.[108]

As to why she built the analyzer, the historical record is silent. Although a toy's parts were its primary construction material, Hartree had shown in 1933 that the Meccano models were capable of performing useful work, in particular, solving Hartree's self consistent field equations for the hydrogen atom.[109] Until the fall of 1948 the Committee on Computing Machines was ignorant of most computing work done in England, but the Meccano analyzers were an exception. In the early 1940s, Griffith is known to have included a lecture on them in his senior undergraduate applied math-

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[106] Gellman may have helped a bit too. Harvey S. Gellman, interview by Michael R. Williams, 9 June 1992, Transcript provided by Michael R. Williams.

[107] Douglas R. Hartree and Arthur Porter, "The Construction and operation of a Model Differential Analyzer", *Manchester Literary & Philosophical Society Memoirs and Proceedings* 79 (1935), 51–73.

[108] Beatrice H. Worsley, Construction of a Model Differential Analyzer, 10 September 1948, Queen's University Archives, Accession 1053, Box 3, Folder 10.

[109] Arthur Porter, "Building the Manchester differential analyzers: A personal reflection", *IEEE Annals of the History of Computing* 25, no. 2 (April–June 2003), 88.

ematics courses.[110] Hartree had also given a talk on differential analyzers at the 1945 Canadian Mathematical Congress, attended by V.G. Smith.[111] Unfortunately, it appears that Worsley's model was just that, a model. With only three integrators it was not particularly useful to the Computation Centre.[112] But more telling is that in August 1949 Griffith had no idea if it was even working, one year after Worsley finished the project and left to start her Ph.D. studies in Cambridge.[113] Left dormant for a few years, work was restarted by another student in the early 1950s, possibly as another student research project. Again, it appears to have been used for demonstrations and little else.[114] At an unwieldy size of three by three metres, infrequent use doomed it to the scrapheap.[115]

To best solve this mysterious situation, instead of considering how analog computers were used, consider where they were used. Case studies of computing in the United States and the United Kingdom before and during the Second World War show that analyzers only fit well within a strong hands-on engineering culture.[116] The optimal arrangement for problem solving with analog computers demanded a close relationship between the engineer, the particular problem and the analyzer.[117] More important, the mindset that went along with analog computing machines was much

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[110] Calvin C. Gotlieb, interview by Michael R. Williams, 29 April 1992, Transcript provided by Michael R. Williams.

[111] Hartree, "The Use of the Differential Analyzer to the Evaluation of Solutions of Partial Differential Equations", 327–337.

[112] There is evidence that sometime in the early 1950s some trial backwater calculations were carried out with an analog computer by Computation Centre staff, but there's no confirmation that it was Worsley's analyzer. Calvin C. Gotlieb, "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", *The Engineering Journal* (February 1960), 63. The analog computer might have been owned by Ontario Hydro. See section 3.3.2 for more information on the backwater calculations.

[113] B.A. Griffith to N. Mendelsohn, 22 August 1949, UTARMS B1988–0069, Box 1, Folder 2. Gotlieb indicates that she simply never told anyone about it until shortly before she left for Cambridge in September 1948. Calvin C. Gotlieb, conversation with author, Toronto, 24 November 2005.

[114] Keith W. Smillie, "People, Languagaes, and Computers: A Memoir", *IEEE Annals of the History of Computing* 26, no. 02 (2004), 64.

[115] Finding space on campus for the expanding centre was a constant problem, and nine square meters of wasted floor space would not have lasted long.

[116] Bowles, "U.S. Technological Enthusiasm and British Technological Skepticism in the Age of the Analog Brain", 5–15.

[117] J.M. Ham to V.G. Smith, 10 June 1951, UTARMS B1999–0025, Box 1, Folder H.

closer to "the wave motions of 19th-century physics and the cycles of radio, telephony, and electrical power transmission."[118] Digital approaches were only appropriate to the new generation of theoretically minded engineers and physicists, accustomed to pulses, intervals, and counters. They could more readily perceive the flexibility of 'dumb' switches built from electromagnetic relays and vacuum tubes than the former group, who preferred analog thinking and computing. The two generations co-existed in the period around the war, but did not co-mingle in general, and the latter eventually replaced the former.

The University of Toronto Committee on Computing Machines cannot be characterized as having a strong hands-on engineering mindset. In 1946, the group was top-heavy with applied mathematicians, with just one electrical engineer, V.G. Smith. At the time, the University of Toronto Faculty of Applied Science and Engineering did not have a strong tradition of research or even change. Indeed, its focus up until then had been teaching; at the mid-century mark the curriculum had not changed much in the past 50 years.[119] It might have been useful to them to bring in a differential analyzer, given the potential of an analyzer as a learning environment for differential equations. At the 1945 Canadian Mathematical Congress, at least four talks on engineering mathematics discussed the seemingly perennial problem of too many engineering undergraduates lacking a deep or intuitive understanding of applied mathematics.[120] In general the Faculty probably had little time for the computing centre project, overwhelmed at it was by returning veterans in the immediate post-war years.[121]

There was not much room for research into analog computing techniques. Bush's RDA was at the pinnacle in terms of accuracy and precision for mechanical analyzers.

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[118] Owens, "Where Are We Going, Phil Morse? Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957", 37.

[119] White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000*, 171.

[120] "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945", 45–63.

[121] White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000*, 158–165.

There was some research and development of electronic analyzers following the war, but unsurprisingly most of it took place at centres like MIT, where a strong analog culture already existed.[122] A relatively poorly funded Canadian university professor or graduate student could not really hope to make substantial improvements to the technology outside of such centres. Only one serious attempt was made in Toronto in the early 1950s, and notably took place outside of the Computation Centre. Between 1950 and 1953 J.F. Perrier, a doctoral student of V.G. Smith, designed and built an electronic analogue computer to solve tenth degree polynomials.[123] In general, polynomials greater than degree four can be solved analytically only rarely and instead laborious iterative techniques are required. By use of a method developed by Kempner, polynomials could be transformed to a parametric form and solved mechanically or electrically. Perrier's computer at Toronto built on this earlier work, and provided a few improvements in its technical implementation.[124] At the time of his oral defence, the computer was only partially complete and though there were plans for a technician to finish the model, it could not yet solve polynomials of tenth degree. It may have been used for lesser scientific computations, but there was no connection to the Computation Centre.

Digital computing was an area ripe with potential. For many of those building computers at the time, it was clear that digital was where all the future action would be. When the IBM 602 had finally arrived at Toronto, it made any pressing need for

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[122] At least two University of Toronto graduates conducted post-graduate research at MIT on analog computing. J.M. Ham, later president of the University of Toronto, wrote a master's thesis on a general integrator for electronic analog computation. J.M. Ham to V.G. Smith, 20 September 1947, UTARMS B1999–0025, Box 1, Folder H. As mentioned above, B.H. Worsley's 1947 master's thesis included an appendix on error analysis of differential analyzers. Beatrice H. Worsley, "A Mathematical Survey of Computing Devices With an Appendix on Error Analysis of Differential Analyzers", Master's thesis, MIT (1947).

[123] J.F. Perrier, "An Electronic Analogue Computer for the Solution of Tenth-Degree Polynomials", Ph.D. thesis, Electrical Engineering, University of Toronto (1953). A second student, J.H. Aitcheson, worked with Perrier on the project, and his research was published in a thesis submitted for his Master's of Science in 1951.

[124] In the introduction to his dissertation, Perrier describes several other mechanical and electrical computers built according to Kempner method. A.J. Kempner, "On the separation and computation of complex roots of algebraic equations", *University of Colorado Studies* 16 (1928), 75–87.

the large-scale relay computer or an analog computer unnecessary for the immediate future. The 602 was not a perfect substitute for an analog computer, as programming it to handle differential equations was difficult, especially for a crew as inexperienced as the Computation Centre. Yet Gotlieb was anxious to attempt such equations, noting that "practice elsewhere has indicated that the range of problems increases considerably as experience is acquired."[125] Although he was still considering purchasing an electronic differential analyzer for the Computation Centre for about $10,000 in mid 1949, the plans were vague. It is clear that he much preferred the idea of the Centre building upon its knowledge of numerical solution by digital techniques rather than analog. Though V.G. Smith was still interested in analog computing, as Perrier's doctoral supervisor, his influence in the mathematical operations of the Computation Centre was minimal.

By the end of the 1940s, these various factors conspired against any serious interest in analog computing devices in Toronto. As the control of the committee was gradually shifting away from the mathematicians towards the physicists and engineers, it remained focused on digital computing. With EDVAC-type computers offering true general-purpose computing and virtually unlimited accuracy just over the horizon, and few – though not zero – incoming problems that were ideal for analog solution, an analyzer was not a priority. In a 1951 review of computing machines in *Physics in Canada*, Gotlieb summarily dismissed analog technology as less flexible and less accurate. He admitted that there were some useful special cases of analog computers, such as power system network analyzers and wind tunnels, that by their very nature were unlikely to disappear. He even went so far as to claim that analog computing devices would never fade away entirely, as "there are may problems not worth programming on an expensive digital computer."[126] He was wrong. In the early 1970s one of the last bastions of analog computing, the humble slide rule, was replaced by

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[125] C.C. Gotlieb to N. Mendelsohn, 17 May 1949, UTARMS B1988–0069, Box 1, Folder 2.

[126] Calvin C. Gotlieb, "Machines for Thought", *Physics in Canada* (1951), 4.

the electronic calculator, an event made possible by the advent of cheap computing power, the microprocessor.[127]

2.3 The Electronic Side of the Computation Centre

The task of designing and building an electronic digital computer was handed over to the electronic side of the Computation Centre. Much like the mathematical side, virtually all of the work was handled by graduate students and technicians, not faculty members. By almost any standard they were an inexperienced group and via some inverse law of ambition they attempted one of the most complex electronic digital designs of the late 1940s. Their overconfidence probably doomed things, and their computer never made it beyond the prototype stage. For many reasons, the project was cancelled in 1952 before a full-scale version could be built. However, the story is not as simple or straightforward as it might appear. It is necessary to start with an narrow, internal history of the computer itself, from the first plans to the final machine, but to follow up with a broader perspective, analyzing why it was eventually cancelled and gauging the overall impact it had on computing in Toronto.

2.3.1 Planning, Design, and Construction of UTEC

There are two major historical accounts of the University of Toronto Electronic Computer, or UTEC.[128] The first is Michael Williams's short, internalist 1994 article in the *IEEE Annals of the History of Computing*.[129] In it, he lays out the UTEC specifications, the choice of storage technology, and some of the resource constraints that limited their

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[127] Not coincidentally, electrical engineering departments had definitively begun to shift away from analog towards digital by this time. Ceruzzi, "Electronics Technology and Computer Science, 1940-1975: A Coevolution", 257–275.

[128] Confusingly, other names and acronyms were used at various times, though there is no doubt that all referred to the same machine. The name UTECS is found in many early design notes – the meaning of the posterior 'S' is unknown – and some later documents expand UTEC into the University of Toronto *Experimental* Computer or Electronic *Calculator*.

[129] Williams, "UTEC and Ferut: The University of Toronto's Computation Centre", 4–12.

options. His paper is based on an initial survey of the University of Toronto archives and a series of interviews that he conducted with several of the key participants. Perhaps restrained by the limits of an article, he does not delve too deeply into the design decisions or the context surrounding the eventual cancellation. The second major account can be found in John Vardalas's 2001 book, *The Computer Revolution in Canada*, in the first chapter "Canadian Military Enterprise and the University."[130] Vardalas uses a considerably greater number of sources and a broader context in covering much of the same story, but from a perspective beyond the gates of the university. The book as a whole is an exploration of the relationship between computer technology and a post-WWII military and government agenda of national self-reliance. That story begins at the University of Toronto, where "the quest for military self-reliance required a domestic capacity for large-scale, automated, high-speed computations . . . resulted in the military's support of a university effort to design and build Canada's first electronic digital computer."[131] The military did support UTEC financially through the Defence Research Board, but it had almost no influence in any of the planning, design, or construction. Vardalas's version of the story lacks a coherent description of the computer itself and a thorough examination of all relevant parties' participation. It also ends abruptly in 1952 when the DRB withdrew their financial and strategic support. As this marks the effective end of hardware research at the University of Toronto, Vardalas's interest in academic computing ends there.

Unfortunately, no known UTEC hardware remains, though partial blueprints and plans exist in various documents. Two dissertations were written at the University of Toronto by members of the UTEC team, that will be discussed below, and the University of Toronto Archives contains several of Gotlieb's files pertaining to UTEC. There are also three contemporary descriptions of UTEC that were published beyond the University of Toronto. The first can be found in Beatrice Worsley's 1952 dissertation,

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[130] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 15–43.
[131] Ibid., 12.

"Serial Programming for Real and Idealized Digital Calculating Machines", written to fulfil the requirements of her Ph.D. from Cambridge University. As mentioned above, in 1948 she left Toronto for Cambridge, to pursue her doctoral degree and learn what she could of modern computing from EDSAC. The 'real' machines referred to in the dissertation title are EDSAC, the Manchester Mark I (a subject of chapter 3 of this present dissertation), and UTEC. With experience using all three, she was able to compare and contrast the various features and idiosyncrasies with program code examples.[132] The second description of UTEC can be found in the conference proceedings of the Association for Computing Machinery meeting held in Toronto, September 1952. R.F. Johnston, one of the members of the UTEC team, gave a talk at the conference describing the specifications of UTEC, which was also demonstrated to attendees, though the project had been cancelled six months earlier.[133] Finally, in a 1958 book co-authored by Gotlieb UTEC was depicted as a simple but genuine computer suitable for introductory study. Though no longer completely contemporary, this is perhaps the last objective view of UTEC not significantly tinted by retrospective pride or revision.[134]

UTEC was to be a modern computer, but also the gateway in Toronto from premodern to modern computing. Though there is no single or official definition of modern computer, and plenty of debate surrounding which is the 'first' such computer, historians of computing generally recognize that von Neumman-Turing type stored program electronic devices represent modern computers, while all other machines, digital or analog, represent the older class. This includes the IBM 602 calculator and the Bell Labs relay calculators which were useful, influential, and digital, but they represented technological lines that did not continue.[135] UTEC falls into the mod-

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[132] These are the only known UTEC programs to have survived. See Appendix A

[133] Robert F. Johnston, "The University of Toronto Electronic Computer", in *ACM '52: Proceedings of the 1952 ACM nation meeting (Toronto)* (ACM Press, 1952), 154–160.

[134] Calvin C. Gotlieb and J.N.P Hume, *High-Speed Data Processing* (New York: McGraw-Hill Book Company, Inc., 1958), 67–72.

[135] Michael R. Williams, "A Preview of Things to Come: Some Remarks on the First Generation of

ern class, an electronic, digital, stored-program machine, with each of the five logical components laid out in the 1945 EDVAC report: storage, control, arithmetic, input, and output. Remarkably, when the DRB and NRC boosted their funding in the spring of 1948 to finance a modern computer in Toronto, not one such computer had been finished – all were still half-built prototypes or still in the planning stages.

V.G. Smith, of the Department of Electrical Engineering, was the first person in Toronto to consider the problem of constructing an electronic machine.[136] Smith maintained relatively close ties with the applied mathematicians and physicists on campus and during World War II was involved in computational work related to war research, possibly related to the theoretical aspects of radar. His first foray into building a computer came in early 1947, before the NRC or DRB agreed to provide financial assistance. Smith began a very small research program, within reach of his own meagre means, on 'rapid electronic conversion' of numbers from decimal to binary and and vice versa.[137] The inspiration may have been the Harvard Symposium on Large Scale Digital Calculating Machinery in January 1947 that he had recently attended. There was a panel of talks on input and output devices that likely discussed this problem; although ENIAC was a decimal machine, newer machine designs were drifting towards binary arithmetic and storage, which would make conversion necessary.[138] What progress he made is unclear beyond one line found in the 1948 University of Toronto *President's Report*: "An intensive study of some fundamental problems in electronic digital computers is being carried out."[139] From inception to final prototype UTEC used binary internally and a modified binary on the input and output so its possible this specific project was dropped before it even began.

Computers", in Rojas and Hashagen, *The First Computers: History and Architectures*, 1–13.

[136] Smith was born 17 July 1901 in England and immigrated with his family to Toronto, Canada in 1912. After serving in the Canadian Army in France during World War I, he took up engineering at the University of Toronto, where he was eventually hired as an assistant professor. V.G. Smith to Gerhard P. Van Arkal, 26 November 1956, UTARMS B1999–0025, Box 1, Folder H.

[137] V.G. Smith to M. Rubinoff, 26 February 1947, UTARMS B1999–0025, Box 4, Folder R.

[138] Curtiss, "A Symposium of Large Scale Digital Calculating Machinery", 229–238.

[139] University of Toronto, *President's Report* (University of Toronto, 1948), 120.

In the fall of 1947, around the same time that the NRC first agreed to a $6,500 grant, Smith received a $2,000 grant from the Advisory Committee on Scientific Research of the University of Toronto Board of Governors to cover research into "Basic Problems in Electronic Computers."[140] Nothing happened until 1 May 1948 when Smith hired two summer students, A.G. Ratz and E. Doeringer. The former was to be a key member of the UTEC team. Alfred George Ratz, born in Hamilton, Ontario in 1922, graduated with honours from Engineering Physics at the University of Toronto in 1944, and served in the Navy briefly before completing his Masters in 1947 in Engineering Physics. He was hired in 1946 as a special lecturer at the Ajax division of the Faculty of Applied Sciences.[141] Doeringer was another engineering graduate student, but did not last long on the project. On May 15 they were joined by J. Kates, the other key member of the UTEC team, another University of Toronto student. It is probable that Smith did not hire Kates, but that Bullard or Griffith hired him via the recent joint NRC-DRB grant to work on the electronic computer. Born in 1921 in Vienna, Austria, Kates left Austria in 1938 to avoid Nazi rule, ending up in a refugee internment camp in Canada from 1940 to 1942.[142] After two years of working on war optics for Imperial Optical, he entered the University of Toronto in the Mathematics and Physics program. At the same time, he held a job at Rogers Majestic (now Philips) in radio tube manufacturing, and in 1946 wrote and passed the professional engineering examinations.[143]

Smith, Ratz, Doeringer and Kates spent the summer of 1948 surveying all available literature on the general problem of designing and constructing a electronic computer.[144] For three students and one professor to contemplate constructing their own

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[140] This was the same source of funds that had previously covered the tour of computer centres in the United States.

[141] V.G. Smith to G.A. Sutherland, 13 April 1946, UTARMS B1999–0025, Box 4, Folder R, and G.F. Tracy to H.J. MacLeod, 14 June 1950, UTARMS B1999–0025, Box 4, Folder R.

[142] Josef Kates was born Josef Katz, but sometime around 1950 changed his name, in part to avoid the "Katz and Ratz" jokes from colleagues in the Computation Centre.

[143] Josef Kates, interview by Michael R. Williams, 9 June 1992, Transcript provided by Michael R. Williams.

[144] Report on Scientific Research for 1947–1948, UTARMS A1968–0007, Box 37, Folder 7.

electronic computer from scratch was exceedingly ambitious, but the group was not working entirely in the dark. Smith, of course, was a member of the Committee on Computing Machines that had toured the North East United States in 1946 to visit and study the many computer centres operating or under construction. This would have provided some exposure to the technology that could not be gained from the pages *Mathematical Tables and Other Aids to Computation* (MTAC) or other journals and articles.[145] Though he had missed the Moore School lectures dedicated to EDVAC-style machines, a copy of the widely distributed proceedings arrived in Toronto as Smith and his summer students began their study. These lectures guided the design and construction of many computers around the world, including EDSAC in Cambridge.

Smith was also in close contact with a handful of former students who were involved with other computing projects. One, Werner Buchholz, finished writing his thesis for Smith in 1947 while at the California Institute of Technology. He kept Smith up to date about the analog computer and electronic multiplier that was under construction in the electronics laboratory there.[146] Buchholz also wrote to Smith to ask for a summer job in 1948, but his request arrived just days after Smith had hired Ratz and Doeringer. Smith wanted to hire Buchholz but lacked the funds and the authority for an additional temporary appointment.[147] Buchholz was one of a handful of Toronto alumni with modern computing experience who were denied an opportunity to return and help with UTEC.

The most significant of these was another of Smith's correspondents, the peri-

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[145] MTAC was the most relevant periodical with up-to-date information on modern computers and computing methods.

[146] W. Buchholz to V.G. Smith, 27 March 1947, UTARMS B1999–0025, Box 1, Folder B.

[147] V.G. Smith to W. Buchholz, 5 May 1948, UTARMS B1999–0025, Box 1, Folder B. This decision had far-reaching consequences, as Buchholz would join IBM the next year, where he was a member of various hardware design teams including the IBM 702, 705, and the famous 7030 "Stretch" data processing computer in the 1950s (see page 255). It was early during the Stretch project when he coined the term *byte* to denote "a group of bits used to encode a character, or the number of bits transmitted in parallel to and from input-output units," and remains fixed at eight bits to this day. Werner Buchholz, "Anecdotes: Origin of the Word Byte", *Annals of the History of Computing* 3, no. 1 (January–March 1981), 72–72.

patetic Morris Rubinoff. Rubinoff, a Toronto engineering graduate, had worked with Gotlieb during and shortly after the war on proximity fuse problems and wrote his doctoral dissertation on the subject.[148] In 1946 when he became interested in large-scale computing he turned to Smith, an adviser to the proximity fuse research group, for reference letters that he might be admitted to a computing centre in the United States. In the fall of 1946 Rubinoff left Toronto for the Computation Laboratory at Harvard University. The two corresponded occasionally to discuss the components and specifications of the Harvard computers in use and under construction.[149] When the Harvard Symposium was held the following January, it was Rubinoff who extended the invitation to Toronto, adding that many at Harvard felt that "one of the most impressive groups to visit the lab was the one from Toronto."[150] In March 1948, he left Harvard to join the Princeton University Institute for Advanced Study Computer Lab, under von Neumann's direction. Although Rubinoff had hoped to return to Toronto, he was disappointed with what he perceived as the slow progress there; nevertheless continued to correspond with Smith, sharing his knowledge of the IAS computer.[151] As mentioned above, when Bullard was casting about for a director of the Computation Centre, Rubinoff's name came up as a contender but von Neumann's tepid recommendation knocked him from the race. In 1951, Rubinoff was hired as an Assistant Professor of Electrical Engineering at the University of Pennsylvania where he settled for the remainder of his long career in computer engineering.[152]

In the second half of the 1940s other students of Smith did computer related graduate work at MIT. Most notable was James M. Ham, who finished an undergraduate degree in Engineering Science at Toronto in 1946 and was teaching electronic engineering courses at MIT in 1947 as he studied analog computation and completed a

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[148] Rubinoff, "A new method of measuring the angular motion of a spinning projectile in flight".

[149] M. Rubinoff to V.G. Smith, 3 October 1946, UTARMS B1999–0025, Box 4, Folder R.

[150] M. Rubinoff to V.G. Smith, 12 October 1946, UTARMS B1999–0025, Box 4, Folder R.

[151] M. Rubinoff to V.G. Smith, 22 March 1948, UTARMS B1999–0025, Box 4, Folder R.

[152] "Deaths: Dr. Rubinoff, CIS Pioneer", *University of Pennsylvania Almanac* 50, no. 17 (13 January 2004), 3.

Ph.D.[153] Ham and Smith corresponded for several years, sharing descriptions of the Whirlwind project and the latest computing news from Toronto. They also discussed the field of analog computing, as the interest in Toronto for such techniques waxed and waned. Despite the lack of development following Worsley's Meccano differential analyzer, in 1951 Smith asked Ham for advice on purchasing a commercial differential analyzer.[154] What Smith did with the advice is unknown, though one of his doctoral students attempted to build an electronic analyzer around this time. Despite these many connections to high-profile computer groups, Smith's available letters show no significant flow of knowledge into Toronto.

The 1945 EDVAC report had made it clear that the crucial problem in electronic computing was the design and use of suitable storage elements. It was in this general direction that Smith and his three assistants turned their attention in the summer of 1948. Two ideas were explored. The first area of enquiry was neon gas discharge tubes, proposed by Smith. From May until November of 1948 they investigated the technology as a storage scheme, but it was eventually rejected, for unknown reasons.[155] Ratz also "worked out on paper a complete computing centre and tested some of the components. He is now trying to simplify the scheme and at the same time make it faster in operation."[156] Exactly what is meant by 'computing centre' is unclear, but given what is known of Ratz's later work, it could have been a control or arithmetic unit.

In October 1948, Kates compiled all of their knowledge of the computer projects underway worldwide into a large table, outlining the type (parallel or serial), the primary storage technology (electrostatic Williams tubes, magnetic drums, delay lines,

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[153] J.M. Ham, "The solution of a class of linear operational equations by methods of successive approximations", Ph.D. thesis, Electrical Engineering, MIT (1952).

[154] J.M. Ham to V.G. Smith, 10 June 1951, UTARMS B1999–0025, Box 1, Folder H. In 1952, Ham returned to Toronto to join the Department of Electrical Engineering, where he rose to dean of Engineering in 1966 and president of the University of Toronto in 1978. White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000*, 204,239.

[155] A binary adder may have been constructed at this time using the tubes. Calvin C. Gotlieb, conversation with author, Toronto, 24 November 2005.

[156] Report on Scientific Research for 1947–1948, UTARMS A1968–0007, Box 37, Folder 7.

or flip-flops), current status, the number of staff involved, the names of the principal engineers, and a brief comment explaining various design choices. Von Neumann's IAS computer at Princeton occupies the top row, and was clearly the most impressive to him: "the logic of this machine is well worked out, and the machine promises to be the fastest and simplest of the machines to be developed in the near future." Lower rows included the Harvard Mark III and V and a disparaging remark about Aiken's "conservatism" and the inherent speed limitations of these designs.[157] ENIAC made his list, but Kates emphasized the known limitations of lengthy setup times and a too-small storage, and noted that one successor, the EDVAC, solved both problems. Eckert and Mauchly's Computing Corporation UNIVAC and BINAC projects are mentioned but without much comment. Two other commercial computers are also listed: the REEVAC from the Reeves Instrument Company and an unnamed Raytheon project (presumably the RAYDAC), but little seems to have been known about them. Kates admits to inadequate knowledge of much of the plans for the National Bureau of Standards computer or MIT's Whirlwind. The remaining entries on the list were the major electronic computer projects from England: EDSAC, ACE, and the preliminary work at Manchester leading to the Mark I. D.R. Hartree supplied much of the data for the table – particularly that pertaining to projects in the United Kingdom – when he visited Toronto that month to give three lectures on digital calculating machines.[158] On the whole, the group in Toronto had very little practical information on how to build a computer, and equally little experience or direct exposure to other projects.

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[157] List of Major Electronic Computing Projects, 13 October 1948, UTARMS B1988–0069, Box 1, Folder 1.

[158] University of Toronto, *President's Report* (University of Toronto, 1949). Hartree was a famous British applied mathematician who was an important conduit across the Atlantic of analog computing before WWII, and digital computing after. In 1932 he studied Bush's differential analyzer and returned to construct his own at Manchester University. After the war, he wrote several articles and a book that described computers such as ENIAC and the Harvard Mark I and anticipated the next generation of modern machines. Douglas R. Hartree, "The ENIAC, an Electronic Calculating Engine", *Nature* 158 (1946), 500–506; Douglas R. Hartree, "A Historical Survey of Digital Computing Machines", *Proceedings of the Royal Society of London A* 195 (1948), 265–271; and Douglas R. Hartree, *Calculating Instruments and Machines* (University of Illinois Press, 1949).

Nonetheless, Kates had settled on von Neumann's IAS computer as a model for the basic design, noting "our thinking about this project most closely agrees with that of the Princeton Project which envisages a parallel type of binary machine."[159] Most of the machines on the table were a serial type, but in contrast a parallel design was thought to offer higher computational speeds at the cost of more complicated design and construction. The distinction between serial and data is in the data transmission throughout the machine and its components. A digital computer's fundamental unit of storage is a word; a computer designed to handle n digits is said to have a word length of n. A binary serial machine transmits words as a series of pulses and non-pulses; assuming a 5 bit word length, the binary number 10011 (or 19 in decimal), would be transmitted serially as pulse, no pulse, no pulse, pulse, pulse (figure 2.1). Generalizing, a serial computer with an n bit word requires n clock cycles to transmit one word, but a parallel architecture uses n parallel pathways to transmit n bits in a single clock cycle (figure 2.2). Unfortunately, this requires precise electronic circuits, much more so than required for a serial design. The arithmetical circuitry has to be replicated n times and must work synchronously at each clock cycle. In the late 1940s many predicted that such an approach would be too complex, cumbersome, and unreliable. As Julian Bigelow, part of IAS team, describes their attempts at a 40 bit machine: "It was abundantly clear to us that the occurrence of a single undetected chance error anywhere in such 40-fold circuitry would produce numerical hash at unprecedented rates."[160] The expected payoff from the complex circuitry was vast speed improvements over serial machines, as a parallel circuit accomplished much more per clock cycle.

The feared complication did not materialize. Ultimately, the IAS computer used

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[159] J. Kates, Computation Centre, memorandum, 13 October 1948, UTARMS B1988–0069, Box 1, Folder 1.

[160] Julian Bigelow, "Computer Development at the Institute for Advanced Study", in Jack Howlett, Nicholas C. Metropolis and Gian-Carlo Rota eds., *A History of Computing in the Twentieth Century: A Collection of Essays* (New York: Academic Press, 1980), 294.

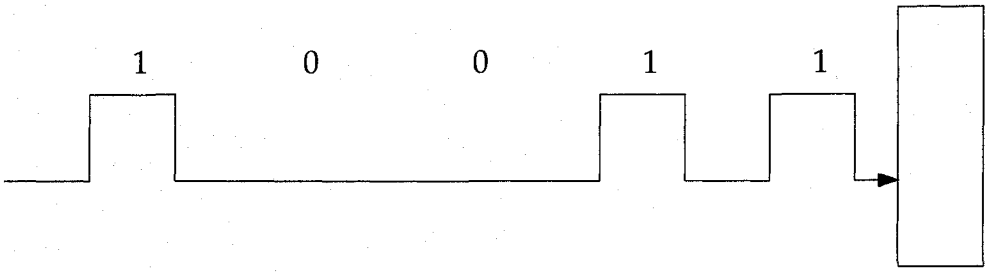

Figure 2.1: Serial transmission of the number 10011 (19 in decimal).

about 2600 electron tubes, surprisingly fewer than expected.[161] However, the difficulties encountered in perfecting the parallel technique explains why the IAS computer was one of the last of the machines on Kates' table to become operational. A serial design was easier to design and build – serial circuits were already common and well understood – which is why the serial Cambridge and the Manchester machines were working sooner, but also slower.

Just as important as the machine type was the storage type. All of the serial designs on Kates' table used delay line storage, an inherently serial technology that could not easily be used in a parallel design. To build a parallel machine, a faster storage mechanism was needed, with precise timing characteristics.[162] By late 1948, von Neumann had decided to use Williams tubes, which could be used in either a parallel or serial machine. In the former case, n bits could be stored across n tubes, one bit of a word per tube. The IAS computer was a 40 bit computer, so at least 40 tubes were needed. In the latter case, a serial computer could use Williams tubes by storing bits serially across the tube. The word length did not determine the number of tubes, the overall amount of storage did, which offered the computer designer some latitude regarding how many tubes were needed. The serial Manchester computers used this sort of storage scheme, and as things progressed from the Baby to the final Ferranti-manufactured Mark I, the number of tubes (and the amount of storage) in-

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[161] Bigelow, "Computer Development at the Institute for Advanced Study", 307.

[162] Williams, "A Preview of Things to Come: Some Remarks on the First Generation of Computers", 6-8.

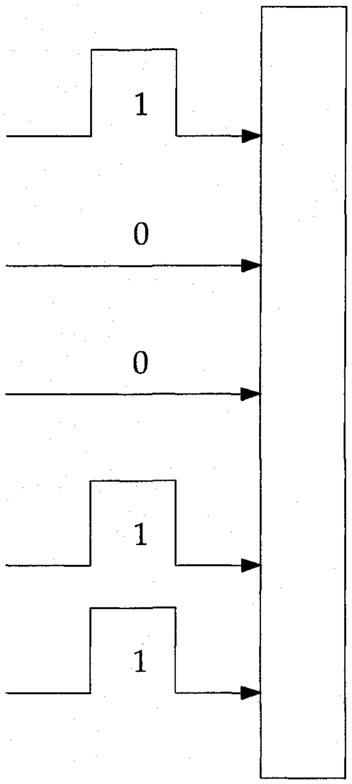

Figure 2.2: Parallel transmission of the number 10011 (19 in decimal).

creased gradually. If Toronto was going to build a parallel computer, there were no other options than Williams tubes, so Kates wrote to F.C. Williams to request any advance papers or other information that he could share.[163] Kates might not have fully appreciated how long it would take to build a parallel computer with Williams tubes, but almost certainly knew it would be more complicated than necessary with a serial design.

By October 1948, Smith, Ratz, and Doeringer had returned to their teaching duties, leaving Kates to work alone on the project until the next spring. He spent the time equipping the laboratory with tools, testing equipment and stock, continuing the research on storage technologies – having dropped the gas discharge technique – and writing to other computing centres for further information. This included a November letter to the Eckert-Mauchly Computing Corporation, home of the UNIVAC and BINAC computers. Interestingly, Kates wrote that if a similar commercial machine appeared on the market at a reasonable price, Toronto "may have a considerable interest in acquiring such a model."[164] It is possible that Kates was simply being courteous, but more likely that he was being honest: without any momentum yet for the electronics side of the Computation Centre, it is doubtful that even the DRB would have minded if they jumped ahead and bought an electronic computer if the price was right. In his October table, Kates suggested that UNIVAC and BINAC were "expected to sell for less than $150,000 and to be delivered within 9 months of order," though the source of this information is unknown. Also, recall that in late 1948 plans were still in place to build the relay computer, though things were stalled as they waited for Northern Electric and Bell Labs to decide on the licensing fee. This would have been a perfect opportunity to drop the relay project altogether and transfer that unspent money into the purchase of an electronic computer, and even continue their electronics research.

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[163] J. Kates to F.C. Williams, 12 October 1948, UTARMS B1988–0069, Box 1, Folder 1.

[164] J. Kates to Eckert-Mauchly Computing Corporation, 2 November 1948, UTARMS B1988–0069, Box 1, Folder 1.

Having set themselves on a parallel machine with Williams tubes, plans were made in late 1948 to visit von Neumann and study the IAS machine, with its similar architecture. Von Neumann, for his part, was especially interested to learn that another group was contemplating a similar project, and warmly welcomed the Toronto group, anticipating that "our exchanges of opinion on this subject will be valuable to both groups."[165] Things were a little busy at the IAS when the Toronto group hoped to visit over Christmas, so it was not until March 1949 that Bullard, Smith, Ratz, and Kates made the trip. The purpose of their visit was to observe the half-built computer, acquire a few new ideas, and to orient themselves properly before tackling the design of UTEC, and after they returned, Bullard ordered several IAS reports describing the project.[166] In general, there was little discussion among the handful of groups building electronic computers. Once a new idea was put forth into the community, many could quickly grasp its implications and move forward with their own implementation.[167] Though several groups built copies of the IAS computer, Kates and Ratz never intended UTEC to be a clone of the IAS machine, but based on the same principles.

In April, Ratz rejoined Kates in the laboratory, and the intensive work began again as the two experimented with "particular circuit components and organs, such as counters, flip-flops, gates, arithmetic networks, special tubes, storage devices, conventional tubes, resistors, germanium diodes, sockets, etc."[168]Better armed with practical knowledge, that spring and summer they began to lay out more concrete plans for UTEC. The logical and block design was established by July, followed by circuit de-

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[165] J. von Neumann to C.C. Gotlieb, 1 December 1948, UTARMS B1988–0069, Box 1, Folder 2.

[166] E.C. Bullard to J. von Neumann, 29 March 1949, UTARMS B1988–0069, Box 1, Folder 2. Bullard wrote to von Neumann when they returned, thanking him for advice "of the sort of difficulties one has to meet and the kind of organization necessary to cope with them," but as demonstrated in later sections, these lessons did not penetrate far. Von Neumann may not have been the best person to proffer advice on this subject as the IAS computer project was not always well organized. See William Aspray, "The Institute for Advanced Study Computer: A Case Study in the Application of Concepts from the History of Technology", in Rojas and Hashagen, *The First Computers: History and Architectures*, 179–193.

[167] Bigelow, "Computer Development at the Institute for Advanced Study", 308–309.

[168] A.G. Ratz and J. Kates, Review and Estimates of the Electronic Computer Section of the University of Toronto, 23 January 1950, UTARMS B1988–0069, Box 1, Folder 1.

signs that were finished around October along with a rough layout and construction plans. Unfortunately, most of the details during this time of historical interest, such as any debate surrounding the design specifications or how it would best fit the needs of the Computation Centre, are lost. A series of UTEC reports were written to document their progress that may have contained this information, but they do not appear to have circulated outside of the University of Toronto and have not been located.

It is crucial to note that their plans called for a small prototype computer "to provide experience in the techniques involved, promote the investigation of component systems and circuitry and finally test circuitry to be used in a large machine," that when sufficiently reliable would be turned over to the mathematical side of the Computation Centre for the interim while a full-scale machine was built.[169]The prototype would be too small for any substantial computation, but it is hard to argue with this plan.[170] The electronics group needed experience in computer design and construction; what better way to obtain it than by attempting a small model first?

The design for the prototype, to be known officially as the UTEC Mark I, was a parallel, binary, one-address digital computer, with Williams tubes for the primary storage.[171] A binary computer performs all internal operations using binary numbers, in contrast to the many other decimal machines of the era, such as ENIAC, or the the Bell Labs relay computers' bi-quinary system that was partially decimal. A one-address computer uses instructions that consist of one operation and one address to specify the operand; one instruction generally occupies one word. Other configurations, such as three-addresses are possible, but to accommodate the extra addresses, a multiple-address design requires much larger words.[172] For a parallel computer with

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[169] A.G. Ratz and J. Kates, Review and Estimates of the Electronic Computer Section of the University of Toronto, 23 January 1950, UTARMS B1988–0069, Box 1, Folder 1.

[170] See page 127 for more on the usefulness of UTEC.

[171] The official name was used very rarely; virtually all instances refer to the prototype simply as UTEC.

[172] The relative advantages and disadvantages of single and multiple addresses is discussed on page 180.

Williams tubes, every extra bit of word length counted dearly: an n bit word required n Williams tubes, which were expensive and the technology relatively untested. The model computer had to strike a balance between usefulness and simplicity and so they settled on a 12 bit word. Three bits were used to indicate a maximum of eight instructions ($2^3 = 8$ instructions) and the remaining nine bits could be used to reference one address from a maximum store of 512 words ($2^9 = 512$ words).[173] Eight instructions was woefully close to the absolute minimum number that a useful modern computer needed. The first such stored-program computer, the Manchester Small Scale Experimental Machine (SSEM), or "The Baby", of June 1948 also had a three-bit instruction length, but was expanded within two months to four bits for a maximum of 16 instructions ($2^4 = 16$).[174] During the planning stages, in collaboration with a few undergraduate students hired for the summer, they had studied their options and decided that eight instructions was adequate.[175]

The project was split roughly into logical components, corresponding to the five laid out in the 1946 EDVAC report: storage, arithmetic, control, input, and output. Though Kates and Ratz led the overall project, the work was split roughly into teams, led by Kates and Ratz, each with their own technician assistants, L. Casciato and H.H. Stein. Kates worked on storage, for the most part, Ratz focused on the arithmetic unit, and they appear to have collaborated on the rest. They were joined by R.F. Johnston later in the project in May 1950, who would take over the input and output units.

Construction commenced sometimes towards the end of 1949, but in earnest the next year. By the end of March 1950, a number of components were in place.[176] An

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[173] They did not reach this maximum of 512 words until quite late in the project, after it was effectively cancelled. Most of the time it could only address 256 words.

[174] R.B.E. Napper, "The Manchester Mark 1 Computers", in Rojas and Hashagen, *The First Computers: History and Architectures*, 367.

[175] Two of the undergraduates were D.B. Gillies and J.P. Mayberry, whose valuable reports (UTECS No. 24 and 31) on the mathematical capacity of UTEC cannot be located.

[176] Computation Centre Progress Report to March 31, 1950, UTARMS B1988–0069, Box 1, Folder 2.

arithmetic unit was complete, with a binary adder and subtracter. Extensive testing showed that it could run without failure for several days. A second, faster adder circuit was bread-boarded and tested, and a few plans were made for a multiplier, but these were never added to the prototype.[177] The team tested several vacuum tubes for the storage and a few revisions of their original plans were necessary. Kates was also devising a new theory to better explain the storage properties of cathode-ray tubes.[178] While testing these two components, they ran into trouble with reliable and stable power supplies, and spent time designing and building more appropriate ones. Concrete plans for the input-output unit were made, using a commercial teletype and Raytheon magnetic tape drive unit with their own interface circuits. Kates had also devised a binary adder tube known as Additron in cooperation with Rogers Electronic Tubes that was promising, and he planned a special storage tube based on his new theory of electrostatic storage.[179]

Things continued to move quickly. By the end of June the control unit was complete and tested in conjunction with the arithmetic unit (see Appendix A for a more thorough explanation of the internal control of UTEC). A single bit storage unit was built and tested; satisfied, they started to build the twelve duplicates necessary for the storage system. The power problems had been solved to some extent by a battery power supply that was stable enough to drive the model. Rogers Electronic Tubes had produced a few of Kates's adder tubes and an arithmetic unit was built to test them. Kates and Ratz were also invited by von Neumann back to the IAS computer project "to discuss the electrostatic storage and other problems," a significant indicator of their progress and acceptance by the community of modern computing.[180] Further

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[177] Ratz wrote his Ph.D. dissertation on the design of the arithmetic unit. Alfred G. Ratz, "The Design of the Arithmetic Unit of an Electronic Digital Computer", Ph.D. thesis, Electrical Engineering, University of Toronto (1951).

[178] Kates wrote his Ph.D. dissertation about his new theory, supervised by Gotlieb. Josef Kates, "Space Charge Effects in Cathode-Ray Storage Tubes", Ph.D. thesis, Physics, University of Toronto (1951).

[179] For more on the Additron and the subsequent patent issues, see Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 29–33.

[180] Computation Centre Progress Report, 1 April 1950 to 30 June 1950, UTARMS A1968–0007, Box 110,

evidence of this latter success were the other visitors to the Computation Centre that summer who included M.V. Wilkes, director of the EDSAC project at Cambridge, and C.C. Hurd of IBM who was expected that fall.[181] Hartree also returned later that academic year to give three additional lectures on electronic computers and numerical analysis.[182]

By September, the control and arithmetic units were working well together, and could carry out a test sequence at a rate of about 5000 orders per second for eight hours without error.[183] The storage system was nearing completion and undergoing tests, but the input-output components were still on order and their final integration would wait until the rest of the computer was operational.

Two other events from that September 1950 are worth noting, which must have appeared innocuous at the time but in retrospect were of considerable significance: for the first time the Computation Centre began to consider the next stage of the project – a full-scale computer – and a letter arrived from W.B. Lewis, director of the NRC's Atomic Energy Project at Chalk River. Regarding the first, at a September 29 Computation Centre meeting, a discussion arose concerning "the desirability of appointing a senior production engineer whose chief duty would be to produce a computer, rather than develop or use such a machine."[184] Such an engineer would be responsible for the construction of a full-scale computer, but there were concerns that someone experienced enough could be difficult to locate and that such a person might make "arbitrary rulings ... fatal to the project." In the end the UTEC team avoided a decision by placing V.G. Smith in charge, a man with no production experience and who was otherwise occupied by his teaching duties. This left the same team of graduate stu-

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Folder 4.

[181] Computation Centre Committee, meeting minutes and agenda, 29 September 1950, UTARMS B1988–0069, Box 1, Folder 3.

[182] University of Toronto, *President's Report* (University of Toronto, 1951).

[183] Computation Centre Progress Report, October 1, 1949 to September 30, 1950, UTARMS B1988–0069, Box 1, Folder 2.

[184] Computation Centre Committee, meeting minutes and agenda, 29 September 1950, UTARMS B1988–0069, Box 1, Folder 3.

dents and technicians in charge. Lewis was not happy with this arrangement, and a letter of his that arrived that month was critical of "the manner in which the model computer is being constructed."[185] This was not his first complaint; six months earlier, Lewis had made it clear that he was merely satisfied with their progress.[186] As director of the atomic energy research at Chalk River, Lewis carried considerable influence with the NRC and DRB, so his criticisms could not be ignored. Nor would they have been entirely uninformed: Lewis was an electronics expert, who had spent time in the Cavendish Laboratory designing electronic counters using vacuum tubes.[187] However, the electronics team felt that they could meet his criticisms and invited him to Toronto for a face to face meeting.

Work between September 1950 and May 1951, when the next progress report was issued, was not as rapid was before. A previous plan had been to demonstrate UTEC by late spring, but that was pushed off until at least September because of unspecified delays.[188] The storage circuits and tubes were physically complete, but tests were not, and they had not managed to perfect a full 512 word storage, suggesting difficulties with either Kates theory or the actual implementation. As a result the control and arithmetic components, both long complete, were waiting to be integrated together with the storage, as were the input and output equipment which had been recently delivered.[189] By the end of June, the storage, control, and arithmetic components were still not integrated, and tests continued as modifications were made to the still imperfect vacuum tube storage system.[190] Finally, by October, the major components were

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[185] Computation Centre Committee, meeting minutes and agenda, 29 September 1950, UTARMS B1988–0069, Box 1, Folder 3.

[186] K.F. Tupper to S.E. Smith, 11 March 1950, UTARMS B1988–0069, Box 1, Folder 2.

[187] Wilfrid B. Lewis, "A "Scale of Two" High-Speed Counter using Hard Vacuum Triodes", *Proceedings of the Cambridge Philosophical Society* 33 (1937), 549–558 and Wilfrid B. Lewis, *Electrical Counting: With special reference to alpha and beta particles* (Cambridge: Cambridge University Press, 1942).

[188] Computation Centre Committee meeting minutes, 1 May 1951, UTARMS B1988–0069, Box 1, Folder 3.

[189] Computation Centre Progress Report, October 1, 1950 to March 31, 1951, UTARMS B1988–0069, Box 1, Folder 2.

[190] Computation Centre Progress Report, 1 April 1951 to 30 June 1951, UTARMS B1988–0069, Box 1, Folder 2.

combined into a functional electronic computer and a new round of testing began.[191] Eight instructions were chosen, pending an analysis of a more appropriate permanent set.[192] The input and output teletype equipment had been incorporated, but the biggest problem was still satisfactory operation of the storage system, and technical difficulties, such as electrostatic interference, had limited the useful storage to 256 words rather than 512. In at least one test, just over 11 hours of continuous operation of the storage were run before an incorrect bit appeared. Buoyed by their progress, they hoped to give a demonstration of the model in the following weeks if they could increase the reliability, expand the storage to 512 words, build a proper cabinet and operating console, and choose a final set of eight instructions.

Planning was by then underway at the Computation Centre for the full-scale model. The proposed machine would again use parallel Williams tubes, but with 1024 words of 44 bits. Secondary storage would be available on a 10,000 word magnetic drum that would be purchased from an outside supplier, such as Engineering Research Associates. The arithmetic unit would include a multiplier and divider, unlike the UTEC prototype. Addition and multiplication times would be about 20 and 200 microseconds, respectively, a dramatic improvement.[193] Input and output would be handled via a photoelectric paper tape reader and teleprinter typewriters. The full-scale version would continue to use single address instruction codes, but would have 76 instructions, instead of the paltry 8 on the original.[194] Some instructions were intended to facilitate floating-point operations, but it would be a fixed-point machine. Ratz hoped that the design and construction phases would take no more than one year each, though this would depend greatly on there being minimal difficulties with

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[191] Computation Centre Progress Report, October 1, 1950 to September 30, 1951, UTARMS B1988–0069, Box 1, Folder 2.

[192] See table A.1.

[193] The prototype took 240 microseconds to add two 12 bit words. A more appropriate comparison is to the multiple word arithmetic routines, where 48 bit addition took 1.4 milliseconds and multiplication for the 12 and 48 bits were 18 and 260 milliseconds. See Table A.2.

[194] Computation Centre Progress Report, 1 October 1951 to 31 December 1951, UTARMS A1968–0007, Box 110, Folder 4.

procurement, staffing, or finding space on campus.[195] If work began immediately, he hoped a full-scale model could be completed near the end of 1953.

In October 1951, less than two weeks after Ratz submitted the full-scale proposal, a bombshell was dropped on the project. At a Computation Centre meeting on 5 October 1951 a proposal was delivered from Ottawa suggesting that Toronto should acquire a "Ferranti Machine".[196] More properly known as a Ferranti Mark I, it was a commercially manufactured version of the Manchester Mark I, the product of about five years of research and development in the Manchester University Computing Machine Laboratory.[197] The suggestion originated from Lewis, who had learned that Ferranti could install such a computer in Canada for $220,000.[198] He convinced C.J. Mackenzie, president of the NRC, that Chalk River needed greater computational power in the near future for the atomic energy research and the Ferranti computer could provide it much quicker. In turn Mackenzie then phoned Toronto to propose they should acquire one.[199]

Unsurprisingly, the reaction in Toronto to this suggestion was negative, particularly if it implied that the electronic development would come to an end and the plans for the full-scale UTEC were to be abandoned. Two principal objections were raised: they believed that the Ferranti computer (a serial machine, though it did use Williams tubes) would be obsolete in the short run and inadequate in the long run and this, combined with the loss of the electronic development project would remove Toronto from a position of "eminence in the computing field."[200] These were legitimate con-

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[195] A.G. Ratz, The University of Toronto Full Scale Computer, 20 September 1951, UTARMS B1988–0069, Box 1, Folder 1.

[196] Computation Centre Committee meeting minutes, 5 October 1951, UTARMS B1988–0069, Box 1, Folder 2.

[197] More technical and historical details of the Ferranti Mark I can be found in section 3.2.

[198] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 37.

[199] The exact details of Mackenzie's proposal are unknown, but presumably the government would cover the costs of the Ferranti machine and have it delivered to Toronto to be operated in the Computation Centre.

[200] Computation Centre Committee meeting minutes, 5 October 1951, UTARMS B1988–0069, Box 1, Folder 2.

cerns. The parallel UTEC prototype was considerably faster in principle, but because it had to resort to the multiple word routines, addition times for similar number lengths were about the same, and multiplication on UTEC was considerably slower with a hardware implementation. However, if the full-scale UTEC was as fast as Katz predicted, it would easily outpace the Ferranti. Also, at the time there was little status to be had in the computing field for merely using computers. Many people had not yet recognized that writing programs would be just as challenging, if not more so, as designing and building computers.[201] Toronto declined the proposal from Ottawa and Chalk River.[202]

However, the proposal did not die, for in December the DRB and NRC worked out a financial plan to pay for the Ferranti computer, if Toronto would agree to acquire the machine. The DRB had been initially prepared to offer $300,000 to the Computation Centre to build the full-scale UTEC, but that grant was now to be split in two. Both the DRB and NRC would contribute $150,000 towards the estimated $300,000 cost of the Ferranti computer, and the DRB agreed to continue to fund the electronics research with the remaining $150,000.[203] Lewis was almost certainly behind the reborn proposal, and he travelled to Toronto in January 1952 to try and convince the Computation Centre to accept the new offer. His primary argument was that Chalk River could not wait two years as it required large-scale computing facilities more quickly or else calculations would have to sent to England or the United States, the very situation the Computation Centre was to have prevented. This left the Computation Centre in an awkward position. The Atomic Energy Project had been one of the most important clients of the mathematical side of the Centre, making it hard to refuse the suggestion from Lewis. However, it was difficult to imagine purchasing the Ferranti

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[201] A clear indication of this can be found by scanning conference proceedings from the time period, which gave little space for the problems of programming. Consider, for example, the proceedings republished in Campbell-Kelly and Williams, *The Early British Computer Conferences*.

[202] Computation Centre Committee, meeting minutes, 11 January 1952, UTARMS B1988–0069, Box 1, Folder 2.

[203] O.M. Solandt to K.F. Tupper, 22 December 1951, UTARMS A1968–0007, Box 110, Folder 4.

and being able to continue development of the full-scale UTEC, despite the $150,000 the DRB had promised. Nevertheless at a Computation Centre meeting on 11 January 1952 a motion was put forward to purchase the Ferranti with the joint NRC and DRB funds, voted on, and carried.[204] This would make the University of Toronto the second organization in the world to purchase a commercial computer, after the United States Census Bureau's March 1951 acquisition of a UNIVAC.[205]

It also was the beginning of the end of the electronics research and development in Toronto, at least temporarily. Another Computation Centre meeting was called five days later to decide what to do with the other half of the original DRB grant, as the $150,000 was not enough to build the full-scale UTEC originally planned. Three alternative plans were discussed: to build a less expensive and smaller 20 bit computer with fewer features; to close down the electronics section altogether once the UTEC prototype was finished; or to split the electronics research into separate projects that would not lead to the construction of a computer, each managed by individual professors.[206] Mackenzie and Solandt had both suggested this last option.[207] A vote was held, weighted for preference. The results were narrow and indecisive, though the preference was to build the 20 bit version rather than shut the project down or, worse, balkanize everything. This list was forwarded to the DRB for approval, but a month of discussion led nowhere. By mid-February the Computation Centre felt it was best to simply complete the UTEC prototype and return the remaining unused portion of the grant to the DRB.[208] The logic was at least to finish what had been started and ensure that the research came to a conclusion rather than be left open-ended.

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[204] Computation Centre Committee, meeting minutes, 11 January 1952, UTARMS B1988–0069, Box 1, Folder 2.

[205] The same Ferranti model that ended up in Toronto was originally sold to the British government, but that contract was nullified due to austerity measures implemented after the initial purchase. Williams, "UTEC and Ferut: The University of Toronto's Computation Centre", 10

[206] Computation Centre Committee, meeting minutes, 16 January 1952, UTARMS B1988–0069, Box 1, Folder 2.

[207] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 38.

[208] Computation Centre Committee, meeting minutes, 12 February 1952, UTARMS B1988–0069, Box 1, Folder 2.

With this restricted goal of getting UTEC operating, work continued that spring, and by the beginning of March it had run satisfactorily for several weeks, though still with just 256 words of storage.[209] It had also been used to compute a number of generic numerical problems. The first computation was a test of their multiple word multiplication routine, which was followed by routines to calculate e^{-x} and $\sqrt{x}$. Convinced that the prototype was now a reliable high-speed computer, a number of modifications were made throughout March, including a final set of eight instructions, which were felt to be more useful than the original set, and the input and output scheme was improved. The storage tubes were replaced with a newer type, considered more reliable, and continued attempts were made to increase the size of storage to the originally planned 512 words, which did happen sometime that spring or summer of 1952.[210] No further changes of significance were made, and only a few attempts were made over the summer to use UTEC to compute any numerical problem of consequence, although it was programmed to play a game of NIM.[211] After a demonstration to some international visitors at a computing conference held in Toronto that fall, UTEC was dismantled.[212]

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[209] Computation Centre Progress Report, 1 January 1952 to 31 March 1952, UTARMS A1968–0007, Box 110, Folder 4.

[210] A photograph of a single storage tube was published showing a full 512 complement of bits. It was also setup to display 'UoT' on the screen, one final hurrah. See Johnston, "The University of Toronto Electronic Computer", 154–160.

[211] Josef Kates, interview by Henry S. Tropp, Computer Oral History Collection, edited transcript of tape recording, 29 June 1971, Archives Center, National Museum of American History, 7. NIM is an old and simple game with piles of tokens, where two players take turns removing as many tokens as they wish from a pile; the player to remove the last token wins. The mathematics of NIM are well-known and straightforward, and mid-century computer demonstrations of NIM were common. See, for example: J.M. Bennett ed., *Computing in Australia: The Development of a Profession* (Sydney, NSW: Hale & Iremonger in association with the Australian Computer Society, 1994), 55,57.

[212] The international visitors were in Toronto for the first ACM meeting held outside of the United States. See page 144. Sometime after UTEC was cancelled, the parts were sold for scrap. Bleackley and La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years*, 10.

2.3.2 The Many Layers of UTEC

It is tempting to think of the entire UTEC project as a failure, as others have done. In perhaps the first broad history of Canadian computing, Bleackley and LaPrairie's *Entering the Computer Age*, the authors question whether "the failure to produce a full-scale computer base on UTEC [was] an opportunity lost for Canada?"[213] Certainly, it was a demoralizing affair for the electronics group, which disbanded shortly after the university purchased the Ferranti computer. Though other Canadian organizations, notably the Royal Canadian Navy and Ferranti Canada, would tackle the problem of designing and building an electronic computer around this time, the University of Toronto was no longer in the game.

Previous attempts to explain the rise and fall of UTEC have tended to treat the entire project in a monolithic manner, particularly from a perspective external to the University of Toronto. In fact, there were several umbrellas under which the UTEC project operated, and without delineating these various levels it is impossible to understand the entire story. First was the electronics group itself, consisting of the primary hardware architects Kates and Ratz, plus their assistants and latecomers such as Casciato, Stein, and Johnston. Next was the Computation Centre, led by Acting Director Gotlieb. Advising Gotlieb was the original Committee on Computing Machines, chaired by E.C. Bullard until 1949, and then K.F Tupper. They answered to President Smith and the various other departments on campus with an interest in the project, and to the federal agencies that were funding the Computation Centre, the NRC and DRB. There were at least four organizational levels with some responsibility for the success or failure of UTEC. Most were interrelated as well, within the university and without. If the mathematical side of the Computation Centre had failed miserably to satisfy the computing needs of Chalk River, instead of succeeding, it is easy to

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[213] Bleackley and La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years*, 10.

imagine the NRC funds supporting UTEC drying up.[214] One of the key persons who was involved both outside and inside the university was W.H. Watson, who at the beginning of the UTEC project was at Chalk River submitting problems to the Computation Centre but by the end had joined the university as chair of the Department of Physics and was quickly added to the computing committee. There is also evidence that these multiple levels did not operate harmoniously, with differing objectives and levels of support for UTEC, and differing organizational missions and capabilities to guide their participation. Oversimplifying these factors obscures the fact that UTEC was mismanaged and given little chance of success.

First off, consider the purpose of UTEC. According to the electronics group, their goal was to design and construct a small model of a computer which was "intended to provide experience in the techniques involved, promote the investigation of component systems and circuitry and finally test circuitry to be used in a large scale machine."[215]When they considered it reliable and no longer subject to experimentation, their plan was to turn it over to the mathematical group (who were still using the IBM 602) until the full-scale version could be completed, though it would not be particularly useful given its size limitations. The clear advantage of this approach was to not tie the project to a specific technology or design before investing in a large-scale computer. In late 1948, when these plans were first laid, the design of electronic computers was in no way wedded to a particular template or technology. Texts were widely available that described modern computers, such as von Neumann's preliminary report of 1946 or the proceedings from the Moore School Lectures, but there were many possible implementations and no one right way. For example, decisions had to be made as synchronous versus asynchronous circuitry, serial versus parallel storage and arith-

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[214] The reverse is also worth considering. Had the electronics research been an immediate disaster, rather than slowly and eventually producing an operating computer, the NRC and DRB may have declined to continue funding the mathematical side of the Computation Centre.

[215] A.G. Ratz and J. Kates, Review and Estimates of the Electronic Computer Section of the University of Toronto, 23 January 1950, UTARMS B1988–0069, Box 1, Folder 1.

metic, and hardware versus program implementation of mathematical routines, all of which were crucial distinguishing features on which the computing community did not agree. Without any consensus on the best electronic computing technology, the best strategy was to sit back and wait until the best machine could be obtained "without serious risk of a major error of policy."[216] But for reasons that will be explained below, the electronics group decided that a fast computer using a parallel design was the way to go.[217] Presumably the Committee on Computing Machines and the NRC and DRB agreed to this plan, but it is a bit of a mystery as to why this computer was given the go ahead when a slower, serial design could have been built much sooner to replace the even slower punched card equipment and desktop calculators.

For the Computation Centre, the primary objective – as sanctioned by the NRC and DRB – was to handle computational problems provided by other universities and government departments across Canada. This mandate included the electronic computer project but also the relay computer in order to acquire large-scale computing power as quickly as possible. The Committee on Computing Machines was quite willing to spend over $100,000 right away if it meant that a relay computer could be installed immediately. Only when that project died was the electronics research accelerated, but the end goal remained the use of a computer and not its development. Frustration at this conflict was well expressed by V.G. Smith, the sole engineer on the advisory committee: "Of course I recognize that *use* is the ultimate object, but the development will be lots of fun, and we shall know better how to improve and modify a machine of our own design."[218] This situation was never resolved, and the electronic and mathematical sides of the Computation Centre rarely collaborated, if at all. When the decision came in January 1952 to either build a full-scale UTEC or buy the

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[216] E.C. Bullard, NRC Grant Application, "Establishment of a Computation Centre to handle problems provided by Universities and Government Departments.", 27 January 1949, LAC RG77, Volume 52, File 17–28b–1.

[217] Von Neumann had dictated that speed was essential for the IAS Computer at Princeton, based on his perceived computational needs. See Aspray, *John von Neumann and the Origins of Modern Computing*.

[218] V.G. Smith to M. Rubinoff, 15 April 1948, UTARMS B1999–0025, Box 4, Folder R.

Ferranti computer, the computing committee overseeing the Computation Centre was forced to agree that the latter would best serve the Centre's mandate as a service centre. None of the members of the electronics group were on that committee and they doggedly refused to accept the decision and submitted several modified proposals to the committee to continue the UTEC research and development program.[219] When Ratz failed to convince anyone to continue to build even a limited 20 bit version or to extend the research program for a few years he abandoned academia for industry, before the prototype was even finished.

The leadership of the Computation Centre itself was unstable and unable to keep a close eye on things, a detriment to the UTEC project. When Bullard was hired at the university he also agreed to chair the Committee on Computing Machines, which pleased President Mackenzie of the NRC. Bullard was an internationally respected physicist, a man of vision and authority, with experience directing large scientific enterprises. He was an ideal man to lead the Computation Centre. However, in June 1949 Bullard resigned his positions at the University of Toronto, as he and his family were unhappy with their lives in Canada. He was to take up a new position as director of the National Physical Laboratory, but volunteered to stay on until the end of the year.[220] His replacement as chair of the Department of Physics was none other than W.H. Watson, hired from Chalk River where Watson had been sending computational problems since 1947. Watson did not arrive until midway through 1950 and joined the computing committee in September, though he was not immediately influential.[221]

This left a sizable hole in leadership that Gotlieb, as Acting Director was still too junior to fill. The first name put forward to replace Bullard was C. Barnes, a physics professor. Bullard himself suggested Barnes over V.G. Smith, noting that tact and management skills were more important than "a great knowledge of computing," as the

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[219] A.G. Ratz, A Two-year plan for the Electronic Section, 20 February 1952, UTARMS B1988–0069, Box 1, Folder 2.

[220] McKenzie, "Edward Crisp Bullard. 21 September 1907-3 April 1980", 78-79.

[221] W.H. Watson to S.E. Smith, 13 September 1950, UTARMS B1988–0069, Box 1, Folder 2.

"project employs several prima donnas."[222] Instead, President Smith chose K.F. Tupper, dean of the Faculty of Applied Science and Engineering to succeed Bullard as chair of the Committee on Computing Machines. A mechanical engineering graduate of the University of Toronto in 1929, Tupper had considerable research and industrial experience, and had been recently recruited to his new position from the Atomic Energy Project at Chalk River, where he had headed the Engineering division.[223] Tupper warned Smith that he had no previous interest or knowledge of computing machinery, but Smith was desperate for someone with leadership ability in addition to contacts and confidence from Ottawa to take over.[224] Ottawa approved of Tupper's involvement on the committee but there were reservations from within the university, especially from Dean S. Beatty of the Faculty of Arts and Science, who had started the entire computing project in the first place. He informed Smith that the physics professor C. Barnes would have been a better choice, as he had been involved with the Committee on Computing Machines from the beginning and might have been better able to find additional space on campus in the Physics Building as the computing centre expanded.[225]

By the end of 1949 Tupper reluctantly agreed to take on the chairmanship. President Smith welcomed his participation, sure that he could provide "real leadership without becoming immersed in details."[226] Smith's wisdom here was fallible, as Tupper's tenure would be marked by indecision and confusion regarding the role of the Computation Centre.[227] When the full-scale UTEC was cancelled in January 1952, his

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[222] E.C. Bullard to C.J. Mackenzie, 29 September 1949, UTARMS B1988–0069, Box 1, Folder 2.

[223] White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000*, 72–73.

[224] S.E. Smith to S. Beatty, 1 December 1949, UTARMS A1968–0007, Box 62, Folder 18.

[225] S. Beatty to S.E. Smith, 8 December 1949, UTARMS A1968–0007, Box 62, Folder 18. Mackenzie had approved of Barnes before Tupper's name was put forward. Beatty, may have also believed, as a mathematician and dean, that the Faculty of Arts and Sciences was a better place to host the project, rather than in the hands of the engineers.

[226] S.E. Smith to K.F. Tupper, 1 December 1949, UTARMS A1968–0007, Box 62, Folder 18.

[227] Tupper also had a reputation for not being fully committed to his job as dean, finding "the meetings endless and the wheels of academic democracy hopelessly slow," and he left the academic world in 1954 for industry. White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering,*

influence was waning as Watson's was gradually increasing. As a theoretician, the latter also much stronger convictions about using electronic computers, rather than building them.

Beatty made one final suggestion to President Smith before excusing himself from any further involvement: reform the first Committee on Computing Machines to assume responsibility for the Computation Centre and to provide the Director – Tupper, then Watson – with the necessary assistance and guidance.[228] It took four months, but Tupper established the new Computation Centre Committee in April 1950. Some explanation for the delay can be found below, but the membership was not drastically different from the former committee, and its responsibility: "policy respecting the computational work undertaken by the Computation Centre" is unsurprising.[229]

Tupper's and the committee's direct oversight in the Centre was nominal. The electronics group was able to work almost entirely unsupervised, despite the fact that both Kates and Ratz intended to convert their research into Ph.D. dissertations. This was because few people could keep up and understand all the details. As Acting Director and a member of the Department of Physics, Gotlieb supervised Kates's Ph.D., but has admitted that Kates's theory of electrostatic storage, the subject of his 1951 dissertation, was a mystery to most people: "Kates knew a lot but he did so much double talk that, to this day, I am not sure if the physics and theory behind it is completely right. It worked ... but whether that mathematics described the situation properly I still don't know."[230] As long as the electronics group made good progress, few could question them on that front.

One of the results of this hands off approach was that the vaunted connections

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1873-2000, 173.

[228] S. Beatty to S.E. Smith, 8 December 1949, UTARMS A1968–0007, Box 62, Folder 18.

[229] Beatty's influence and interest were declining and he was not on the new committee. The only other original member of the Committee on Computing Machines not invited to join the new committee was A.F.C. Stevenson, who had resigned from the University that year.

[230] Calvin C. Gotlieb, interview by Michael R. Williams, 30 April 1992, Transcript provided by Michael R. Williams. The question was made irrelevant by the arrival of magnetic core storage, replacing Williams tube technology.

of people such as Bullard and Tupper could not be used to any advantage. The UTEC team was constantly hampered by university and post-war procurement policies that prevented them from acquiring decent supplies in a reasonable amount of time. Months could go by waiting for a request to go through the university purchasing department, and some parts were not easily available in Canada. Some potentially valuable war-time assets existed, but were scheduled for destruction even as waiting lists were forming for the equivalent civilian peace-time components. The project was saved not by any of high-level political connections to the DRB, but low-level correspondence with other engineers and technicians. One of those was Jim Richardson, who had worked as Kates's assistant early in the project, but had since joined the Los Alamos Scientific Laboratory in its quest to build an electronic computer. Armed with a larger budget and infinitely better access to American suppliers he was able to send hundreds of components to Toronto, practically as a gift. Another benevolent contact was an unnamed junior officer in the Royal Canadian Navy, probably Lieutenant Jim Belyea, who was able to supply the UTEC group unofficially with surplus radar equipment that was cannibalized for parts, especially the vacuum tubes.[231]

Left to their own devices, bitter rivalries developed beneath the surface of the electronics section. While Kates and Casciato struggled to build the storage system with tubes cheaper and smaller than desired, the UTEC Input and Output component was to be handled by commercially purchased teletype and tape drive equipment that cost twice as much. It occupied about a third of the UTEC material budget, but was a low-priority part of the prototype that was deliberately put off until the end.[232] Casciato recalled his anger at this perceived waste of money: "People never had any qualms about these things . . . they had that sort of war-time attitude. If the boat sinks,

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[231] Len Casciato, interview by Michael R. Williams, 6 July 1992, Transcript provided by Michael R. Williams. Belyea was a crucial instigator on the DRB and Ferranti Canada electronic computer project known as DATAR that began around the same time as UTEC but also never made it past the prototype stage. Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 45-78.

[232] A.G. Ratz and J. Kates, Review and Estimates of the Electronic Computer Section of the University of Toronto, 23 January 1950, UTARMS B1988–0069, Box 1, Folder 1.

it sinks!"[233] In September 1950, around the middle of the project, Tupper considered bringing an experienced industrial engineer on board to clean things up and produce a properly built computer. This notion was rejected by the Computation Centre Committee, to prevent outside authority from interfering.

Outsiders with experience in modern computing were prevented from participating. Bullard chose Gotlieb as Acting Director of the Computation Centre in part because of the modest salary requirements, but Gotlieb had minimal experience. Certainly he had less than M. Rubinoff, another candidate for the job with several years of firsthand knowledge working in the Harvard Computing Laboratory and on the IAS Computer. Another Toronto alumnus, W. Buchholz, wrote several letters to V.G. Smith between 1947 and 1948 describing his work at the California Institute of Technology where they were building electronic computers. When the time came to hire people to design and build what would be UTEC, Buchholz was never seriously considered, though he asked for a position. It was apparently difficult to keep experienced people in Toronto. Richardson left early on, and Ratz left the university within weeks after it became clear to him that a full-scale UTEC would never be built. D.B. Gillies and J.P. Mayberry were undergraduates at the University of Toronto in 1949 when hired as summer students to study the mathematical capacity of UTEC and even wrote some hypothetical code designed to handle multiple word arithmetic. To be fair, programming was an unappreciated skill at the time, especially if the computer was not even finished, but no attempt was made to hold on to either of them. By 1950 both were at Princeton, working on the IAS computer and studying game theory under von Neumann.[234] This is the worst kind of technological transfer: losing skilled people to other organizations. The problem was a lack of commitment from the Computation Centre

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[233] Len Casciato, interview by Michael R. Williams, 6 July 1992, Transcript provided by Michael R. Williams.

[234] Gillies then went on to an unfortunately truncated career at the University of Illinois in computer science, before his early death in 1975. While there, he participated in the design of the ILLIAC II, the subject of chapter 5. Mayberry continued to study game theory. He is currently Professor Emeritus of Mathematics at Brock University in St. Catharines, Ontario.

Committee and from the University of Toronto.

On the whole, the rest of the University of Toronto remained agnostic as to the purpose and activity of the Computation Centre. This may explain why the overall university support for the project was poor, despite the prestige of the large financial awards flowing into the university. In fact, by 1951 the joint NRC and DRB agreement with university had brought in nearly $200,000, leading President Smith to declare to the University of Toronto Board of Governors that in terms of capital and annual support this was the largest scientific grant to any Canadian university, even greater than that to the cyclotron at McGill University.[235] Smith had been upbraided by Mackenzie in 1948 for failing to pay close attention to the computing centre plans (see page 53), but his mindfulness had not improved significantly when the Computation Centre Committee had to decide between the UTEC and the Ferranti computer. His first knowledge of the momentous shift in plans came while reviewing the university accounts and learning that the DRB grant had been split to cover half of the cost of the Ferranti. "Have we given up on the project to develop the big machine" he asked, unaware that the decision had been made nearly one month earlier.[236]

Given President Smith's lack of involvement, the lackluster organizational support the University of Toronto offered to the Computation Centre, and UTEC specifically, was unsurprising. For example, space on campus for the project was a perennial problem. To be fair, after World War II space at the university was at a premium thanks to the federal government's promise to provide free university education to ex-servicemen, who then overwhelmed the grounds.[237] This meant that the computing centre staff and equipment bounced around campus for many years, unable to find a permanent home until 1952, when the Ferranti computer was installed in the

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[235] S.E. Smith to W.E. Phillips, 20 August 1951, UTARMS A1968–0007, Box 110, Folder 4.

[236] S.E. Smith to K.F. Tupper, 11 February 1952, UTARMS A1968–0007, Box 110, Folder 4.

[237] So desperate for facilities, the Faculty of Applied Science and Engineering moved a substantial portion of their first and second year teaching and students east of Toronto to a refurbished munitions facility in Ajax for three and half years until the enrolment boom was over. White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000*, 157-164

Physics Building. In 1951, the electronics group was forced to move UTEC in 1951 from the Physics Building to the Mining Building, though it was in a crucial stage and nearing completion.[238] The move was in anticipation of the full-scale project needing more space, but the UTEC prototype had to be disassembled and rebuilt in a matter of weeks in the new laboratory to prepare it for a demonstration.

Another failure on the part of the university was staffing. The core members of the electronics section – Kates and Ratz – were only able to work on the project because they were not burdened by the usual academic complication of teaching assignments and were able to hire technical assistants. This was a positive factor, but there was a high turnover of low-level technicians, such as those employed for routine soldering work. New hires were typically warned by the university that it would be a temporary position, which discouraged skilled workers. Moreover, the university was unable or unwilling to pay assistants a wage or salary commensurate with their work experience, insisting on a scale tied to earlier academic performance, which again prevented skilled hands from participating. The results were predictable. As Kates's right-hand-man Len Casciato put it: "you end up with all the dregs and you end up having to do their work."[239] The University of Toronto was simply not an ideal location to host the development of a large-scale electronic computer. Aside from the lack of space, there was no suitable laboratory to work in, as the vast majority of equipment and supplies had to be purchased from the grant money.[240] Nor was there any substantial experience or knowledge of quality control techniques or production.

For the duration of the UTEC project, the NRC and DRB remained relatively ignorant of the specific goings on in Toronto, happy to send cheques and read progress reports from afar. However, a number of times both were forced to step in, reasserting

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[238] Computation Centre Progress Report, October 1, 1950 to September 30, 1951, UTARMS B1988–0069, Box 1, Folder 2.

[239] Len Casciato, interview by Michael R. Williams, 6 July 1992, Transcript provided by Michael R. Williams.

[240] A.G. Ratz and J. Kates, Review and Estimates of the Electronic Computer Section of the University of Toronto, 23 January 1950, UTARMS B1988–0069, Box 1, Folder 1.

their authority over the Computation Centre to establish their own distinct visions of a national computing centre. For much of the time UTEC was under construction, it proved difficult for all sides to come to a consensus regarding the role of a Computation Centre, which complicated matters considerably.

The first such case was the 1949 debacle concerning the Bell Relay computer. When Bell Laboratories demanded a $25,000 license fee it pushed the cost of the machine higher than anticipated. While Bullard and the rest of his committee felt this was reasonable in the hopes of acquiring a versatile computer quickly, the NRC and, in particular, the DRB did not agree. Bullard continued to pursue the plan until the DRB made it unequivocally clear that the Computation Centre was to use the DRB grant to accelerate the electronics research and build a computer. Inside the Computation Centre the news came hard, though the excitement surrounding the renewed focus on electronics compensated. But inside the NRC, there were concerns that the relay machine should not have been cancelled, alongside doubts that Toronto was the best place to host an electronic computer project and anxiety at having no large-scale computer in Canada for the near future. Three different parties with three different perspectives: the DRB felt it was sponsoring an electronics development project, the NRC a large-scale computing centre, and the University of Toronto was still not sure what it was doing.

The trouble continued to brew throughout 1949 and into the next year when Tupper replaced Bullard. Much confusion can be traced to an event in September 1948. That month B.H. Worsley completed her Meccano differential analyzer and left Toronto to enrol in the Ph.D. program at Cambridge University. There she continued her graduate work from MIT, studying mathematics and physics, but also worked with Maurice Wilkes, director of the EDSAC group. Her plan, once finished the Ph.D., was to return to Toronto and the Computation Centre.[241] After a few months she was

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[241] Campbell, "Beatrice Helen Worsley: Canada's Female Computer Pioneer", 51–62.

joined by her undergraduate classmate and Computation Centre colleague J.P. Stanley, who also registered as a Ph.D. candidate. He was sent by the Committee on Computing Machines to study under Wilkes and "to gain experience in modern computation methods which are badly needed in Canada," and was scheduled to return to Toronto at the end of 1949.[242] Although the extent of their participation is difficult to judge, they were both present when EDSAC ran for the first time, in May 1949, and Worsley gained a small measure of fame as the author of a historical report that described the demonstration that day.[243] It is unclear if sending Stanley was planned all along, or only arranged after Worsley left, but as part of the arrangement the Committee agreed to continue their salaries while they were overseas, reasoning that their training at Cambridge would be valuable when they came back. The Committee felt this was reasonable given that their original mandate included training.[244] Unfortunately, the NRC and the DRB had no knowledge of these activities. When things came to light in the spring of 1949, quite by accident, neither were happy to learn about Stanley's unauthorized travel or the two salaries going to people who were not physically working in the Computation Centre.[245] Although they were willing to accept the situation as a *fait accompli*, much noise was made that tighter controls needed to put in place.

The awkward mess went unresolved though the NRC and DRB both suggested that the other agency should take sole administrative responsibility.[246] Neither did to any extent, though Mackenzie and Solandt agreed to cancel the relay computer a few weeks later, despite some internal dissension at the NRC. The fallout continued later that year when Stanley returned from Cambridge with a large table that had been

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[242] B.A. Griffith to W.H. Barton, 28 April 1949, LAC RG77, Volume 52, File 17–28b–1.

[243] Beatrice H. Worsley, "The EDSAC Demonstration: Report on a Conference on High Speed Automatic Calculating Machines", Technical report (Cambridge University Mathematical Laboratory, January 1950).

[244] B.A. Griffith to W.H. Barton, 28 April 1949, LAC RG77, Volume 52, File 17–28b–1.

[245] W.H. Barton to C.J. Mackenzie, 3 May 1949, LAC RG77, Volume 52, File 17–28b–1.

[246] C.J. Mackenzie to W.H. Barton, 12 May 1949, LAC RG77, Volume 52, File 17–28b–1.

calculated on EDSAC with the assistance of Wilkes.[247] Though it could have been published in the UK, Wilkes estimated delays of two years or more so the Computation Centre decided to publish it as a book in Toronto and Gotlieb innocently wrote to the NRC about money for publishing the table.[248]

When his letter arrived in November 1949 it set off another round of debate concerning the administration and the proper role of the Computation Centre. In general, NRC grants were to be used to conduct the research covered in the grant application; support for publication of results required a separate grant. Because Bullard had not specified 'publishing tables' in the grant application the previous year, the NRC was averse to including the costs in the existing consolidated grant. This may have been a bureaucratic stalling point, but it does help illuminate a great deal of the confusion surrounding the different interpretations of the proper role of the Computation Centre. It is clear from their response that the NRC viewed the Computation Centre as a research unit, not a publishing house. Yet in his request Gotlieb expressed the opinion that "we should like to be able to publish and make available for general distribution any tables which we felt were particularly useful."[249] Tupper, who was now putting out fires started inadvertently by Bullard, felt the same: "it is pointless to spend a sum perhaps reaching one or two thousands of dollars to prepare a table which will then be put in the Computation Centre's filing cabinet and henceforth forgotten."[250] Underlying both of their arguments was the assumption that the Computation Centre was a service organization first though research was a close second. An analogy used at the time was to compare the centre to a machine shop: the function in both cases was to turn out results to specifications submitted by outside customers. At times, it

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[247] James P. Stanley and Maurice V. Wilkes, *Table of the Reciprocal of the Gamma Function for Complex Argument* (Toronto: Computation Centre, University of Toronto, 1950). Wilkes autobiography clouds the issue of who had done most of the work writing the program for EDSAC. Maurice V. Wilkes, *Memoirs of a Computer Pioneer* (Cambridge, Mass.: MIT Press, 1985).

[248] Correspondence between C.C. Gotlieb and H.H. Saunderson, 15 and 23 November 1949, LAC RG77, Volume 52, File 17–28b–1.

[249] Cited in K.F. Tupper to S.P. Eagleson, 12 January 1950, LAC RG77, Volume 52, File 17–28b–1.

[250] K.F. Tupper to S.P. Eagleson, 12 January 1950, LAC RG77, Volume 52, File 17–28b–1.

would also be necessary to experiment and perform research as to the best manner to produce those results. Though modern electronic computers would eliminate scientific tables within a matter of years, producing tables was the bread and butter of scientific computing centres of the time.[251]

Their patrons were unconvinced. Mackenzie wrote Tupper, complaining of "the lack of clarity in my own mind as to whether we are running a mathematical research enterprise, a straight service agency, or a research project in electronic computing machines."[252] He also wrote to President Smith and questioned his administrative myopia. Smith then turned to Tupper and learned that a meeting had been arranged for March 9 in Ottawa to settle things once and for all. Attending that meeting were Mackenzie, Lewis and Watson representing the interests of the NRC, Solandt and Field of the DRB, and Tupper as the sole representative from Toronto.[253] Tupper was able to satisfy them. Presumably this was by expanding upon his machine shop analogy or by outlining the progress made to that point – nearly fifty computing problems were completed or underway – but the historical record of the meeting does not say. He was able to report back to Smith that Watson spoke enthusiastically about the computational work, though Lewis was less impressed by the electronics work completed to that point. Ratz's arithmetic unit was operating by then, and Kates was busy testing his new theory of electrostatic storage, but Lewis was never able to bring himself fully to support Kates's theory. The biggest change in the operation of the Computation Centre Committee that came out of the meeting was that the NRC and DRB would now approve all major hiring decisions and major changes in policy.[254]

Satisfied that things would be running more smoothly, Mackenzie agreed to let the Computation Centre publish their table using the consolidated grant, as a one-time

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[251] See Croarken, *Early Scientific Computing in Britain* and much of Campbell-Kelly, *The history of mathematical tables: from Sumer to spreadsheets*.

[252] C.J. Mackenzie to K.F. Tupper, 6 February 1950, LAC RG77, Volume 52, File 17–28b–1.

[253] K.F. Tupper to S.E. Smith, 11 March 1950, UTARMS B1988–0069, Box 1, Folder 2.

[254] By all impressions, these approvals were rubber-stamped, but the Computation Centre was treading much more carefully in subsequent progress reports and correspondence.

event only.[255] It was also agreed that the DRB and the NRC would split their funding along the lines of capital and operating expenses. In broad terms, this corresponded to the DRB sponsoring the construction of the electronic computer, and the NRC funding the mathematical side of the Computation Centre. With this settled, things continued at the university more or less undisturbed from outside interference for the next year and a half. The grants were gradually increased to cover the increased staff and IBM rental costs and the expected costs of the full-scale UTEC.[256] It was only in the fall of 1951 that the federal agencies stepped back into the picture, when the Ferranti computer came up for discussion.

To summarize, though it would be easy to blame the failure of UTEC on the inexperience of the electronics group and their overambitious plans, a broader look at the context fails to support this accusation. The Computation Centre Committee, the University of Toronto, the NRC, and the DRB all contributed to the failure to produce a full-scale electronic computer. Physical support, aside from cash, was entirely absent and it took several years for everyone to agree upon the mission of the Computation Centre. One can hardly fault the electronics group for choosing a difficult design rather than a conservative one when guidance and advice was in such short supply and no serious effort was made at any level to recruit experienced help.

2.3.3 Was UTEC a Failure?

Was UTEC a failure? For a complete answer, this question must be approached from a different perspective than of a prototype computer that never worked well or for long. As computer historian William Aspray notes, a computer's value comes "from its uses," but also "the proof of principles that it demonstrates, the design ideas that

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[255] S.P. Eagleson to K.F. Tupper, 28 March 1950, LAC RG77, Volume 52, File 17–28B–1. It was indeed a one-time event as it was the only table published by the Computation Centre.

[256] NRC of Canada Application for Consolidated Grant for Research, K.F. Tupper, 24 January 1951, UTARMS A1968–0007, Box 76, Folder 2.

it embodies, the theory that is developed in connection with the machine, the people who are trained upon it, and its role as a cultural icon."[257]

Regarding the first value, UTEC was intended to aid in the fulfilment of the mission of the Computation Centre, that is, it was to be used to perform numerical calculations. It was only a prototype, but as the full-scale version was never built, the prototype is all that can be assessed. Unfortunately, even the electronics group was forced to admit that UTEC had little practical or potential usefulness.[258] Only two problems of note were ever computed, which are discussed below. With a 12 bit word it was just too small for practical work. As computers needed at least eight instruction codes to be useful, this limited the address space to a maximum of 512 words.[259] Eight instruction codes was not enough to implement every arithmetical operation, such as multiplication or division, so these had to be performed by programs.[260] They were much slower: addition and subtraction of a single word took 240 microseconds each, but multiplication and division took 18 milliseconds and division 36 milliseconds respectively, roughly two orders of magnitude slower. This was still two to three orders of magnitude faster than an IBM 602, but doesn't take into account the fact that a signed 12 bit binary word corresponded to just three decimal digits. Thus, multiple-word arithmetic routines were needed for virtually any real world problem, which were considerably slower.[261] Of course, some problems don't require great accuracy and relatively simple iterative calculations, such as some differential equations, eigenvalue problems, or function tables which might have been handled in a reasonable

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[257] Aspray, "The Institute for Advanced Study Computer: A Case Study in the Application of Concepts from the History of Technology", 189.

[258] Johnston, "The University of Toronto Electronic Computer", 156.

[259] For a one-address computer like UTEC, a complete instruction requires one instruction code and one address, and both must fit within a single word. The eight instruction codes were specified in the first three bits ($2^3 = 8$), which left nine bits to indicate at most 512 addresses ($2^9 = 512$).

[260] The corresponding hardware for a multiplication or division instruction was never implemented on UTEC.

[261] See Table A.2 for timings.

fashion. For example, the elliptic integral defined by

$$K = \int_0^{\Pi/2} \frac{d\Phi}{\sqrt{1 - msin^2\Phi}}$$

was used as a test case and could be computed by an iterative process to six decimal digits in 6 seconds, compared to 90 seconds on the IBM 602.[262] It is worth noting that the Ferranti computer that replaced UTEC could do the same calculation in under two seconds. Although it was fundamentally slower, as a serial machine, the 40 bit word length reduced the need for multiple word arithmetic. The elliptical integral program was one of the only a handful of problems ever run on UTEC, and it was merely a demonstration not a scientific problem. Another was a test of an iterative function that was to be used in a series of backwater calculations that the Computation Centre was working on for Ontario Hydro and the St. Lawrence Seaway.[263] Though faster and more convenient than the IBM 602, UTEC was simply too small to be used for production runs on the problem.[264]

Compared to other university-based electronic computer projects, UTEC was crippled by its short word. Scientific calculations demanded longer word lengths: the Manchester Small Scale Experimental Machine (SSEM) that preceded the Ferranti computer had a 32 bit word, the EDSAC had 18 bit words, the IAS Computer 40 bits. Progress on the UTEC was much slower than the two British computers, which were serial and thus easier to build. For example, the SSEM was running in June 1948, and the first full sized Mark I was running by October 1949; the EDSAC was running in May 1949. In North America, where von Neumann's preference for parallel designs was more influential, progress on UTEC was not much worse than any other project.

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[262] That example was provided by Johnston, who neglected to include input and output time, or the time it would take to write the program. These are non-trivial factors, and their absence highlights the frequent obsession with speed of execution.

[263] See section 3.3.2.

[264] To be fair, the Ferranti computer was also too small, and the problem had to be broken in multiple fragments.

Indeed, most parallel 'von Neumann type' computers were not finished after after their serial cousins were; the IAS Computer was not completed until 1951, and its many clones appeared even later.[265] The difficulties of perfecting the parallel circuitry and storage were the root problem. The historical oddity here is the EDVAC at the University of Pennsylvania, the first modern electronic computer project out of the gate in 1946, but one of the last across the line in 1952, even though it was serial.[266]

Despite the optimistic tone in the UTEC progress reports, it was never very reliable, even in the spring of 1952 when it was said to be operating satisfactorily. By all accounts the arithmetic unit was sound, but Kates and Casciato never managed to perfect the shielding on the Williams tubes. As electrostatic devices, it was said that by combing your hair in the same room could destroy the contents of the storage tubes. This can by portrayed as a serious failure, but evaluating computer reliability in this era is not as straightforward as it might seem. UTEC was, of course, an experimental prototype, and this was acknowledged in the full-scale plans.[267] Other computer designers acknowledged that a machine should be engineered to reduce faults, but these were in some ways inevitable: "it must be the object of the engineer to make sporadic errors extremely rare, but he need not be discouraged if he fails to remove them altogether."[268] Intermittent hardware failures were normal, and an experienced user would never assume that a machine worked perfectly. Some centres ran test programs every hour to confirm proper operation.[269] Others assumed that the most likely source of faults were human drafted programs, and so concentrated their efforts on writing perfect programs or even programs that could recover from hardware fail-

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[265] Ceruzzi, "Electronics Technology and Computer Science, 1940-1975: A Coevolution", 262.

[266] The delay can be attributed to poor management of the project and the fact that all of the leaders abandoned the project quite early to build their own computers.

[267] Ratz suggested that some experiments could be made to determine if the Williams tubes could be replaced with magnetic cores or even transistorized storage. A.G. Ratz, A Two-year plan for the Electronic Section, 20 February 1952, UTARMS B1988–0069, Box 1, Folder 2.

[268] A.A. Robinson, "The Reliability of High-Speed Digital Computing Machines", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 199.

[269] Robinson, "The Reliability of High-Speed Digital Computing Machines", 199–201.

ure.[270] Gotlieb wrote in 1951 that in the interests of lower costs it was occasionally necessary to throw the burden of reliability on the programmer than to build extra hardware.[271]

In this context of reliability the proper justification to build a parallel computer in Toronto can be explained. Although speed is normally cited as the reason to chose parallel over serial, Ratz's dissertation makes it clear that that a parallel design was selected because he believed it would be more reliable. This may seem contradictory: in general, parallel designs were considered to be more complex than serial, and in practice they took much longer to perfect. However, a parallel computer could be smaller, simpler, and built with fewer parts, and according to Ratz this made it more reliable. This explanation was used to justify much of the design of UTEC. In deciding whether to build a binary or decimal machine, Ratz pointed out that "the simplicity of binary arithmetic permits a decrease in both the time required for an arithmetic operation and the size of equipment necessary to carry it out, so that a further increase in reliability results."[272] It was also important to keep reliability in mind when choosing a word length, though it required a delicate balance. A short word length reduced the number of parts but a long one reduced the number of computer cycles needed to complete a given computation. Both variables could affect reliability so it was necessary to choose a length sufficiently large to meet one's computational needs.[273] While speed was an important goal for computer designers, Ratz saw this only a means to an end: reducing the cycle time should also produce more reliable circuits, and increasing the speed could only be justified if it "yields a more reliable computer."[274] Circuits

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[270] David J. Wheeler, "Checking Facilities", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 106.

[271] Gotlieb, "Machines for Thought", 4. The context of his statement was binary-decimal conversion, which is more specific than the general case but no less valid an example.

[272] Ratz, "The Design of the Arithmetic Unit of an Electronic Digital Computer", 15.

[273] He acknowledged that the 12 bit UTEC was simply too small to be useful. It is interesting to note that the full-scale UTEC was to be a 44 bit machine, larger than many other designs at the time, but Ratz was willing to accept a 20 bit version when he made his final proposal in March of 1952.

[274] Ibid., 12.

were designed to prevent overheating. Ratz was even able to vindicate UTEC's absolute minimum of eight orders. Multiplication or division operations, he argued, were redundant and could be provided by addition and subtraction to reduce the number of components, and better guarantee reliability.

Ratz's position found support from a figure no less than Maurice Wilkes, who wrote in 1951 that the first consideration for a designer was "how he is to achieve the maximum degree of reliability for his machine" by limiting the number of parts, the overall complexity and the repetition of components.[275] If the electronics group in Toronto could not build a reliable prototype, it is difficult to imagine that Ottawa would be prepared to sponsor the full-scale version. It is thus somewhat ironic that despite their best efforts, UTEC never was very reliable.[276]

Thus a key to understanding UTEC is to not treat it as an impenetrable black box, but to look inside the machine and see what the designers intended. Having considered the many organizational levels that determined the fate of UTEC, it is also necessary to explore the organization of the machine itself. Similarly, if limited to an evaluation of how successfully the machine was used, this will fail to capture the entire story. As sociologists of technology have pointed out, "a historical account founded on the retrospective success of the artifact leaves much untold."[277] It is necessary to broaden the definition of success to include criteria other than 'did it work'.

For example, the design documents and progress reports reveal that the electronics group, and the Computation Centre in general, felt that UTEC was an experimental platform to test various ideas concerning the design and construction of an electronic

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[275] Maurice V. Wilkes, "The Best Way to Design an Automatic Calculating Machine", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 182–184.

[276] It must be said that Ratz's arithmetic unit was the first component finished and the most reliable. Perhaps if Kates had not been side tracked by the Additrons and his own theory of electrostatic storage, and had focused on shielding the storage tubes then UTEC might have been finished earlier and history might have turned out differently.

[277] Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts: Or How Sociology of Science and the Sociology of Technology Might Benefit Each Other", in Wiebe E. Bijker, Thomas Parke Hughes and Trevor J. Pinch eds., *The Social Construction of Technological Systems* (Cambridge, Mass.: MIT Press, 1987), 24.

digital computer. It was a training ground to learn the necessary skills before a full-scale attempt. In that sense, the electronics group certainly believed it to be a success: "as a result of the two and half years taken for its development, the Computation Centre possesses a nucleus of engineers with sufficient experience to build a full scale machine. Thus Model I has served its primary purpose."[278] Given their inability to make UTEC reliable and their aversion to outside assistance, this statement can and should be questioned.

Whether the design or the designers had any influence on other technology should also be considered. From a technical standpoint, UTEC was unremarkable in comparison with other projects underway at the time, and as delays continued, its relevance decreased. It was of little if any influence to future computer designs. The only novel part of UTEC was Kates's theory of electrostatic storage, but it was never fully implemented on UTEC, nor were the ideas carried far.[279] The other major design ideas it embodied were not unique and were implemented better elsewhere.

We turn to the electronics group then to look for significance. Ratz left Toronto when it was obvious that a full scale, or even half scale, UTEC would not be built and no further information is known about his career. Kates, Casciato and Johnston attempted to take their knowledge outside of academia to produce a similar computer intended for sale to government or industry.[280] The project never found solid footing or funding, although Kates and Casciato would stay together long enough to form KCS in 1955 with a third man, Joe Shapiro. Over the next ten years KCS became Canada's most successful computer services and consulting company.[281] The UTEC

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[278] A.G. Ratz, The University of Toronto Full Scale Computer, 20 September 1951, UTARMS B1988–0069, Box 1, Folder 1.

[279] Jim Richardson tested Kates's theory at Los Alamos, with positive results, but as this was shortly before the project was cancelled there was no followup.

[280] Their company was named Digitronics and they intended to design and build a compact general purpose computer with parallel electrostatic storage, similar to UTEC. See Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 40-41.

[281] Bleackley and La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years*, 32–34. Gellman also left his position in the Computation Centre around this time to start his own successful computer consulting company, H.S. Gellman and Co.

laboratory provided an ideal training ground for a small group of engineers to spin-off their own computer businesses.[282]

Though UTEC was not a novel computer and it has been forgotten for the most part in the annals of modern computers, it did provide an important entry point for Toronto into the computing community. In general, most groups that were building their own computers operated independently from others, without frequent contact. Many did not have time to integrate new ideas from other groups, preferring to build upon their own successes and avoid being sidetracked.[283] That said, members of the Computation Centre were invited to give talks, to visit other centres, and to share their knowledge. Kates, Ratz, and V.G. Smith found time to give several talks at international conferences on computing technology.[284] At least twice Kates and Ratz visited von Neumann to discuss computer technology. Letters from the Manchester Computing Laboratory and Project Whirlwind at MIT indicate that other groups were curious about Kates's special tubes and his theory of electrostatic storage. Taking advantage of their new status within the community, the Computation Centre was able to convince the newly formed Association of Computing Machinery to host their annual conference in Toronto in September 1952.

Finally, the positive effects of cancelling UTEC must be considered, in particular those that would not have come about had the full-scale version gone ahead. The Computation Centre, from inception until 1951, was divided internally between the mathematical and electronic sides – even the budgets were handled separately. This led to almost no end of confusion regarding the role of the Centre, at least until the Ferranti computer was ordered. The new computer created clarity, as all of its energy and resources could be brought about to focus on programming. Though Gotlieb

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[282] Kates and Johnston's names also appear in the Computation Centre records in the mid 1950s, as authors of subroutines for the Ferranti program library.

[283] Bigelow, "Computer Development at the Institute for Advanced Study", 308-309.

[284] Josef Kates and Victor G. Smith, "The Scotch Plaid Raster", *Transactions of the American Institute of Electrical Engineers* 70 (1951) and Alfred G. Ratz and Victor G. Smith, "A Method of Gating for Parallel Computers", *Transactions of the American Institute of Electrical Engineers* 70 (1951), 510–516.

remained Acting Director of the Computation Centre, the singular purpose created challenges and there was a period of indeterminacy, as the mathematical and electronic groups collapsed and reformed around the new goal. Some staff members chose to leave, some welcomed the new purpose, and new people joined the effort. These changes would have been delayed for many years while the full-scale UTEC was under construction.

The Ferranti placed the University of Toronto at the forefront of a new wave of computing activity that was no longer concerned with building computers but with using them. It was one of the first schools in the world to have a first generation digital computer project and to focus entirely on programming, at the cost of closing its electronic laboratory. By 1960 there were few universities left in the world that built their own large-scale computers.[285] It was no longer economical in the face of an robust commercial market led by IBM and the seven dwarfs.[286] Ultimately, the failure of UTEC put the University of Toronto on a successful, but different, road.

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[285] The University of Illinois's ILLIAC series was the last, when it finished the ILLIAC IV in 1974.

[286] IBM was the undisputed leader of the computer field by the end of the 1950s, with seven other companies, or seven dwarfs, fighting over the remainder of the market. They were: Sperry-Rand, Burroughs, National Cash Register (NCR), RCA, Honeywell, General Electric (GE), and CDC (Control Data Corporation).

Chapter 3

The Ferut Era, 1952–1955

"Realization of the potentialities of the new computers has been retarded somewhat owing to the amount of skilled human effort required to code individual problems for machine solution."

– B.H. Worsley and J.N.P. Hume, describing the primary problem with computers in the mid 1950s.[1]

On 7 April 1952 the *Manchester Pioneer* sailed from Manchester, bound for Toronto on its maiden voyage. Thanks in part to its diminutive size, it offered the first direct service between the United Kingdom and the Great Lakes, for which it was welcomed heartily by Toronto based manufacturers. As it passed through the narrow locks to Lake Ontario with just one foot of clearance, the cargo included an "electronic brain for the University of Toronto, packed in 15 boxes."[2] That brain was the Ferranti Mark I, and it is a delightful twist of fate that the same computer would be used to help design the St. Lawrence Seaway and thus eliminate the need for such a small vessel.[3]

Sometime shortly before the April 28 arrival, Beatrice Worsley nicknamed the new computer Ferut, for Ferranti at the University of Toronto.[4] Over the next few years,

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[1] Beatrice H. Worsley and J. N. P. Hume, "A New Tool for Physicists", *Physics in Canada* 10, no. 4 (Summer 1955), 11–20.

[2] "Ship's Maiden Trip Starts Toronto-Manchester Service", *The Globe and Mail* (April 29 1952), 3.

[3] This twist of fate was pointed out in Martha Hendriks, "An Institutional History of The Department of Computer Science at the University of Toronto: 1948-1971" (1992).

[4] Unlike the name of most other computers in North America at the time, the name 'Ferut' was an

the staff of the Computation Centre had to learn how to use a large-scale computer, and to teach others across Canada how to do the same. It was a transitional period in academic computing, from using computers as a means to an end, towards the study of computers as an end in itself. The computing instruction and research can be recognized as elements of computer science, although the discipline (and the phrase) did not yet exist. There are two important themes in this chapter. The first is knowledge transfer. At the University of Toronto, there was almost no experience writing programs for modern computers, but at Manchester University, where the Ferranti Mark I was developed, a group of mathematicians had been doing so and collecting a subroutine library since 1949.[5] When the Mark I was sold to the University of Toronto, the contract made no mention of this, but without the library, Ferut would be next to useless. It was vitally important that the technological knowledge in Manchester be transferred to Toronto so that the Computation Centre could begin using Ferut as soon as possible. The second theme, of technological momentum, plays a lesser role in this chapter, but deserves recognition. For a number of social and technological reasons, the Ferranti Mark I was very difficult to write programs for. Though there was an opportunity for a clean break in Toronto, momentum carried the same difficulties across the Atlantic. Before exploring these events in greater detail, it is necessary to lay out the social changes underway at Toronto that would affect the technological decisions for the rest of the decade.

3.1 New Directions

As mentioned in the previous chapter, President Smith was caught off guard when he learned in February 1952 that the Computation Centre no longer planned to build its

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initialism and never spelled all in capitals.

[5] For a while, the British spelling of 'programme' was used in Toronto, but by about 1954, the now-favoured 'program' was in use. The latter will be used exclusively in this text except for direct quotes.

own computer. K.F. Tupper, chair of the Computation Centre Committee, informed Smith that it was the logical course of action, given the primary responsibility of the centre. The electronics group had not simply given up, as Smith assumed, but were in limbo. When the DRB diverted half of its grant to cover the cost of the Ferranti, it left insufficient funds to build the full-scale UTEC, which put everybody in an awkward position, unclear if the electronics group should continue their research or not. Though O.M. Solandt, Director of the DRB, suggested a new research program on individual electronic components, the UTEC team, Ratz in particular, was unwilling to accept much less than an entire computer.[6] The awkwardness persisted for months, as morale inside the Centre drifted downwards and the team contemplated an unknown future.

Uncertain as to how the university should react, Smith turned to Dean A.R. Gordon and W.H. Watson for advice. Gordon, head of the Department of Chemistry and dean of the School of Graduate Studies, was also a board member of the NRC and DRB. Watson had arrived at the university a year and half earlier from the NRC's Atomic Energy Project. These two men were ready to drop the electronics research altogether, noting that in the three years it would take to build the full-scale UTEC it could be obsolete.[7] Together, the three agreed that the university could not compete with commercial computer designs. Watson was most direct about the situation, as he regretted the time already lost: "we have put a lot of our energy into the machine rather than the computing." He believed that the best course was to redirect all the Computation Centre's energy to get the Ferranti computer running as soon as possible.[8] Yet Tupper, as chair of the Computation Centre Committee and an engineer,

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[6] K.F. Tupper to O.M. Solandt, 6 March 1952, UTARMS A1968–0007, Box 110, Folder 4.

[7] This is not entirely reasonable. Ratz's final plan in early 1952 offered a great deal of flexibility regarding the most crucial component, storage, so that if and when more promising technologies were ready they could easily be used. Moreover, the UTEC group would have argued that the Ferranti Mark I was already obsolete, with its serial rather than parallel operation.

[8] Memorandum – Conference with Watson and Gordon, 20 February 1952, UTARMS A1968–0007, Box 110, Folder 4.

was still hoping to push the DRB to continue funding the electronics program. With two opposing opinions divided along disciplinary lines the university was unable to present a unified front to the DRB. The agency hesitated in the face of one set of people averse to dropping the electronics research and another willing to forge ahead without.[9] Again, a conflict had erupted between Toronto and Ottawa concerning the proper mission of the Computation Centre.

By April, Tupper's hopes faded, as the two bright lights behind UTEC, Ratz and Kates, decided to leave. The two had waited long enough for a decision, and Ratz was leaving for a job with the Canadian Westinghouse Company while Kates planned to emigrate to the United States.[10] Without much in the way of recognition or encouragement for their research and effort on UTEC, they simply abandoned it. Without Ratz and Kates, Tupper had no reason to protract things, and he agreed to Watson's plan that the university withdraw from the field of electronic computer development.[11] This left about $70,000 of unallocated funds in the DRB grant to the Computation Centre, and though the DRB agreed to consider research proposals from individual professors none were forthcoming.[12] The money was eventually reallocated to cover the DRB's $20,000 annual commitment to the maintenance of the Ferranti computer, and the University of Toronto was officially no longer involved in electronics research and development leading to a computer.[13]

Some people, such as Gordon, felt that because "from here in it will be comput-

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[9] K.F. Tupper to S.E. Smith, 22 April 1952, UTARMS A1968–0007, Box 110, Folder 4.

[10] K.F. Tupper to O.M. Solandt, 4 April 1952, UTARMS B2002–0003, Box 2, Folder 1. H.H. Stein, who worked with Ratz and had been on the project since the beginning ended up at Ferranti Canada, to be trained in the maintenance of the Ferranti Mark I. Other team members simply left, with little further contact with the Computation Centre. Computation Centre Progress Report, 1 October 1951 to 30 September 1952, UTARMS B1988–0069, Box 1, Folder 2.

[11] The absence was short-lived. By the end of the decade, Toronto had sent physics professor R.W. McKay and engineering graduate student K.C. Smith to participate in the design of the ILLIAC II at the University of Illinois. Their plan was to build a copy of the computer in Toronto when Illinois finished theirs. See section 4.3 and chapter 5.

[12] Correspondence between S.E. Smith and O.M. Solandt, 25 April 1952 and 2 May 1952, UTARMS A1968–0007, Box 110, Folder 4.

[13] E.L. Davies to S.E. Smith, 25 March 1953, UTARMS A1968–0007, Box 110, Folder 4.

ing rather than designing, mathematics rather than machine," that Watson should replace Tupper as chair of the Computation Centre Committee.[14] Tupper's tenure was marked by indecision and confusion regarding the role of the Computation Centre, but Watson had stronger convictions. At the 1945 meeting of the Canadian Mathematical Congress he made an explicit call to develop a national computing centre.[15] While at Chalk River, first as Head of Theoretical Physics then as Assistant Director, he enthusiastically supported the mathematical work of Computation Centre. When hired as Head of Physics in 1950, one of his conditions was that he would have control over mathematical physics on campus, removing the subject from the domain of Department of Mathematics. Among other reasons, he wanted to guarantee the effectiveness of training people in computing methods.[16] He had good reason to suspect that the Department of Mathematics was not the best place for this, for its members had expressed little interest in the computing project past the initial stages, though they were not hostile to computing in general.

Gordon was not alone in his thoughts regarding the role Watson should play. As part of the joint funding arrangement between the university, the NRC, and the DRB that covered the costs of the Ferranti computer, a new seven person advisory Computation Centre Joint Committee was created, composed of at least two members from each organization. This was to be an arms length committee with infrequent meetings, intended to oversee the policy and operations of the Computation Centre by reviewing progress reports, not managing activity directly.[17] Above all, they were "not concerned with the development of computing machinery."[18] At their first meeting, in June 1952, Watson was made chairman of the Computation Centre Advisory Com-

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[14] Memorandum – Conference with Watson and Gordon, 20 February 1952, UTARMS A1968–0007, Box 110, Folder 4.

[15] See page 14.

[16] W.H. Watson to S.E. Smith, 31 May 1950, UTARMS A1968–0007, Box 63, Folder 1.

[17] Agreement made as of the 1st day of April, 1952 between NRC, DRB, and University of Toronto., UTARMS B1988–0069, Box 1, Folder 3.

[18] Computation Centre Advisory Committee First Meeting, 25 June 1952, UTARMS A1968–0007, Box 110, Folder 4.

mittee, at the suggestion of E.W.R. Steacie, recently elevated president of the NRC.

In November 1952 the University of Toronto Board of Governors approved of the joint funding agreement. Though Tupper had represented the university during the negotiations, he happily stepped back from the role so that Watson could replace him as Director of the Computation Centre early the next year.[19] The arrival of Watson came with another reorganization of the Computation Centre Committee in the New Year as its function was split in two. The Advisory Committee (Administration) was chaired by Watson and included Tupper, Gordon, Webber, and A.G. Rankin, comptroller of the university. This group had no executive power, but guided Watson with respect to financial matters. To manage the daily operations of programming and scheduling, Gotlieb was elevated to Chief Computer, and provided with an Advisory Committee (Programming). In addition to the original instigators of Webber, Barnes, Griffith, and V.G. Smith from 1945, nine newcomers were invited to join the committee. J.N.P. Hume was the sole representative from the physics department, but had already involved with programming Ferut. The others included five mathematicians and three engineers.[20] The relatively large number of mathematicians – a total of seven versus four from physics (including Watson) and four from engineering – misrepresents the actual activity in the Computation Centre. Though the NRC had made it clear that the reason it had supported the entire venture in the first place was the existence in Toronto of "the largest and most active Applied Mathematics Department in Canada," and that it was important that mathematics not be dissociated from the computing project, most of the calculations done that year and the next were at the behest of scientists or engineers, with little or no contact with the applied mathematicians.[21] Moreover, few of the new committee members took much direct interest in Ferut and they played little role overall in the development of the Computation Cen-

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[19] S.E. Smith to W.E. Phillips, 16 January 1953, UTARMS A1968–0007, Box 110, Folder 4.

[20] They were: G.F.D. Duff, A. Robinson, N.E. Sheppard, J.A. Jacobs, and G. Lorentz, along with B. Etkin, G.N. Patterson, and G. Sinclair.

[21] K.F. Tupper to S.E. Smith, 11 March 1950, UTARMS B1988–0069, Box 1, Folder 2.

tre; their connection was via their students who used it for computations related to their own research.

Watson and Gotlieb guided the Computation Centre for the next ten years, with little change in the organizational or command structure. The two had immense influence over the development of computing at the University of Toronto from this point forward. As the home of the only large-scale computer in Canada, this influence extended over much of the country for several years. However, exploring their roles at the heart of Canadian computing in the 1950s will be left until the next chapter. For now, the focus will be on the more immediate problem they faced operating the Computation Centre with an electronic computer. To paraphrase Gordon, from here on it was about learning how to program.

3.2 The Ferranti Mark I

When it was installed in Toronto in 1952, the Ferranti Mark I represented the culmination of six years of research in England at Manchester University and collaboration with Ferranti Limited, UK. Other comprehensive histories of the technology are available, but a brief summary here will illuminate the necessary technical details for a comparison.[22]

In July 1946, M.H.A. Newman obtained a Royal Society grant for a Computing Machine Laboratory housed at Manchester. Newman had been at Bletchley Park during the war and had drawn up the functional requirements of Colossus, the top code-breaking computer that was built there in 1943.[23] After the war, he moved to Manchester to join the mathematics department, and with the new lab intended to

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[22] For the pre-history of the Ferranti Mark I see: Martin Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", *IEEE Annals of the History of Computing* 2, no. 2 (April-June 1980), 130–168; Williams, *A History of Computing Technology;* Napper, "The Manchester Mark 1 Computers", 365–377; and F.C. Williams, "The University of Manchester Computing Machine", in Campbell-Kelly and Williams, *The Early British Computer Conferences,* 171–177.

[23] Simon H. Lavington, *Early British Computers* (Manchester: Manchester University Press, 1980), 11.

build a stored-program computer similar to that proposed in the EDVAC report. Also in 1946, F.C. Williams, of the Telecommunications Research Establishment (TRE), an electronics engineer of international reputation, visited the United States, and learned of difficulties that many had storing digital data for high-speed electronic computers. By the end of the year, Williams had devised a new technique, the use a cathode ray tube (CRT) as a storage device. Eventually known as a Williams tube, the technique stored one of two different charges on an array of spots on the tube. The two charges represented either 0 or 1, and could be detected using a metal grid or plate outside the tube. A continuous refresh cycle, reading and writing the charge, was necessary to maintain the data.[24] Newman brought Williams and his assistant, T. Kilburn, to the Manchester Laboratory in January 1947 where, with the support of the TRE, they were able to improve the CRT storage tube technology over the next year. By late autumn they had a 1024 bit prototype working, and in October, a successful 2048 bit storage system.

From this starting point, the team of engineers constructed the Small Scale Experimental Machine (SSEM) by June 1948 to test the Williams tube storage system as a component in a digital computer. Affectionately known as 'The Baby', it initially had just seven instructions. This was temporary, as unlike UTEC, its 32 bit word permitted many more instructions. The main CRT could store 32 words, while a second 'A' tube held the 32 bit accumulator and a third 'C' tube held the address of the current instruction, and a forth tube could be used to display the contents of any of the others. This was the world's first fully electronic machine to execute stored programs, though they were small problems used simply to verify that the prototype was working properly. The SSEM proved the suitability of Williams tubes for storage and was the first demonstration of the stored-program concept. One crucial distinction is that the SSEM was a serial machine: each word was accessed serially by a bit by bit horizontal sweep

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[24] The detector obscured a visual examination of the tube, making it necessary to implement a second display tube that would mimic the contents of the storage tube.

across a single tube. UTEC and von Neumann's IAS computer used a parallel storage scheme, which required that each bit of a word be stored on a different CRT. This increased the number of tubes and the complexity, but made for a faster machine.

In October 1948, the electrical engineering department decided to build a full-size computer, and in November Ferranti was contracted by the government to build a commercial production computer based on the result of this effort. The SSEM was gradually expanded over the next year: the 32 bit word was expanded to a 40 bit word that held one number or two instructions; the main store was increased to consist of two Williams tubes of 128 words of 40 bits; and a magnetic drum secondary store that could hold a further 1024 words was added. The arithmetic unit was improved to include multiplication. An innovative third auxiliary 'B' tube was added – named B because A and C were already taken – that contained two special 20 bit registers, known as B-lines. When an instruction was fetched from the store, the content of the second B-line was added to the instruction before execution (by convention, the first B-line always held the number zero). This enabled a program to modify its own instructions, a dangerous precedent, but the feature could also be used to modify the instruction addresses, which was very useful. For example, during a program that performed array or vector operations the B-line could be used to gradually increment a storage address for each array element. Today, these would be recognized as index registers, and they quickly became a standard part of computer architecture.

By autumn 1949, the design and operation of the modified SSEM, now known as the Mark I, was sufficiently stable that the specifications could be laid down for Ferranti to construct a properly engineered production version. Confusingly, this Ferranti machine was also called the Mark I, although other names were used: MADM, MADAM, Manchester Electronic Computer Mark II, MUDC, and MUEDC. The main store consisted of eight CRTs, the size and contents of which were known as pages. Each page held 64 words of 20 bits, or 'lines'. An instruction occupied one line and number two lines; arithmetic was thus 40 bit. The page, line, and word nomenclature was an obvious attempt to mimic the layout of a book.[25] The magnetic drum was also expanded to a maximum of 512 pages, and the number of B-lines was increased to eight, from two. There were 51 instructions to handle arithmetic, control, the B-lines, input, and output. It is interesting to note that because it used the same serial design as the SSEM, the Ferranti Mark I was inherently slower than UTEC, though vastly more capable and reliable. In February 1951, the first Mark I was delivered to Manchester University.

A second Mark I was ordered by the British Atomic Energy Authority, but it was unexpectedly cancelled after a new government was elected in 1951 and cancelled all outstanding orders above $100,000 as an austerity measure. The second Mark I was finished but without a buyer, until January 1952, when the University of Toronto Computation Centre agreed to purchase a Ferranti Mark I at the behest of the NRC and DRB. It arrived at the end of April 1952, with its new name Ferut, and Ferranti engineers began to set it up, aiming for operation by early September.[26] The computer consisted of two bays of cabinets about sixteen feet long, eight feet high, and four feet wide containing the bulk of the components.[27] The operator sat a desktop console, where input and output were handled. Though not entirely ready by that time, automatic checking routines had successfully tested the circuitry and by the end of September, few tasks were outstanding, none of which obstructed use of the computer.

Unfortunately, Ferut was not quite operational when it was demonstrated at the

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[25] The Ferranti Mark I nomenclature and word size was slightly different than the Manchester Mark I, but in both cases 20 bits were used for instructions and 40 bits for numbers. For simplicity, a 20 bit line will be defined as a single word.

[26] Computation Centre Progress Report, 1 October 1951 to 30 September 1952, UTARMS B1988–0069, Box 1, Folder 2.

[27] As an article in The Globe and Mail newspaper put it after Ferut was installed: "the main works fill two gleaming double rows of cupboards which any housewife would be proud to have bare in her kitchen" "Electronic Computer Mathematics Genius, Poor Checker Player", *The Globe and Mail* (September 6 1952), 19.

Association of Computing Machinery (ACM) conference, held in Toronto in September 1952. The ACM had formed in 1947, and in 1951 Gotlieb took the initiative to invite the recently established society to Toronto. It accepted the invitation, and Gotlieb took charge of local organizing and served as program chair. Though it was the second ACM general conference that year – the first was held in Pittsburgh in May – and the first ACM meeting held outside of the United States, the Toronto gathering was well attended. Many of the major computing projects in the United States were represented: the IAS Computer at Princeton; MANIAC (Mathematical Analyzer Numerical Integrator And Computer) of the Los Alamos Scientific Laboratory, the SEAC (Standards Eastern Automatic Computer) of the National Bureau of Standards (NBS), the ORACLE (Oak Ridge Automatic Computer and Logical Engine) of the Argonne National Laboratory, and the Computing Laboratory of the BRL (Ballistic Research Laboratories) at Aberdeen Proving Ground, whose computing facilities comprised the EDVAC, ENIAC, some Bell Relay calculators, and the ORDVAC (Ordnance Variable Automatic Computer).[28] The meeting also attracted attendees from the United Kingdom, including M.V. Wilkes, director of the EDSAC project at Cambridge, and several people associated with the Ferranti Mark I in some way: J.M. Bennett, D.G. Prinz, and M.L. Woods spoke on subroutines, C.S. Strachey gave a talk on non-mathematical programming, and A. Robinson discussed testing of Williams tubes at Manchester.[29] Of course, the Computation Centre was given a chance to impress the visitors with its own accomplishments. R.F. Johnston, responsible for the input-output on UTEC, gave a talk on the computer and visitors were given a tour of the facility.[30] But the star of

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[28] The ORDVAC was from the von Neumann family of computers. It was built at the University of Illinois under contract to the BRL, but a second very similar machine, known as ILLIAC, was also built and kept by at Illinois. See page 233.

[29] J.M. Bennett, D.G. Prinz and M.L. Woods, "Interpretative sub-routines", in *ACM '52: Proceedings of the 1952 ACM national meeting (Toronto)* (ACM Press, 1952), 81–87; Christopher Strachey, "Logical or Non-mathematical Programmes", in *ACM '52: Proceedings of the 1952 ACM national meeting (Toronto)* (ACM Press, 1952), 46–49; A. Robinson, "The testing of cathode ray tubes for use in the Williams type storage system", in *ACM '52: Proceedings of the 1952 ACM national meeting (Toronto)* (New York, NY, USA: ACM Press, 1952), 42–45.

[30] Johnston, "The University of Toronto Electronic Computer", 154–160.

the show was Ferut. The technicians were not quite finished with the installation, but things were running well enough that Strachey was able to demonstrate part of his checkers program to attendees.[31]

3.3 Learning How to Program

Though work continued on UTEC throughout the summer of 1952, long enough that it could be demonstrated to the ACM attendees, most of the Computation Centre activity that year was redirected towards Ferut. Two major branches of work were established that lasted until late 1953. The first was to simply learn how to use Ferut. The second major effort was to solve a series of backwater calculations for the St. Lawrence Seaway Project, submitted by the Hydro-Electric Power Commission of Ontario. These two interrelated activities were a trial by fire for the Computation Centre, as there was virtually no experience in Canada using modern electronic computers.

3.3.1 Painful Lessons

Writing programs for the Ferranti Mark I, or any of its predecessors, was never easy. Until mid 1949 merely inputting instructions was difficult. The SSEM had a panel of push buttons for input and output that consisted of visual inspection of the CRTs. That summer a proper input and output system based on standard teleprinter five-hole punched paper tape was added to the prototype. The equipment was acquired by Alan M. Turing from his former haunt, Bletchley Park. Turing had joined the Manchester project the previous September when he was appointed Reader in the Department of Mathematics and expected by Newman to "lead the mathematical side" of

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[31] Martin Campbell-Kelly, "Christopher Strachey, 1916-1975: A Biographical Note", *Annals of the History of Computing* 7, no. 01 (1985), 26. Ferut was working well enough to display the checker board on one of the display tubes, but not play a game.

the project. This meant he would be responsible for writing programs and developing a programming system for others to use.[32] With his assistant Cecily M. Popplewell, who arrived in October 1949, the teletype equipment allowed him to develop a programming scheme to handle input, output, and a small library of subroutines. With this final piece of the puzzle in place, many more programs could be written by Turing and others to solve real problems, such as work on Mersenne primes, the Riemann hypothesis, ray tracing, symbolic logic, and Laguerre functions.[33] After the Ferranti Mark I arrived in February 1951, Turing's programming scheme was quickly adapted to the new machine, but programming remained quite difficult on the Ferranti.

When the University of Toronto purchased Ferut, the system library was never specifically mentioned during negotiations, and no programming documentation was shipped with the machine. Much of this material made its way across the Atlantic in the form of experienced programmers from Manchester. In an era before prepackaged software and bound manuals, the transfer of knowledge was haphazard, even primitive. The first case took place when Gotlieb was sent to Manchester in late April for six weeks to learn how to use Ferut. During his stay, he was given instruction in programming, and wrote a few routines to solve simple problems. More importantly, he was able to obtain "the complete subroutine library at Manchester," by making physical copies of the paper tapes and bringing them home.[34]This amounted to approximately 9000 lines of code, which represented a sizable amount of experience and knowledge that could easily by transported.[35]

The first programming manual for the Mark I was written by Alan Turing in 1951, but it was not easy to read.[36] It is likely that Gotlieb brought a copy of this manual

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[32] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 135.

[33] Ibid., 136.

[34] Computation Centre Progress Report, 1 October 1951 to 30 September 1952, UTARMS B1988–0069, Box 1, Folder 2.

[35] Calvin C. Gotlieb, "The Cost of Programming and Coding", *Computers and Automation* 25 (September 1954), 14.

[36] Alan M. Turing, "Programmers' Handbook for Manchester Electronic Computer" (Manchester

with him back to Toronto. As Turing's interest in computing waned, R.A. Brooker was hired away from Cambridge to take over programming at Manchester and he compiled a more comprehensible second edition of the manual in August 1952.[37] Copies of this second edition eventually appeared in Toronto, but not immediately.[38] Instead, the first written documentation in Toronto that was useful to the novice programmer was provided by D.G. Prinz, when he visited Toronto in 1952. Prinz, an employee of Ferranti and part of their programming group, had written an introductory programming manual for the Mark I. It was intended as a supplement to the Turing and Brooker editions, which he considered "perhaps unnecessarily detailed for persons who only want to acquire a superficial acquaintance with its capabilities and the technique of programming in general, or who wish to obtain some guidance enabling them to estimate whether the solution of any particular problem by the machine may be worth serious examination."[39] The Turing and Brooker guides do go into greater depth, but Prinz's guide is certainly sufficient to give an introductory overview of programming the Mark I.

Prinz attended the Toronto ACM meeting in September 1952, and although he didn't bring a copy of the guide with him, he offered to recreate it there, from memory. Gotlieb was busy with the organization of the ACM meeting which left Worsley and J.N.P. Hume to talk with the visitors from Manchester about the Mark I. Worsley was already familiar with the machine; before she completed her 1952 doctoral degree at Cambridge, she apparently found time to work with the Manchester Mark I. A thor-

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University, 1951).

[37] He was given assistance by Popplewell and others at Manchester. R.A. Brooker, "Programmers' Handbook for the Manchester Electronic Computer Mark II" (Manchester University Computing Machine Laboratory, 1952).

[38] The first and second chapter has been found in the UT archives. Chapters from the Programmers' Handbook (Edition 2) For the Manchester Electronic Computers (Mark II), March 1953, UTARMS A2005–0021, Folder March 1953, and Programmers' Handbook (Second Edition) For the Manchester Electronic Computers (Mark II), Chapter 2, Coding Examples, UTARMS A2005–0021, Folder October 1953.

[39] D.G. Prinz, An Introduction to Programming on the Manchester Electronic Digital Computer, made by Ferranti Ltd, Moston, Manchester 10, UTARMS A2005–0021.

ough description of the machine and code samples can be found in her dissertation.[40] Hume was less experienced. He has described in his autobiography how he shared an office with Gotlieb – both were Assistant Professors of Physics – across the hall from where Ferut was installed in the Physics Building. He had already taken an interest in the IBM calculators for his own work and was now intrigued by the Ferut. He and Worsley sat with Prinz to learn what they could as Prinz recreated his manual. As Hume recalled: "Talk about your two-bit operation ... I sat there while he recreated it, not [at] an electrified typewriter. A typewriter. He typed this darned thing! ... He left us with this record of what it was."[41]

While in the United Kingdom, Gotlieb also invited any interested Manchester people with experience on the machine to visit Toronto to help with the training of programmers. He did hire one person directly – Peter Bandler, a student of Turing – but the majority of the direct assistance from Manchester was through temporary visitors.[42] After Ferut was installed, Christopher Strachey, an experienced Mark I programmer, visited for several months, and others such as Cecily Popplewell and Audrey Bates were loaned temporarily to Toronto from Manchester to help with programming and teaching others how to program.[43]

The first problem with programming Ferut was getting a program from paper into the machine, either into the electronic storage or onto the magnetic drum. On the SSEM it had been done at the console by tediously toggling switches to flip each bit of a word on the CRT. On the CRT, each word was aligned horizontally, and rather than recite 20 or 40 bits at a time, the five-bit international teletype code was adopted

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[40] Beatrice H. Worsley, "Serial Programming for Real and Idealized Digital Calculating Machines", Ph. D thesis, University of Cambridge (May 1952).

[41] J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R. Williams.

[42] Bandler would later join the Department of Aeronautical Engineering.

[43] Popplewell and Bates also had been Turing's assistants at Manchester but were excellent programmers and had helped write much of the Manchester subroutine library. Popplewell spent the first six months of 1953 in Toronto, and helped with the backwater calculations discussed below. Computation Centre Progress Report, 1 October 1951 to 30 September 1952, UTARMS B1988–0069, Box 1, Folder 2Bates remained and married, becoming Audrey Wallis.

Decimal	Symbol	Binary	Decimal	Symbol	Binary
0	/	00000	16	T	00001
1	E	10000	17	Z	10001
2	@	01000	18	L	01001
3	A	11000	19	W	11001
4	:	00100	20	H	00101
5	S	10100	21	Y	10101
6	I	01100	22	P	01101
7	U	11100	23	Q	11101
8	$\frac{1}{2}$	00010	24	O	00011
9	D	10010	25	B	10011
10	R	01010	26	G	01011
11	J	11010	27	"	11011
12	N	00110	28	M	00111
13	F	10110	29	X	10111
14	C	01110	30	V	01111
15	K	11110	31	$	11111

Figure 3.1: Teletype codes.[46]

in the fall of 1948 to simplify things.[44] For example, a 20 bit instruction was split into four teletype symbols that could more easily be transcribed to paper or read aloud. Over the summer of 1949 a teletype five-hole punched paper tape reader was added as the standard input mechanism.[45] However, these two decisions meant that Mark I users had to memorize the 32 teletype symbols, an awkward base-32 system. As shown in section 3.4.4, it was not until 1954 that more intuitive systems were devised by programmers in Manchester and Toronto.

Programmers generally wrote a program on a sheet of graph paper with two pre-printed columns of 32 rows, which were designed to mimic two pages of the electronic store. The columns and lines were numbered using the base-32 notation: the first was '/', the second 'E', and so on. Often, the paper was marked with comments, diagrams, or blocks to signify important segments of code. The style of hand programming was

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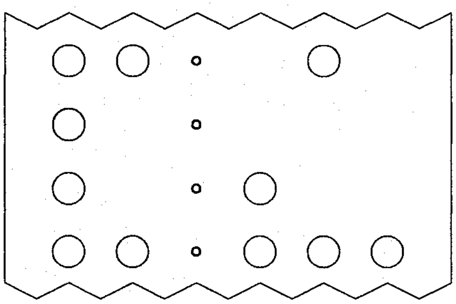
[44] See figure 3.1.

[45] See figure 3.2.

[46] One minute difference between the United Kingdom and North American teletypes was the £and $ symbols. Also note that this is little-endian binary – the least significant digits are first.



11 = J = 11010

01 = E = 10000

05 = S = 10100

31 = $ = 11111

The four lines correspond to a 20 bit word. The large holes correspond to 1s, the absence of holes to 0s, and the very small holes guide the paper. In base-32 it is JES$, and in decimal 361,663.

Figure 3.2: An example of punched paper tape.

copied directly to Toronto via the virtually identical Ferut programme sheets. Even the spelling of 'programme' was carried over from the British tradition, rather than 'code' or 'program' favoured in the United States. Around the same time as their contacts with Manchester were severed, the American spelling came to be used at the Computation Centre.[47]

When a programmer was satisfied with their program, it was punched to paper tape, using the five-hole teleprinter code. An input routine on the computer was needed to transfer information from the tape. This was a program, but stored permanently on the magnetic drum which made it available immediately after the computer was turned on. Several input routines were written for the Manchester and Ferranti machines, but their purpose was identical: "to read programs from tape, perform certain alterations on routines or numerical data, and store the routines or data in assigned locations in the machine."[48] The implementation and sophistication of each input routine varied, and most importantly this was the first respect in which Toronto's use of the Mark I diverged from Manchester's.

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[47] See, for example: Computation Centre, "TRANSCODE Manual" (University of Toronto, October 1955).

[48] FERUT System of Input and Output Organization, UTARMS A2005–0021, Folder October 1953.

The first input routine was written by Turing in the fall of 1949. Being the first, it set a number of standards which later versions had to accept, improve, replace, or erase. As information was read from tape, it was delimited by three different warning characters which indicated to the input routine what action was to be taken with the characters that followed. Generally, they indicated where instructions were to be stored on the drum. When the tape was transferred, the program was pulled from the drum to the electronic store and entered. Turing's first input routine has been called simple, primitive, and rudimentary, which it was. No attempt was made to avoid using the awkward teletype characters from earlier practice, which could have been done by using more readable symbols. This established a near-unbreakable pattern for every input routine that followed.[49] In the spring of 1951, Turing adapted his input routine for the Ferranti Mark I, which had been delivered to Manchester just prior. It was now known as Scheme A, and was more flexible than before with six additional warning characters, but did not do away with the teletype code.[50]

Over the summer of 1951, A.E. Glennie and R.A. Brooker arrived at Manchester, and Brooker wrote a new input routine known as Scheme B. Ready in the spring of 1952, it was a dramatic improvement over Scheme A, especially in handling the transfers from tape to drum and drum to electronic store. Normally, each track of the drum stored two pages that when needed for execution were copied directly to the store. Unfortunately, the drum was not very reliable at the time and faulty tracks played havoc with routines that were hard coded to use specific tracks. Under Scheme B, a directory was maintained that provided a link between tracks and routines, which were numbered. If a track happened to fail, the contents of the faulty track could be reloaded from tape to another part of the drum and the directory updated. The program itself would not need to be rewritten. Turing's Scheme A did offer drum direc-

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[49] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 141-142.

[50] See section 3 of Campbell-Kelly, "Punched Card Machinery", 122–155.

tories, but the implementation and usage was less elegant. It is also worth noting that Scheme B occupied just two pages - half as many pages as Scheme A. Unfortunately, Scheme B did not do away with the teletype codes.[142]

Brooker wrote a third input routine, known as TELEINPUT or Scheme C, in early 1953 that did not require that the programmer use the directory. This was only possible because the drum was now more reliable. By August 1953, it had replaced Scheme A and B entirely. A fourth input routine, F/TELEINPUT was written at Manchester by D.G. Gillies sometime the following year or so that extended TELEINPUT but did not replace it. Previous input routines limited routine storage to the first two pages in the electronic store but F/TELEINPUT could relocate them to any of the eight pages. Though not generally useful, special situations and programs might benefit from having several routines in storage rather than having to access the slower drum frequently.

To grasp fully the importance of directories, an understanding of how subroutines were handled on the Mark I is necessary. The concept of breaking large problems down into smaller, often reusable subroutines was widely known in the early 1950s, though implementations varied considerably from machine to machine.[51] With regards to how it was done on the Mark I, relative to most other British and American electronic computers, the CRTs provided a much smaller electronic store but the magnetic drum offered a large secondary store that most other systems lacked entirely. Thus, non-trivial problems were typically too big for the CRTs so programs were stored to the drum in sections, two pages per track. As the program progressed when one section had finished another was called to the electronic store. Handling these transfers properly was crucial to successful programming, and several techniques were devised to assist the programmer.

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[142] campbell-kelly80

[51] Cambridge pioneered subroutines on the EDSAC; many of their practices spread elsewhere. See Martin Campbell-Kelly, "The Development of Computer Programming in Britain (1945 to 1955)", *Annals of the History of Computing* 4, no. 02 (1982), 121–139.

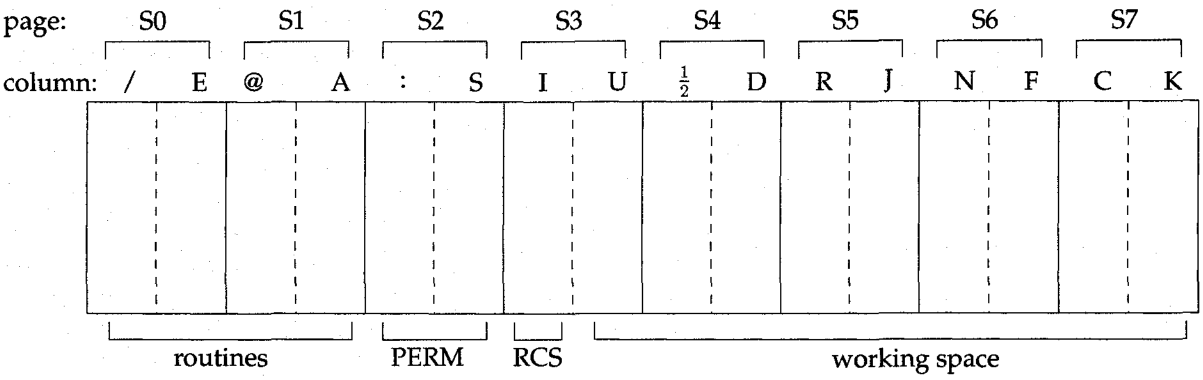

Figure 3.3: Storage organization on the Mark I.

The general organization of the storage on the Mark I can be seen in Figure 3.3. PERM, which will be explained momentarily, was kept in storage permanently, and contained useful data and code that all other routines might need. The first two pages, S0 and S1, were reserved for programs. As a track on the drum held two pages programmers designed routines to fit into either a half or full drum track, which corresponded to either the first store page S0, or the first and second store pages, S0 and S1.[52]

Programs were organized into a single master routine and collection of subroutines. Once the input routine loaded an entire program to the drum, the master routine was loaded to the store. It called the first subroutine, which might in turn call additional subroutines. When finished, the subroutine returned control to the calling routine at the point immediately following that at which it was left.[53] Each time a routine was called from the drum, it was placed into pages S0 and S1, wiping out the previous contents; returning control to an earlier routine meant re-reading it from the drum into the store. The code handling these transfers from drum to store and from routine to routine was called the routine changing sequence (RCS) and stored

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[52] As many sources have noted, programmers fought to squeeze code into two pages or less, but once that limit was met might not bother to optimize their code much further.

[53] A second kind of routine, an ad-routine (adjacent routine), did not return when complete, but called another routine. In this way, a routine that could not be made to fit in two pages could be chained together over more pages.

permanently in the PERM page, S2.[54]

The first RCS was devised by Turing for the prototype Mark I, and was carried over without much change to Scheme A on the production Mark I. Brooker's Scheme B improved on the technique considerably, by implementing a more elegant and optimal 'Wheeler Jump', a technique devised by D.J. Wheeler for writing subroutines for the EDSAC at Cambridge. Before Brooker joined Manchester he had worked at Cambridge and almost certainly borrowed the technique from Wheeler.[55] It was Scheme B's RCS that made it possible to refer to subroutines stored on the magnetic drum via the directory rather than specific tracks.[56] It used three lines: a self-referential record of the current position, a call to enter RCS, and the directory number on the drum of the subroutine. The self-reference enabled RCS to return to that point when the subroutine ended. RCS maintained a stack of these return points in a column 'I' of S3.

Little documentation has survived in Toronto concerning the arrival of Ferut and the initial programming experiences in the Computation Centre. This makes it difficult to determine which scheme was inherited from Manchester when Ferut was first switched on. The installation date is too early for Scheme C, and Scheme B was available on the Manchester Mark I in the Spring of 1952, around the same time Ferut was shipped to Toronto and Gotlieb visited Manchester. Gotlieb could easily have brought both Scheme A and Scheme B back, though he was tutored primarily by Brooker while at Manchester making the latter more likely. Worsley's Ph.D. dissertation includes routines that were written with Turing's Scheme A, but it is most likely that she completed this in England, not Canada. The copy of Prinz's manual that he recreated in Toronto does not include sufficient details to determine which Scheme was in use.

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[54] PERM also held useful constants such as the powers of 2 for quick multiplication.

[55] The Wheeler jump was a neat method by which instead of executing a sequence of subroutines that were implanted in the middle of a program, a program could jump to a remote subroutine that ended by returning control to the main program where it had left off. For more on the Wheeler jump, see Martin Campbell-Kelly, "Programming the EDSAC: Early Programming Activity at the University of Cambridge", *Annals of the History of Computing* 2, no. 01 (1980), 14.

[56] For Brooker's RCS, see Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 144.

However, programs written in Toronto several months after Ferut was operating do include instructions compatible with Brooker's RCS.[57]

One of the first projects in the Computation Centre was to improve the input and subroutine organization for Ferut. Eventually known as the Ferut Organization System, it began as early as Gotlieb's visit to Manchester, when he first made plans to modify and simplify the input routines with a view towards making the system easier to use and teach.[58]The two new routines, INPUT/T and RCS/T, were authored primarily by Hume, with assistance from Strachey, Gotlieb, Gellman, and other members of the Computation Centre staff.[59] The changes Hume made were not overly dramatic, but effective: "I thought ours was a nicer thing but it wasn't an original creation."[60] In particular, he cleaned up the warning characters of the input system. Turing had originally chosen warning characters "from those which are not very frequent in English," to enable a programmer to include English words on the tape, presumably for adding comments. Hume changed them to be more mnemonic and easier to remember. For instance, the warning character J was used instead of the original Q to print characters to the teleprinter as they were subsequently read from the tape. The purpose was to act as a check to guarantee that the correct routine was used. The character J was chosen as it suggested jot, because it was used to print the title of a subroutine as it was read from tape: "a little far fetched, but we agree it will assist your memory."[61] The characters U and D were chosen to suggest writing data Up and reading data

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[57] These early programs were Strachey's St. Lawrence Seaway subroutines, explained in section 3.3.2. As an experienced programmer from Manchester familiar with both schemes, presumably Strachey could have chosen either scheme if they were available. However, given the difficulties they were having in Toronto getting the drum to work reliably, it is likely he would have been forced to use Brooker's RCS and directories, if available.

[58] Computation Centre Progress Report, 1 October 1951 to 30 September 1952, UTARMS B1988–0069, Box 1, Folder 2.

[59] The '/T' suffix was commonly used to indicate a subroutine originally from Manchester but modified in Toronto. J.N.P. Hume, "Technical Developments: Input and Organization of Sub-Routines for Ferut", *Mathematical Tables and Other Aids to Computation* 8, no. 45 (1954), 35.

[60] J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R. Williams.

[61] FERUT System of Input and Output Organization, UTARMS A2005–0021, Folder October 1953.

Down with respect to the magnetic drum and the electronic store. The up and down language descended from a period in 1949 when the Manchester prototype Mark I's magnetic drum was housed one floor above the rest of the computer.[62]. The warning character K, which read data from the tape directly to the store, was not changed. "K suggests absolutely nothing but is used for this purpose by all other input systems."[63]

The principles of Brooker's Scheme B directory system were also adapted for Ferut, though with a more mnemonic warning character on the input tape. As useful subroutines were added to the program library, they were assigned permanent directory numbers, so that any programmer could call the routine from their code, without concern about faulty tracks on the drum. The first sixteen entries in the directory were reserved for any program and the contents were considered temporary. One small change was made in Toronto to Brooker's routine changing sequence (RCS/T). A subroutine was called in a program with four lines, instead of three: the current position, the call to RCS/T, a new control entry, and the directory of the subroutine. Some subroutines were written with multiple functionality, and control entries specified the entry location in the subroutine to each separate function. For example, the library routine COSORSIN/T had two control entries, $$ and $\frac{1}{2}$E, which a programmer specified in the RCS sequence to select whether they wanted to compute the cosine or sine of an angle.[64]

All of Hume's changes meant that the entire library of subroutine tapes from Manchester was now incompatible and had to be updated to meet the new standards.[65] To ensure that the wrong tapes were never used, all Toronto tapes began with a series of T characters instead of C.[66] Gotlieb later estimated that adapting sixty

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[62] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 135.

[63] Hume, "Technical Developments: Input and Organization of Sub-Routines for Ferut", 32.

[64] COSORSIN/T, 13 July 1953, UTARMS A2005–0021, FERUT Library. It is yet unconfirmed if control entries were introduced in Toronto or if Scheme B or latter schemes from Manchester included this feature.

[65] As was the case in Manchester when new schemes were introduced

[66] Notes on the Use of the FERUT Library of Routines, UTARMS A2005–0021, Folder October 1953.

Manchester routines to the Toronto input scheme was the equivalent of writing ten new routines.[67] In Manchester, a compound tape of all routines in the library was usually used by programmers for convenience.[68] In Toronto, the programme librarian kept a stock of pink individual routine tapes copied from a white master tape. The pink tapes could be carefully attached to a program tape with transparent scotch tape, or duplicated onto a program tape.

The Computation Centre benefited from more than the Manchester library of subroutines. A number of programming practices were also carried over.[69] One of those practices was program checking, better known today as debugging. One example of a checking technique was called peeping. A diagram of the Mark I console can be seen in Figure 3.4. By flipping a switch, the two large 6-inch S-tubes could display the contents of any of the eight electronic store pages, while the four 3-inch tubes monitored the B-lines, control tube, accumulator, and multiplier directly. The S-tubes displayed data in 32 rows of 40 bits, but to simplify visual inspection the bits were grouped horizontally into two large 20 bit columns and further subdivided into groups of five bits, to match the 5 bit teletype code. Similarly, the rows were grouped vertically into four rows to improve readability. By observing these tubes while a program was running, a programmer operating the computer had a comprehensive view of the program's progress by 'peeping' at the tubes. It was also possible to step through a program one instruction at a time by 'single pre-pulsing' and observing the tubes carefully to ensure that what appeared matched expectations.

Peeping was immediately picked up in Toronto, and many programmers became experts at the technique: "You could get to read the dots just as well as you could read the code ... it was quite the feat."[70] While it offered the programmer a great

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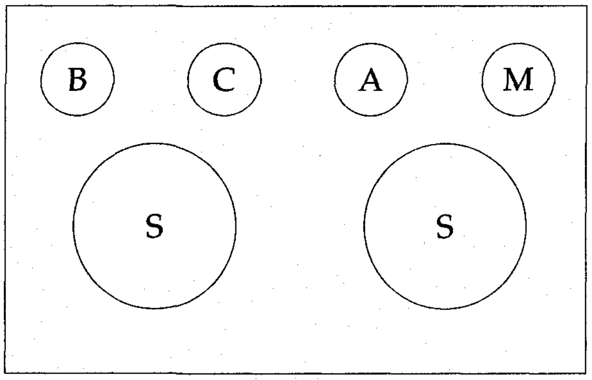
[67] Gotlieb, "The Cost of Programming and Coding", 14–15,25.

[68] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 145.

[69] There is a fine line between a program library and a programming practice. They are interdependent and an argument could be made that library is the embodiment of practice.

[70] J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R.



B	B-line	8	20 bit lines
C	Control	2	20 bit lines
A	Accumulator	4	20-bit lines
M	Multiplier	4	20-bit lines
S	Store	64	20-bit lines

All display tubes show a copy of the corresponding store.

Figure 3.4: Simplified diagram of the Mark I console.

deal of control and flexibility, it also required programmers to be machine operators. By contrast, at Cambridge EDSAC programmers were strongly encouraged to check their programs on paper and eliminate problems before running them on the machine, which was usually handled by a separate operator.[71]

Because peeping was labour intensive and time consuming, as the demand for computer time increased in Toronto other checking techniques were needed. One solution was a routine known as RAYCOCHECK, written by an external group of programmers from Raytheon. They had arranged to contribute a checking routine in exchange for computer time. Unfortunately, the code for the routine has been lost, but Hume has described the general operation of the routine: "It output the contents of the arithmetic registers, the accumulator, and the multiplier as each instruction was executed. It ran interpretively and took forever to generate its pages of teleprint characters."[72] In printing this historical trace of those two CRTs, it could be said that RAYCOCHECK was a lesser paper cousin of peeping. It printed the results in the awkward base-32 teleprinter characters, which would have made tracing the two registers by hand quite daunting, though no less challenging than by visual inspection of

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Williams.

[71] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 154.

[72] Hume, "Development of Systems Software for the Ferut Computer at the University of Toronto, 1952 to 1955", 14.

the tubes. In any case, RAYCOCHECK was used rarely and removed from the Ferut library in November 1954.[73]

A more sophisticated and frequently used routine was PRINTCHECK/T, written by Hume in mid 1953, with some assistance from W.H. Kahan.[74] The routine's description in the Ferut library reads: "To pause at certain lines of a programme (check lines), read and interpret warning characters from tape, which can cause the contents of the accumulator, multiplier, any specified B lines, and any specified set of storage lines to be printed out."[75] To use the routine, the special instruction VS/P was placed at an appropriate line in the program. During normal program execution, this line called the RCS/T routine to load PRINTCHECK/T. Based on the warning characters then loaded from tape, the check routine printed the requested tube contents in decimal, rather than teleprinter characters. The original program then resumed execution at full speed. When the program was tested fully, it was possible to replace the check lines with dummy instructions that the computer could pass over.[76] PRINTCHECK/T offered the power of peeping without the tedium of pre-pulsing through each instruction. It quickly became a standard check routine in Toronto and was assigned a permanent place on the magnetic drum. Even programmers considered virtuosos at the console who relied on peeping converted to the new routine when the time and cost savings were made clear.[77]

Hume did not write PRINTCHECK/T in a complete vacuum. It was adapted from two pre-existing routines, NUMBERCHECK from Manchester University, and

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[73] FERUT Library Supplement, November 1954, UTARMS A2005–0021, Folder November 1954.

[74] W.H. Kahan was an applied mathematics undergraduate student at the time, who also completed his master's and doctoral degrees at Toronto. See page 231.

[75] PRINTCHECK/T, 29 June 1953, UTARMS A2005–0021, FERUT Library.

[76] Hume, "Development of Systems Software for the Ferut Computer at the University of Toronto, 1952 to 1955", 15.

[77] One such person was Kates. Though had been UTEC cancelled, Kates continued to work at the Computation Centre on occasion. Indeed, he authored several parts of the subroutine library that developed for Ferut. However, when he formed his own company and was forced to pay for computer time, he quickly changed his habits and switched to PRINTCHECK/T, as Hume recounts in: J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R. Williams.

STOPANDPRINT from Ferranti. He also borrowed from a number of hardware features that were useful for checking programs. It was possible to run the machine at different speeds: one instruction at a time (single pre-pulse), full speed, and $\frac{1}{64}$ of full-speed. At about 50 instructions per second, this was too fast to see everything, but it was possible to track the progress of a program and perhaps see where it had failed. One switch, known as the development switch, when in the on position, caused the machine to print out the instructions as they were executed.[78] Another set of two switches enabled an optional stop mode, whereby if either of the two corresponding optional stop instructions were encountered in the program execution stopped. This was used to bypass tested sections of code and stop at a critical point for manual pre-pulse checking.

As historian Campbell-Kelly has pointed out, the existence of such powerful checking features implemented in hardware and available at the console of the Mark I made it unlikely that better off-line programming practices would develop.[79] Though it was awkward, the base-32 notation could be used by experienced programmers to locate immediately the contents of an address on the console S-tubes, another reason to operate the computer while testing a program. However, PRINTCHECK/T proved that these habits could be broken. This became important as more problems flowed into the Computation Centre and computer time became more expensive, which resulted in less time at the console for programmers.

3.3.2 The St. Lawrence Seaway Backwater Calculations

The other major branch of work in the Computation Centre during Ferut's first year was a lengthy series of calculations for the Hydro-Electric Power Commission of On-

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[78] Operating Inst. for FERUT, M.Audrey Bates, 13 January 1954, UTARMS A2005–0021, Folder January 1954.

[79] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 155.

tario.[80] Known as 'backwater' calculations, they were essential to the St. Lawrence Power Project, part of the larger St. Lawrence Seaway linking the Great Lakes to the Atlantic.

Canada and the United States had shared interests in developing and improving navigation and power generation along the St. Lawrence River since the late nineteenth century, although their views were not often harmonized. The Erie Canal, built between 1817-1825, was an important incentive at the time to expand the capacity of the St. Lawrence River: "The American waterway, which offered a fast, uninterrupted link between the growing industrial heartland of North America and the Atlantic Ocean through New York posed a serious threat to Canadian shipping and, in particular, to the development of the City of Montreal as a major port."[81] Throughout the nineteenth century, various canals and locks were built along the route, from the Welland Canal at Lake Erie to the Lachine Canal near Montreal, such that a viable lake-to-ocean route was in place by 1900. In the first half of the twentieth century inland iron ore and wheat shipments increased as did interest in electrical power generation. Treaties and commissions were struck between Canada and the United States to study the expanding with the construction of a deeper passage. The 1905 Deep Waterways Commission was followed by the 1909 International Joint Commission, the 1932 Great Lakes–St. Lawrence Deep Waterway Treaty, and the 1941 Great Lakes–St. Lawrence Basic Agreement; the last was not ratified by the United States Senate for eight years. Much of the American recalcitrance was due to influential rail and private industry interests opposed to St. Lawrence expansion. In response, in 1951 the Canadian Government threatened to create an all-Canadian waterway, which brought the United States back to the bargaining table. With careful negotiation, joint plans were put forth to deepen the navigation channels to 8.2m and construct a 2090

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[80] The commission was often referred to simply as "Ontario Hydro", or just "Hydro".

[81] Information Services, "St. Lawrence Seaway History", Technical report (The St. Lawrence Seaway Management Corporation, March 2003), 4.

megawatt Moses-Saunders Powerhouse near Cornwall, Ontario.[82] Construction on the St. Lawrence Seaway and the Power Project began in 1954 and was completed by 1959. That year it was officially opened by Her Majesty Queen Elizabeth II and President Dwight D. Eisenhower.[83]

The Computation Centre involvement in the project is not always clear. Some details have been lost to the usual ravages of history and some were deliberately obscured to prevent political recriminations. Despite the importance of the work to the Centre, only one publication ever emerged, in 1960, after the Seaway was completed.[84] Details were kept quiet throughout the 1950s, apparently to avoid upsetting relations between the United States and Canada.[85]

The Centre's involvement began officially in May 1952, when O. Holden, Assistant General Manager of Engineering at the Hydro-Electric Power Commission of Ontario, wrote to Tupper requesting the assistance of the Computation Centre.[86] The Commission was launching a study of the proposed St. Lawrence River Power Project, and needed help with the complex backwater calculations. The simultaneous deepening of St. Lawrence navigational passages to 8.2m and the construction of a power dam at Cornwall meant that the head-pond would extend upriver to Lake Ontario. Before the project, there was a 25m difference in water levels between these points, and it was necessary to assess the change in water levels and surface profiles along this entire length of the backwater. In practice, the calculations were limited to the approximately 29 km section between Chimney Point (near Prescott, Ontario) and the dam at Cornwall, where all but one foot of the fall occurred.[87]

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[82] G.C. Shaw and V. Kaczkowski, "St. Lawrence Seaway", *Canadian Encyclopedia* (21 March 2006 2006), ⟨URL: `http://www.thecanadianencyclopedia.com`⟩.

[83] Information Services, "St. Lawrence Seaway History", 4-6.

[84] Gotlieb, "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", 61–66. See also the companion piece, H.M McFarlane, "Backwater Computations for the St. Lawrence Power Project, Part A: Hydraulic Engineering Aspects of Computations", *The Engineering Journal* (February 1960), 55–60, 66.

[85] C.C. Gotlieb to C. Popplewell, 23 May 1958, UTARMS B2002–0003, Box 2, Folder 15.

[86] O. Holden to K.F. Tupper, 14 May 1952, UTARMS A1968–0007, Box 110, Folder 4.

[87] McFarlane, "Backwater Computations for the St. Lawrence Power Project, Part A: Hydraulic Engi-

As these were expected to be long and tedious computations, it was hoped that a machine solution was possible at the Computation Centre, and importantly, "over a much greater range of conditions than would be possible by ordinary methods."[88] This would allow three general scenarios to be considered: unimproved channels; an all Canadian navigation, improved channel; and a joint US-Canadian navigation, improved channel. Open water and ice cover conditions were also considered.[89] The calculations were made much more complicated by the numerous islands along the route, and 99 backwater cases were identified.

Holden's letter did not arrive out of the blue, but represented an official request for full-scale assistance. Trial computations had already been carried out at the Centre on desk calculators and the IBM punched card equipment. These had been requested through Professor G.R. Lord, of the university's Department of Mechanical Engineering, and completed in March of 1951 and March 1952.[90] As Gotlieb has suggested: "we did enough that they knew they wanted to do a lot more."[91] More to the point, "the extent of the calculations and the number of cases made it obvious that the existing hand methods were obsolete."[92]Given the complexity and time-consuming nature of full-scale solutions, the Hydro Commission was generous about fees but Holden made clear that this was to ensure the work would be routed to Ferut as soon as possible, though the computer would not be ready until the end of the year. For Tupper, this was to be the first major job for which the Computation Centre would be compensated financially, and he was anxious to demonstrate its usefulness. He asked Gotlieb to prioritize the calculations as high as possible, who estimated that the fees on IBM

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neering Aspects of Computations", 56–57.

[88] O. Holden to K.F. Tupper, 14 May 1952, UTARMS A1968–0007, Box 110, Folder 4.

[89] Gotlieb, "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", 66.

[90] Computation Problems, January 1957, UTARMS B1988–0069, Box 1, Folder 3, Problems 61 and 101.

[91] Calvin C. Gotlieb, interview by Michael R. Williams, 29 April 1992, Transcript provided by Michael R. Williams.

[92] Computation Centre Progress Report, 1 October 1951 to 30 September 1952, UTARMS B1988–0069, Box 1, Folder 2.

602A might lie between $500 and $1,000 per month.[93] Tupper assured President Smith that he would personally follow the progress.[94] The data was ready almost immediately, and by May 1952 the Computation Centre was able to start work with the IBM equipment.[95]

It is unclear how much progress was made with the 602A. When Ferut was considered operational in September 1952, all work was stopped on the calculators but attempts to restart it on the computer failed due to the lack of local programming experience. Despite the many years spent developing an electronic computer, there had been very little attention paid to the problem of writing programs for electronic digital computers. Gotlieb had spent a brief period at Manchester earlier that year, and Worsley had returned to Toronto with her considerable exposure to modern computers but it was not enough to tackle the project.

As a result the Computation Centre turned to Christopher Strachey for help, who was in Toronto for the ACM meeting, but planned to tour other North American computing centres on his trip. Watson, who was now more involved in the Computation Centre than Tupper, explained the backwater problem to Strachey and asked him to return to Toronto after his tour, to help with the programming and to give a lecture that might stimulate greater campus interest in electronic computing. Strachey evaluated Toronto's lack of experienced programmers and agreed to return.[96] Strachey had been hired earlier that year by the National Research and Development Corporation (NRDC), a recently formed organization designed to exploit and patent British technology. Strachey's role at NRDC was not always clear, but in this instance, it was in the interests of the NRDC that he work with the programmers at Toronto to help promote the Ferranti Mark I.[97]

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[93] K.F. Tupper to O. Holden, 17 May 1952, UTARMS A1968–0007, Box 110, Folder 4.

[94] K.F. Tupper to S.E. Smith, 17 May 1952, UTARMS A1968–0007, Box 110, Folder 4.

[95] St. Lawrence River Power Project Water Surface Profile Computation, 28 May 1952, NCUAS 71.1.80/C.37.

[96] C. Strachey, Notes taken on journey to Canada and USA, September 1952, NCUAS 71.1.80/C.33.

[97] Campbell-Kelly, "Christopher Strachey, 1916-1975: A Biographical Note", 25,27.

There were a number of problems preparing the backwater calculations for solution on Ferut. The first problem was of scale – the Ferut was a fixed-point machine with no hardware facilities for floating-point arithmetic. Numbers were stored in 40 bit words as integers (from 0 to $2^{40} - 1 = 1099511627775$) or as fractions with the decimal point on the extreme left (-0.5 to $+0.5$). The backwater equations handled numbers beyond these ranges. Fortunately, there was a floating-point subroutine, *Float Point*, that could manipulate two consecutive 40 bit words to hold the fraction and the mantissa for use with standard arithmetic operations. It was rather slow. A second problem was that the 267 data stations along the St. Lawrence River exceeded the storage capability of Ferut. The route was broken into four sections, and each was computed separately. While not fatal to the project in way, this provides some scope to the calculations.

Strachey is given the most credit for writing the program to solve the backwater equations. Although it has been suggested that by the end of the decade, the backwater calculations could have been easily written by "any competent FORTRAN programmer," Strachey was quite proud "to get the same results using machine code on an unreliable computer without floating-point."[98] Gotlieb guided the entire project along and other Computation Centre staff helped various parts of the program, including Worsley, Popplewell, and J.H. Chung, a Computation Centre mathematician. Two representatives of the Hydro-Electric Commission of Ontario, T.J. Hogg, and his assistant G.V.D. Crombie, were also involved.[99] The program relied on the library of subroutines from Manchester, but the rest of it was new.[100]

The final program contained about 2000 instructions, and the data tape ran nearly

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[98] Campbell-Kelly, "Christopher Strachey, 1916-1975: A Biographical Note", 27.

[99] Gotlieb, "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", 66. Hogg's contributions were considerable. Calvin C. Gotlieb, conversation with author, Toronto, 24 November 2005.

[100] Much of Strachey's hand written notes, routines, and plans survived, many written on pre-printed 'Manchester University Computing Machine Laboratory Programme Sheet's. See Backwater - FERUT, NCUAS 71.1.80/C.38.

2.5 km in length.[101] Without exploring the entire mathematical flow of the program, the most characteristic programming element evident is a deep distrust in the reliability of Ferut. In general, for lengthy calculations programmers were expected to double their work and compare results, to make sure that outcomes matched. Many checks were included throughout the program and in the computer operator's physical routines. Several precautions were also taken to prevent human error by the operators because most of the programmers, including Strachey, were not involved in the production runs. Once the routines had been perfected, careful procedures and instructions were written out for an unrelated set of operators to ensure successful runs. As each routine was read into the computer, the names were printed for verification. To ensure data integrity, the *Data Input* routine, which read and converted the human-readable numerical data to binary, was followed by an *Inverse Data Input* routine that reversed the process and reprinted the decimal data in the original format to provide a visual confirmation that no errors were made by the operator preparing the data or by the machine input. The *Master* routine verified that the correct data sections were loaded before each run by the use of check sums attached to the data and program tapes. A *Tally* routine performed a similar function at the end of each run. During the mathematical sections, to verify that the linear equations solved by elimination were satisfied, the *Section* routine substituted the results into the original equations.[102] As a final verification that the computer and computer program were producing proper results, several of the individual backwater cases and one entire run were computed by hand on a desktop calculator. They were then compared to the equivalent machine run, with favourable results: the water level profile was nearly identical along the first half and within 3 inches (7.6 cm) through the final 29 km.[103] From this it was estimated

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[101] H. Cotton to C. Strachey, 28 March 1956, NCUAS 71.1.80/C.37.

[102] Gotlieb, "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", 63-64.

[103] McFarlane, "Backwater Computations for the St. Lawrence Power Project, Part A: Hydraulic Engineering Aspects of Computations", 60.

that manual computations would have taken 20 man years of time, compared to the 500 hours of machine time over eight months consumed by Ferut.[104]

There was but one publication from the Computation Centre describing the project, part of a special 1960 issue of the *The Engineering Journal* celebrating the St. Lawrence Seaway.[105] Though Gotlieb had made several requests to the Hydro Commission over the years to publish an article, the Commission was worried about upsetting American-Canadian relations and prevented him from describing the role of the Computation Centre until the Seaway was complete.[106] Yet it is clear that the programmers inside the Computation Centre learned a great deal about how to program thanks to the backwater calculations. They were complicated and taxed even Ferut's capabilities, but it provided them with an ideal training ground: "we had to learn the technique for systematically handling large inputs and large outputs, and carrying out error checks, and so on."[107] Just as importantly, they learned how to deal with an unreliable machine "although . . . we did an enormous amount of good calculations by being patient."[108]

In many ways, the backwater calculations were the equivalent of the Atomic Energy Project calculations done in the late 1940s. They were both a matter of trial by fire, learning how to use the computational technology as they went. Both problems were considered important by the Computation Centre leadership, for the obvious reason that they needed to impress outsiders. In the earlier case, it was to ensure that the NRC was happy about sponsoring a computing centre at the University of Toronto. In the latter case, it was to generate a good reputation with industrial customers. The Ferut operating costs were only partially covered by government grants, the rest were

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[104] Gotlieb, "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", 66.

[105] Ibid., 61–66

[106] C.C. Gotlieb to C. Popplewell, 23 May 1958, UTARMS B2002–0003, Box 2, Folder 15.

[107] C.C. Gotlieb, Transcript of Presentation given at Los Alamos, June 1976, UTARMS B2002–0003, Box 14, Folder 5.

[108] Calvin C. Gotlieb, interview by Henry S. Tropp, Computer Oral History Collection, edited transcript of tape recording, 29 June 1971, UTARMS B2002–0003, Box 8, Folder 1.

expected to be made up by charging customers for the computational work. Their success with the backwater calculations brought in $35,000 to the Centre in 1953.[109] This was a positive signal to interested groups and future customers such as the Dominion Observatory, major Canadian insurance companies such as Manufacturer's Life, and industrial corporations such as A.V. Roe, Eastman Kodak, and Imperial Oil.[110] For several years, income from problems submitted by these companies would keep Ferut and the Computation Centre operating in the black.

3.4 Automatic Programming and TRANSCODE

3.4.1 The Problems with Programming

Unfortunately, none of the program checking tools developed at Manchester and Toronto eliminated the fact that writing programs for the Mark I was hard and time-consuming. The three specific problems that all Mark I programmers had to overcome were: dealing with the small electronic store, scaling non-integer operations, and the painful teletype code used to read and write programs. The input and RCS routines helped to manage programs broken into multiple pages and transferring subroutines between drum to store. This did not relieve a programmer of the burden of having to squeeze their code into two pages, or of the mental gymnastics required to manage the directory and jump between subroutines. Even experienced programmers could still find it difficult to fit data into the store for efficient calculation, or even onto the drum. A matrix operation required careful preparation in order to fit vectors into the electronic store. The St. Lawrence Seaway data tape was over 2 km long and the overall problem had to be split into four sections because the drum was simply not big

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[109] Computation Centre Earning, 1 January 1953 to 31 August 1953, UTARMS B1988–0069, Box 1, Folder 3.

[110] See these and other companies in Computation Problems, January 1957, UTARMS B1988–0069, Box 1, Folder 3.

enough to contain the data. These are examples of advanced problems, but at least it can be said that the input routines made life easier for beginners. The scaling and teletype code problems did not go away so easily.

As the Computation Centre learned during the St. Lawrence Seaway project, the Mark I was a fixed point-machine with no hardware facilities for floating-point operations. Thus for non-integer calculations it was restricted to numbers between $\frac{1}{2}$ to $-\frac{1}{2}$, known as the "fractional ± convention". In the early 1950s several methods were developed to deal with the problem for the Mark I in England. At Ferranti, Prinz wrote an interpretive floating-point routine in 1951 but it was only used at Ferranti.[111] In mid 1952 Brooker wrote a more widely used scheme called FLOATCODE, which was part of the Scheme B library. It was much slower than normal arithmetic, by up to a factor of ten, but very useful. FLOATCODE was copied along with other subroutines to Toronto, but instead a routine called FLOATPOINT was used and possibly written by Strachey for the St. Lawrence Seaway Project.[112] However, many of the mathematical routines in the Ferut library relied on the fractional ± convention, rather than floating-point operations. This suggests that in the interests of speed, programmers preferred to scale their work mathematically in advance rather than suffer at the hands of the slower floating-point subroutines.

It might seem that scaling numbers should not be that hard, modifying equations before coding to keep the numerical results within the $\frac{1}{2}$ to $-\frac{1}{2}$ boundary.[113] Most of the problems that were solved on Ferut in the early years were scientific in nature, that would have otherwise been attacked on desk calculators by the scientists proposing

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[111] See Bennett et al., "Interpretative sub-routines", 81–87 and Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 155.

[112] FLOATPOINT may have been a derivative of FLOATCODE. FLOATCODE was available until late 1954 when it was declared obsolete and removed from the library. FERUT Library Supplement, November 1954, UTARMS A2005–0021, Folder November 1954.

[113] Gotlieb gives an example of this with regards to the St. Lawrence Seaway calculations in Gotlieb, "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", 61–66. Campbell-Kelly also shows how it could be done with the Mark I for the TPK algorithm. See Appendix B.

the work. They should have been comfortable, at least in principle, with the problem of scaling. Moreover, this was insufficient to maintain a high degree of accuracy at both the most and least significant ends of the result. With a desk calculator, a human operator could move the decimal point intelligently at each step and minimize rounding errors. Converting this process to electronic computation required careful programming and planning to accommodate careful decimal points shifts that did not lose accuracy.[114] It was a near universal problem for programmers in the early 1950s, such that implementing floating-point operations in hardware became one of the next most crucial issues in computer design, particular those machines intended for scientific use.[115]

The difficulty of using teletype code has already been explained, but cannot be overemphasized. When the hardware engineers first began using the base-32 notation, it was a clever means of quickly reading 20 or even 40 bits during the machine's development phase. But it made the Mark I series of computers perhaps the most difficult to write programs for in the early 1950s. It took time and effort to learn to read and write in the base-32 notation, but it was absolutely essential. Virtually every Mark I manual or programming guide began with the admonition to commit the notation to memory as soon as possible. Yet that after five years of use programmers were still forced to use teletype characters was more properly a remnant of the input routines and the conventions fixed around them, rather than limitations of the machine design. As Prinz pointed out in his 1952 introduction to the Mark I, "it is quite possible to programme the input organization in such a way that all input can be supplied to the machine in decimal form."[116]Yet to continue to use teletype code was simply more convenient for the small number of programmers already fluent, who could draw

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[114] W. Fraser, "Experience of the Defence Research Board in Mail Order Computer Service", in *Canadian Conference for Computing and Data Processing, Proceedings* (Toronto: University of Toronto Press, 1958), 370–376.

[115] Ceruzzi, *A history of modern computing*, 63–64.

[116] D.G. Prinz, An Introduction to Programming on the Manchester Electronic Digital Computer, made by Ferranti Ltd, Moston, Manchester 10, UTARMS A2005–0021.

from a large subroutine library. Prinz listed several other advantages. As originally intended, the 5 bit teleprinter system was better suited to visually reading the console S-tubes than a mental binary to decimal conversion. This system permitted an exact correspondence among what appeared on the program sheet, the punched tape, and the console tubes and any discrepancy could be quickly found and corrected. Because each page of electronic store contained two columns of 32 20 bit lines, it was easy to pin-point each address. By numbering each line and column using the 32 teleprinter codes, a single address could be given with two characters.[117] However, these were only advantages for an experienced user of the Mark I, not a novice programmer with one or two scientific problems they hoped to solve on a new electronic computer.

This situation was not unique to the Mark I, and the problems of floating-point, managing storage, and non-intuitive coding were universal at the time. Learning how to write computer code was hard: "Programming in the early 1950s was a black art, a private arcane matter involving only a programmer, a problem, a computer, and perhaps a small library of subroutines and a primitive assembly program ... the success of a program depended primarily on the programmer's private techniques and invention."[118] The priesthood of professional programmers that emerged at the time did little to improve things, preferring to protect their own professional turf from invasion by amateurs, or even inquisitive but uninformed managers. The job of programming was kept difficult and inaccessible to those outside of the club by avoiding inventing more sophisticated aids.[119]

Despite the exclusive and protective nature of the priesthood, not all felt the same and many recognized the programming economic crisis they faced. It took months to learn how to program and longer to become truly competent. After that, it might still take weeks to write a program and check it for errors, at which point the costs of de-

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[117] For example, the address SC would refer to line S of column C.

[118] John W. Backus, "Programming in America in the 1950s", in Howlett et al., *A History of Computing in the Twentieth Century: A Collection of Essays*, 126.

[119] Backus, "Programming in America in the 1950s", 128.

veloping the program could easily exceed the benefits of using it. One 1953 estimate suggested that 50% to 75% of computer costs were tied up in programming and checking.[120] Moreover, in many computer centres, particularly academic ones, the computer was intended to serve a wide body of interested parties: scientists, faculty members, graduate students, and outside individuals such as government or industry scientists. While it was hoped that outsiders could write their own code, the reality was that "customers with 'small' problems will not be encouraged if they have to spend more than half a day on learning to code."[121] If the time to learn the new programing skills exceeded that necessary to solve their problem at a desk calculator, who could blame them? The alternative was to hand the task off instead to experienced programmers, who were already busy. The computing field was facing a bottleneck of increasing demands impeded by a lack of skilled programmers.

This was a problem at the University of Toronto, where it had taken months for a mere handful of people to learn how to program Ferut with help from experienced Manchester programmers. The few derivative attempts to teach the basics of programming to others in Toronto were of mixed success. Some people picked up the lessons quickly, while others struggled. But even those who passed such courses could run into problems a few months or a year later. One early Ferut user recalled that even people at the university who could maintain casual contact with the machine would still have difficulty knowing all of the conventions developed by those routinely at the console, so that "programming efforts would necessarily be mere guess-work." Ultimately, "these obstacles were just as troublesome for people at the university not engaged full time with the machine as for people . . . out-of-town."[122] The NRC and DRB were funding a computing centre for all of Canada, not just scientists and engineers at the University of Toronto. If training was this difficult and students and

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[120] John W. Backus, "The IBM 701 Speedcoding System", *Journal of the ACM* 1, no. 1 (1954), 4.

[121] R.A. Brooker, "The Programming strategy used with the Manchester University mark I Computer", *Proceedings, Institution of Electrical Engineers, Part B, Supplement* 103 (1956), 154.

[122] Fraser, "Experience of the Defence Research Board in Mail Order Computer Service", 373.

faculty members on campus ran up against this much trouble it could add up to an expensive white elephant in Toronto.

Of course, few outsiders, if any, were familiar enough with the IBM 602A to send plug-board diagrams to run on the mechanical calculator in the Computation Centre. Instead, people approached the Centre with specific equations to determine if and how they might be handled.[123] The best and only way to respond to these questions was to have specially trained mathematicians on hand, able to evaluate and prepare scientific problems for rapid machine solution on the 602A. Technicians or human computers could operate the machines, but somebody had to provide the interface between the scientist and the plugboard. Through luck or foresight, the Computation Centre managed to find the good people, such as J.P. Stanley and H.S. Gellman, for this position.

Once Ferut was installed and operational the obvious solution was to extend this system and arrange for the NRC, DRB and Atomic Energy of Canada Limited (AECL) to station their own representatives at Toronto to write programs for their colleagues. "There were not many programmers and it was a reasonable assumption that a pooling of resources would be beneficial to all parties concerned."[124] If necessary, the representatives received intensive on-the-job programming training. Part of the arrangement between the university and these agencies was that in exchange for providing capital support and ongoing maintenance fees, they received 20 hours of free computer time per month (decreased to 15 hours per month in 1954). The first representative was none other than Gellman, who was hired by AECL to continue to provide the same service as he had done with the punched card machinery.[125] Although AECL was not a direct financial contributor, the director W.B. Lewis had been instrumental in bringing the Mark I to Toronto and there was likely no other project in Canada

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[123] N. Mendelsohn to B.A. Griffith, 17 August 1949, UTARMS B1988–0069, Box 1, Folder 2.

[124] Fraser, "Experience of the Defence Research Board in Mail Order Computer Service", 370.

[125] Harvey S. Gellman, interview by Michael R. Williams, 9 June 1992, Transcript provided by Michael R. Williams.

with higher computational priorities. In June 1953, the Defence Research Board sent W. Fraser, who was joined in September by J.F. Hart from the National Research Council.[126] By March 1954, the AEC, DRB, and NRC had used just over 114 hours, 46 hours and 39 hours respectively of machine time.[127]

The nature of their work was collaborative, between the researcher originating the problem and the programmer. For example, Hart spent most of his time in Toronto but travelled every six weeks or so to Ottawa to consult with NRC scientists who submitted problems. His superior in Ottawa, H.E. Howlett, Director of the Applied Physics Branch, also helped co-ordinate the effort, managing the financial aspects and resolving issues with other participating NRC Divisions. By the end of 1953 twelve problems had been submitted from the NRC to the Computation Centre, such as tabulating functions, solving differential equations, and tackling eigenvalue problems.[128] Some were considered straightforward, suitable for routine solution by means of the standard Ferut library. Others were candidates for a set of matrix routines developed in Toronto, to invert large matrices up to order 48 or discover eigenvalues and eigenvectors for symmetric matrices up to order 32 and non-symmetric to order 64.[129] However, not all problems were tackled so easily. Many were novel in nature and required new routines to be developed, a costly enterprise: the 20 free hours of machine time was insufficient to support the overwhelming amount of programming time necessary, and extra time had to be purchased. The eventual benefit would be a broad library of useful routines, but until then numerical solutions remained expensive for the NRC.[130] One interesting side effect was that the estimated financial cost of a problem could determine its destiny. Only those with "real theoretical or practical

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[126] Fraser, "Experience of the Defence Research Board in Mail Order Computer Service", 370–376; Howlett, L.E. to Watson, W.H., 22 September 1953, LAC RG77, Volume 211, File 15–17–13–C–4.

[127] Meeting of Joint Committee of Computation Centre, 2 April 1954, UTARMS B1988–0069, Box 1, Folder 3.

[128] J.F. Hart to L.E. Howlett, 14 December 1953, LAC RG77, Volume 211, File 15–17–13–C–4.

[129] J.F. Hart to L.E. Howlett, 30 December 1953, LAC RG77, Volume 211, File 15–17–13–C–4.

[130] L.E. Howlett to All Directors, 13 July 1954, LAC RG77, Volume 211, File 15–17–13–C–4.

value" were submitted to the Computation Centre, eliminating "those computations which people can so readily conceive as being nice to have."[131]

Although many people took great interest in the potential of a machine capable of drastically shrinking hundreds of human computer hours worth of their work, theys often had little idea how to proceed. Just as with the IBM 602A, prospective problems had to be carefully examined to ensure they were suitable for machine solution. As Gotlieb wrote in 1951, when the Computation Centre was preparing to transition from plugboards to programming: "Few people realize the detailed extent to which a mathematical problem must be broken down before it can solved on a high-speed computer."[132]

It was often necessary to ensure that problems submitted were not hiding ambiguities or even falling into the category of having no solution. "The solution of a differential equation has been requested when no unique solution existed; values of integrals have been requested when the (infinite) integral was divergent; solutions for inconsistent systems of equations have been sought, and various other impossibilities have been stated as the requirements for the solution of a problem."[133] While potentially embarrassing, such blunders were normally caught during the consultation phase by the representative in Toronto. The programmer also had to ensure that the problem as submitted matched the intentions of the originator. This might have entailed verifying ranges, intervals, or significant digits, or even the numerical method of obtaining a solution.

Strangely, in 1958 Fraser observed that during his early years in Toronto "the desk calculator was to remain the central object in computing plans."[134] Most scientists and human computers maintained libraries of tables and collections of desk calculator routines which they could refer to during their own hand computations. Rather than

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[131] L.E. Howlett to J.H. Parkin, 15 March 1954, LAC RG77, Volume 211, File 15–17–13–C–4.

[132] Gotlieb, "Machines for Thought", 5.

[133] Fraser, "Experience of the Defence Research Board in Mail Order Computer Service", 374.

[134] Ibid., 371.

submit problems for the Computation Centre to solve outright, they obeyed an earlier pattern of the 1940s, and requested new or more detailed function tables to incorporate into their computations. This had been the accepted role of expensive high-speed electronic computers. The Harvard Mark I was often dedicated to printing tables of Bessel functions.[135]

Other problems arrived that were normally solved by hand using large sets of tables as the crucial starting point of the computation or regularly referred to a table. These techniques turned out to be entirely unsuitable for electronic solution as it was general impossible to include large tables in a particular program. New techniques had to be found to solve the same problems in ways more appropriate for the new technology. For example, desk calculations are floating-point as the human operator can adjust the decimal point as necessary. Because Ferut was a fixed-point machine the scaling problem was a very involved part of the programming process. Another problem was space: calculations at a desk are afforded literally unlimited storage space by adding another sheet of paper to the pile. Although Ferut had a sizable magnetic drum, it was not comparably infinite or inexpensive. Difficulties like these were inescapable when attempting to translate desk calculator routines into corresponding computer programs. Eventually, the Computation Centre was able to rely on its own expanding library of routines and a growing body of knowledge surrounding the problem of electronic scientific computation.

The overall experience of these external representatives illustrates the fourth problem facing programmers in the early 1950s. Aside from the first three of limited storage, no floating-point hardware, and general difficulties with input and output, they needed to learn what sorts of problems could be solved and how best to solve them. It did not matter if the act of programming was made much easier if outsiders were unaware of the new possibilities afforded by electronic computers.

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[135] Williams, *A History of Computing Technology*, 242.

3.4.2 Automating Programming in the 1950s

The entire previous section can be summarized easily: writing programs in the early 1950s was hard work. Or, in a slightly longer expression of the same theme, "the transformation from a vague problem specification in natural language to a precisely stated step-by-step computation procedure (i.e., an algorithm) is a very difficult one, involving a significant amount of mathematical maturity, experience, and training."[136] Any difficulty writing a program meant it took longer, which drove up the cost quickly. Thus a technique known as automatic programming, or autocoding, was born. The point was to make programming easier, though the true incentive was to reduce the costs and time spent by programmers. At its heart, the idea was to use a symbolic language that was easier for programmers to read and write. A special program, known as an interpreter or compiler, then translated the symbolic code into machine code, that the computer could execute. There were doubts that these special programs could produce machine code that was as fast and efficient as that written by a human, but this did not always matter, if it significantly reduced the length of time it took to write the program in the first place.

3.4.3 Speedcoding on the IBM 701

One of the earliest North American attempts at automatic programming was the IBM 701 Speedcoding System.[137] It was written in 1953 at IBM's New York Scientific Computing Service. While not the first such attempt or the most significant of the era, Speedcoding was a predecessor of FORTRAN, one of the most important programming languages ever. The actual design and implementation of Speedcoding has little connection to FORTRAN, but several people involved with Speedcoding went on

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[136] William E. Ball, "Programming Languages and Systems", in Pollack, *Studies in Computer Science,* 54.

[137] The IBM 701 was IBM's first large-scale electronic computer manufactured in non-trivial numbers. Ceruzzi, *A history of modern computing,* 34–36.

to help design and write FORTRAN for the IBM 704 the following year.[138] Historically, Speedcoding is best seen as being a successful demonstration of autocoding as a sound concept worth further development, which is how it relates to developments at Toronto.

At the September 1953 meeting of the ACM at MIT, John Backus, the Speedcoding project supervisor, presented a paper describing the system.[139] It caught the eye of the programming group at Toronto for it appeared to solve many of the same problems on the IBM 701 as they faced with the Ferranti Mark I.[140] The machines shared several inadequacies. Like the Mark I, the IBM 701 lacked floating point hardware.[141] Therefore it was necessary to write complicated scaling routines or rely on slow floating-point subroutines. Unlike the Mark I, the IBM 701 did not have B-lines, otherwise known today as index registers, which meant that repetitive code was undesirably long or overly complicated. Both machines used Williams tubes for primary storage but relied on slower secondary storage for larger calculations: a magnetic drum was available for the IBM 701 in addition to magnetic tape. Although the IBM 701 had a larger electronic store (at least eight times greater than the Mark I) managing the transfer of primary and auxiliary storage required just as much care. Fortunately, IBM 701 programs were prepared in ordinary decimal and conversion to binary for execution was handled as part of the standard library, avoiding the awkward base-32 programming notation that plagued the Mark I.[142]

Speedcoding caused "the 701 to behave like a three address floating point calcula-

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[138] They were John Backus and Harlan Herrick.

[139] Backus, "The IBM 701 Speedcoding System", 4–6.

[140] At a 1954 US Navy symposium on automatic programming, another paper was presented on Speedcoding, too late to have influenced any work in Toronto. Nor do the proceedings from the symposium appear to have been available in the Computation Centre. John W. Backus and H. Herrick, "Speedcoding and Other Automatic Programming Systems", in *Proceedings of a Symposium on Automatic Programming for Digital Computers* (Washington DC: The Office of Naval Research, May 1954), 106–113.

[141] The 701 was a scientific computer, intended specifically for scientific computation, but floating-point hardware did not appear on an IBM computer until the IBM 704 was introduced in 1954.

[142] International Business Machines Corporation, "Principles of Operation, Type 701 and Associated Equipment, Form 24-6042-1" (New York: International Business Machines Corporation, 1953).

tor."[143] By means of a pseudo-code – an arbitrary but easy to read instruction language – it was possible to write programs that were translated by the Speedcoding system into native instructions for immediate execution. By default, instead of fixed-point arithmetic, all numeric operations were handled with floating-point subroutines that included square root, sine, arc tangent, exponential and logarithm functions. Three address Speedcoding instructions replaced the single address IBM 701 machine instructions. It was believed this simplified the job of programming – many automatic programming systems used three-address instructions. A computer instruction consists of an operation and the address or addresses that specifies the operand. Most early machines, such as the Ferranti Mark I or the IBM 701 were single address, but multi-address computers, typically two or three address, were common in later years. Each technique offered numerous advantages and disadvantages but there appears to be no consensus among designers or programmers in the 1950s as to a preferred arrangement. Some favoured the flexibility of single addressing, whereby any desired outcome can be programmed, at the cost of code length and complexity. Others favoured the simplicity of programming with multiple address instructions capable of doing the job of a large section of single address instructions. It is arguably easier for a novice to understand three address instructions, making it a good choice if the goal is to make most programming easier to learn.[144]

In this sense, Speedcoding offered "an extensive set of operations to make the job of programming as easy as possible."[145] For example, it effectively simulated the existence of three index registers that the machine lacked. It was estimated that this reduced the number of instructions in a loop by half. Speedcoding included several checking features to ease debugging and ensure that both the machine and program

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[143] Backus, "The IBM 701 Speedcoding System", 4.

[144] Gotlieb and Hume, *High-Speed Data Processing*, 78-81 and Maurice V. Wilkes, David J. Wheeler and Stanley Gill, *The Preparation of Programs for an Electronic Digital Computer*, 2nd edition (Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1957), 11-12.

[145] Backus, "The IBM 701 Speedcoding System", 4.

were operating properly. It also featured easy input and output operations, loading and printing instructions and data from the tape, drum, and punched card. As it was necessary to load the Speedcoding program itself to re-translate the pseudo-code each time, it was considered interpretive.[146]

Speedcoding was a clear success. Programs that might have taken weeks to write using the native IBM 701 instruction set could be written in a few hours. Decreased programming and debugging time reduced the cost of computing, making it "economical as well as convenient to use."[147] It solved the outsider bottleneck as well: armed with a Speedcoding manual customers were successfully able to write their own programs and submit them ready to run on an IBM 701, with minimal aid from experienced hands. In Toronto, they learned about Speedcoding and Backus' work through his talk and a subsequent paper published in the widely read *Journal of the ACM* (JACM). They found the results encouraging enough to consider writing their own automatic programming system.

3.4.4 The Manchester Autocodes

However, the staff of the Computation Centre were not the first to write an automatic programming tool for the Ferranti Mark I. That distinction belongs to A.E. Glennie, who over the summer of 1952 devised a system while at Manchester that he called AUTOCODE.[148] The distinct advantage AUTOCODE had over earlier Mark I programming schemes was that the awkward base-32 notation was replaced with symbolic algebra and English instructions.[149] This was Glennie's major goal: "to make

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[146] The alternate arrangement, whereby the entire pseudo-code program is translated in advance, and can often be stored and executed separately, is known as a compiling.

[147] Backus, "The IBM 701 Speedcoding System", 6.

[148] There are two widely available historical descriptions of AUTOCODE: Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 130–168, and Donald E. Knuth and Luis Trabb Pardo, "The Early Development of Programming Languages", in Howlett et al., *A History of Computing in the Twentieth Century: A Collection of Essays*, 197–274. Both were based largely on unpublished material and private communications with Glennie.

[149] See figure B.3 in appendix B

it easy, one must make coding comprehensible."[150] There was no particular reason that a Mark I programmer should be forced to use the teleprinter code, other than the convenience and considerable momentum offered through pre-existing input routines and the subroutine library.

In that limited sense AUTOCODE was an improvement, but was not intended for the beginner. It made life easier for the experienced programmer by reducing drudgery and coding errors. AUTOCODE was tied closely to Scheme B and the existing subroutine library, so a programmer had to be conversant with the idiosyncrasies of directories and the machine architecture. But because it worked so closely with Scheme B, AUTOCODE interpreted and executed code nearly as fast as normal Scheme B programs, to within 10% or so. Other than the teleprinter code, nothing else was simplified. It did not solve, even partially, the other two problems of managing the magnetic store and floating-point arithmetic.

Ultimately, AUTOCODE was only ever used by Glennie, though he found it very useful personally. He was technically an outsider at Manchester, an employee of the Armaments Research Establishment who spent time at Manchester solving scientific problems for his employer. For him, getting around the teleprinter code was sufficiently useful, but AUTOCODE was never actively promoted to others and he published no papers describing it. Strachey appears to have been the only other person to have recognized its benefits, at least in print. He felt compelled to mention it at the September 1952 ACM conference in Toronto: "it certainly makes the preparation of simple programmes an extremely easy and painless affair."[151] This makes it likely that people in Toronto were aware of it, but there is no evidence that they – or anyone else – ever saw or used the system. Ultimately, AUTOCODE was just a small and uninfluential step in the right direction. After developing the routine and using it for a few of his own problems, "Glennie became involved full time with a much larger

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[150] Quoted in Knuth and Pardo, "The Early Development of Programming Languages", 228.
[151] Strachey, "Logical or Non-mathematical Programmes", 46.

problem for which AUTOCODE was inappropriate, and so it died a natural death."[152]

In early 1954 R.A. Brooker revived the idea of a simplified automatic programming system for the Manchester Mark I, which was called Autocode.[153] Autocode solved the three Mark I programming problems with an algebraic language and a simulated single level store of floating-point variables. Gone were the base-32 notation and various Schemes, to be replaced by a compact language "as simple and as close as possible to elementary arithmetical formulae" that could be specified on "two sides of a sheet of foolscap with possibly a third side to describe an example."[154] Programs were now easy to read and write for novices.[155]

The most interesting technical feature was the storage management and floating-point variables, which were combined, killing two birds with one stone. A programmer no longer had to worry about moving data to and from the electronic store and the magnetic drum. Instead, Autocode offered several thousand 'one-level' floating-point variables that were stored on the drum at program initiation but automatically brought to the electronic store when necessary during execution and replaced on the drum when the need expired.[156] The transfers between store levels would be far from optimal in terms of speed, and could be better managed by a human programmer. However, because time lost in transfers was still less than that lost during the slower floating-point arithmetic there was little to gain by optimizing the transfers any further. Though many experienced programmers preferred to avoid slow floating-point subroutines, other factors could have a greater impact on the speed of a program.

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[152] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 161.

[153] It had little in common with Glennie's AUTOCODE other than the name. Brooker had called his system Unicode at one point, but the earlier name stuck instead. Ibid., 163

[154] R.A. Brooker, "The autocode programs developed for the Manchester University computers", *The Computer Journal* 1, no. 1 (April 1958), 16. Such a specification can be found in Brooker, "The Programming strategy used with the Manchester University mark I Computer", 155-157.

[155] See appendix B for a program example.

[156] This was an ancestor of virtual memory, a feature first implemented in hardware on the Manchester/Ferranti Atlas. See Simon H. Lavington, "The Manchester Mark I and Atlas: A Historical Perspective", *Communications of the ACM* 21, no. 1 (1978), 4–12.

As Strachey pointed out in 1952, a typical program may contain a surprisingly high number of non-mathematical instructions to handle input, output, and program control that had little to do with the arithmetic speed.[157] Until floating-point operations were implemented in hardware and made considerably faster, Autocode and other automatic programming systems could get away with slow storage management.[158]

Brooker finished the first version of Autocode in 1954, and it was first used by outside users towards the end of the year. Over the summer of 1955, Brooker rewrote Autocode, with few changes other than adding complex variables. Brooker also took great pains to ensure that the system could be described simply and concisely, so that beginners could be taught how to use it within a few hours. The manual never grew larger than nine pages from the two to three pages he aimed at initially. It was widely promoted and courses were taught outside of Manchester to potential corporate and government users. The simplicity of both the language and the documentation made it a resounding success. Autocode usage started at less than an hour a day in 1954 but eventually climbed to three or four a day.[159] A computing service was born, whereby outside customers could use the manual to write their own programs, which were submitted by mail. This service took up to twelve hours of computer time a week at the Manchester Laboratory, and results were returned in less than a week to most customers, typically engineers and scientists.[160]

As with Speedcoding, Autocode was an influential system, but in a much more direct fashion. According to historian Campbell-Kelly, it was "probably the most sig-

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[157] Strachey, "Logical or Non-mathematical Programmes", 46.

[158] This dilemma was one of the starting points for the authors of the original FORTRAN on the IBM 704. The 704 was one of the first machines with hardware floating-point, and so the feasibility of an automatic programming system was in question. Inefficiencies could no longer hide behind slow floating-point routines. If autocode programs were substantially slower than hand-written programs, then the autocode might never be used, except by beginners. Backus, "Programming in America in the 1950s", 125–136.

[159] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 163-164.

[160] Brooker, "The autocode programs developed for the Manchester University computers", 16.

nificant programming innovation of the mid-1950s in Britain."[161] It was imitated by many system programmers on later computers, by Brooker himself for the Ferranti Mercury, and others on the Ferranti Pegasus and Ferranti Sirius.[162]. Through these direct descendants Autocode survived well into the 1960s in the United Kingdom, many years after FORTRAN and ALGOL were dominating North America.

3.4.5 TRANSCODE

Despite the success of Autocode in Britain, it had no influence in Toronto.[163] The reasons are a combination of timing and geography. For one, the TRANSCODE project was launched in the fall of 1953, before Brooker started writing Autocode, and in any case, the link to Manchester that had jump-started computing at Toronto had been severed. The University of Toronto Computation Centre now belonged to the North American computing community. In the 1950s, the world-wide computing community was divided between the two sides of the Atlantic. As a result, despite the common machine and program library as a starting point, TRANSCODE is a closer relation to North American automatic programming systems. Speedcoding was the trigger for TRANSCODE and there is a resemblance between the two. However, the actual technical influence was minimal – there simply was no contact at all between Speedcoding users or programmers and Toronto. Instead, they recognized that Speedcoding was a good idea and developed their own version, suitable for Ferut.

Most of TRANSCODE's development was carried out by Hume and Worsley,

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[161] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 164.

[162] The similarity between Brooker's original Autocode and the Pegasus and Sirius autocodes is substantial. A programmer familiar with the former could easily jump forward. The fundamental components – variables, arithmetic, jumps and labels – are nearly identical. See D.G Burnett-Hall, L.A.G. Dresel and P.A. Samet, *Computer Programming and Autocodes* (Princeton, NJ: D.Van Nostrand Company, Inc., 1964), Chapter 6 for a description of the later autocodes

[163] Only one Mark I model was installed outside of the UK: the Ferut. However two Mark I* models, slightly improved versions of the Mark I, were sold to customers in the Netherlands and Italy. It is unknown if Brooker's Autocode played a role at the other British or European sites.

though Gotlieb, Kates, Watson, and Griffith contributed improvements and additional library routines.[164] As with other automatic programming systems at the time, TRANSCODE was intended to provide "a system of coding which is simple to learn and to apply, and which requires only a cursory knowledge of the specifications of the computer."[165] It did so by solving the three Mark I programming problems of awkward notation, storage management, and scaling. Like Brooker, they eliminated the awkward base-32 notations in favour of an easier to read pseudo-code, but rather than his algebraic approach, they chose a three address instruction set, akin to Speedcoding. A TRANSCODE instruction consisted of an operation followed by three addresses. Each of these four units occupied one 20 bit word, or four teletype letters. The operation was a pseudo-english instruction indicating the desired action, such as add, square root, print, or transfer program control, and each address referred to a specific location in the electronic store. TRANSCODE provided three pages in the electronic store, labelled X, Y, and Z, with indexed variables. A typical instruction that added the contents of storage location X01 to that in location Y01 and store the result in location Z01 would be written as:

```
ADDN  X01.0  Y01.0  Z01.0
```

All variables were considered floating-point numbers, stored using three 20 bit words: one for the exponent and two for the significant digits. The sign was stored as well. This provided about 11 decimal digits of accuracy, about the same as other scientific computers of the day and no less than Ferut used normally. As the X and Y pages each occupied a single physical page of sixty-four 20 bit words in the electronic store (the Z page took only half a physical page), there were twenty-one X and Y variables (and thirteen Z variables).[166]

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[164] Computation Centre, "TRANSCODE Manual", i.

[165] TRANSCODE, A System of Coding for the Ferranti Mark I Computer, By J.N.P. Hume and B.H. Worsley, 1 October 1954, UTARMS A2005–0021, 2

[166] A page of twenty-one constants was also set aside, but as the name suggests, these could only be set in advance and remained invariable while the program was running.

If a programmer needed more variables than this, it was possible to read or write the X or Y page to and from any track on the magnetic drum with just two easy instructions, READ and WRTE. This arrangement was a much less elegant solution to the storage management problem than Brooker's one-level store with thousands of variables. Because the programmer had to manage the storage themselves, TRANSCODE's segmented approach made some operations with a great number of variables, such as a large matrix manipulation, more difficult to program. Yet is was still much easier than Scheme B, which had no explicit variables and lacked the straightforward page swapping to the drum.

Both TRANSCODE and Autocode provided indices for a repetitive section of code, but Autocode's eighteen were generically implemented with no reference to the eight hardware B-lines which normally provided this feature. TRANSCODE provided direct access to five of the B-lines to the programmer for a variety of uses. They could be used to refer to an indexed X, Y, or Z variable location. More importantly, TRANSCODE offered a special looping instruction that could be used to cycle through a set of instructions a predetermined number of times and automatically index a variable on each pass through the loop. With Autocode, the programmer had to track each cycle and transfer control manually – no less effective, but Brooker argued that it made the system simpler overall.[167]

There was a crucial, almost ideological difference between Autocode and TRANSCODE.[168] In their simultaneous quests to simplify programming on the Mark I, Autocode made programming a task nearly independent of the underlying machine, but TRANSCODE made little attempt to hide hardware limitations or disguise features. Hume makes it clear that they took no pains to provide a machine-independent sys-

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[167] R.A. Brooker, "An attempt to simplify coding for the Manchester electronic computer", *British Journal of Applied Physics* 6 (September 1955), 310-311.

[168] It must be said that comparisons of TRANSCODE to Autocode or even Speedcoding are not necessarily useful because a programmer couldn't really choose between them. But it is interesting to consider the case of two nearly simultaneous projects on similar hardware, from a similar starting point.

tem and instead "took every advantage of the nature of Ferut's native hardware," and provided many features to make it as flexible as possible for experienced programmers.[169] This led to a longer and more complicated manual, but knowledgeable users could make certain assumptions and optimizations that were impossible with Autocode. For example, instead of the simpler but slower one-level store, a programmer could manipulate the X and Y pages more efficiently and increase the overall speed of the program. Both systems could print results to teletype but whereas Autocode could only output one number per line, TRANSCODE could print multiple formatted columns of numbers each to specified significant digits. And while both systems eventually provided basic functions such as sine or cosine, or more exotic Runge-Kutta routines, only TRANSCODE provided complete access to the entire Ferut subroutine library via a straightforward instruction call. After a TRANSCODE program was translated to machine code it was also possible to punch that code to tape for integration within other TRANSCODE programs.

There were a few internal similarities between Autocode and TRANSCODE. Both systems translated one pseudo instruction at a time into native machine code. Both were limited to the normal S0 and S1 pages while a program was running, so a translated program any larger than two pages used the normal RCS subroutines in PERM to copy code from the drum and back. This was a considerable advantage for programmers who no longer had to worry about code segmentation. Both used standard floating-point routines from their respective subroutine libraries, and kept them permanently on the store to prevent speed losses. Both systems were about the same size, taking 18 tracks on the drum, or about 2300 instructions. However, TRANSCODE was considerably faster than Autocode. It translated about four or five instructions per second, versus Autocode's one instruction every two seconds. TRANSCODE generated faster machine code too. About ten or eleven TRANSCODE instructions were

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[169] Hume, "Development of Systems Software for the Ferut Computer at the University of Toronto, 1952 to 1955", 16.

executed per second, versus six Autocode instructions per second. In relative terms, it was estimated that TRANSCODE was six to eight times slower than a similar program written in native machine code. However, even a very experienced programmer could not hope to write a native machine code program in a fraction of the time it might take with TRANSCODE.[170]

The Computation Centre promoted TRANSCODE extensively. In a 1955 article in the JACM, Hume and Worsley briefly explained how TRANSCODE was used, and outlined the internal construction of the system, usage history, and various design and hardware limitations. They also included a complex code example to demonstrate its capacity for scientific computation.[171] A 1956 issue of the world's first computer related periodical, *Computers and Automation*, published a thorough guide to TRANSCODE's features and capabilities, although the code examples were minimal and few operational details were included.[172]

TRANSCODE documentation was made widely available. When it was completed in October 1954, the Ferut librarian kept a thirty-one page guide with numerous examples.[173] This guide was geared towards experts, and it laid bare the internal implementation of the system for local Ferut programmers with prior experience. Beginners would have found it intimidating and a better text was published in October 1955, when the Computation Centre produced a comprehensive sixty page hardbound reference manual. The book included everything a budding programmer might need to know: the full TRANSCODE instruction set, thorough code examples, details on physically preparing programs by punching them to tape, descriptions of the external functions available in the TRANSCODE subroutine library, and a glossary of terms.[174]

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[170] J. N. P. Hume and Beatrice H. Worsley, "Transcode: A System of Automatic Coding for Ferut", *Journal of the ACM* 2, no. 4 (1955), 251.

[171] Ibid., 243–252

[172] Calvin C. Gotlieb, "Free Use of the Toronto Computer, and the Remote Programming of it", *Computers and Automation* (May 1956), 20–45.

[173] TRANSCODE, A System of Coding for the Ferranti Mark I Computer, By J.N.P. Hume and B.H. Worsley, 1 October 1954, UTARMS A2005–0021.

[174] Computation Centre, "TRANSCODE Manual".

Copies of the manual could be requested by anyone.[175]

Hume and Worsley also published an article earlier that year in *Physics in Canada*, arguably TRANSCODE's target audience. The first half of the text described the benefits of digital computers and the difficulties of learning how to program.[176] In the second half, they described in greater detail how TRANSCODE could help the typical scientist in Canada, listing half a dozen real problems that had already been solved using TRANSCODE: resolving curves obtained during interferometer experiments, calculating radiation patterns for long-wire antenna, determining binary star orbits, analyzing Infrared and Raman rotational bands, and other problems in "chemical kinetics, acoustics, ballistics and low-temperature physics."[177] For each example they included the size of the program and the running time. Most were quite short, just 20 to 30 instructions, with run times less than half an hour. In their conclusion they emphasized the ease with which new programmers could learn TRANSCODE. Some people had begun submitting programs by mail which could be "transcribed to tape and run by operators who need have no knowledge whatsoever of the problem at hand."[178]

This last point is crucial as it suggests a solution had been found for the fourth programming problem of knowing what computers can do and knowing how to translate a scientific problem into a program. In saying that it was now possible for a problem originator to submit correct programs without operator intervention, the large burden of transforming a private problem into a working program had to be transferable beyond the walls of the computing centre. How successful was TRANSCODE in this sense? What does this say about the nature of the knowledge that surrounded computing practices in the mid 1950s? It was one of the building blocks from which the discipline of computer science would emerge, necessitating a close examination of

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[175] The 1956 *Computers and Automation* article was in fact an extracted reprint of this manual.
[176] Much of this would reappear unchanged in the forthcoming Computation Centre manual.
[177] Worsley and Hume, "A New Tool for Physicists", 20.
[178] Ibid.

both promise and reality.

It is clear that TRANSCODE solved the three major programming problems. Experienced programmers were able to balance the need to write programs quickly against the need for programs to run quickly. For programs that might run once or twice, TRANSCODE increased their productivity considerably, but for a project that required repeated runs, they turned to hand written machine code for optimal speeds.

But what of beginners? How easy was it for them to learn how to program Ferut using TRANSCODE? Some numbers suggest that it went well: the Computation Centre reported dramatically in 1955 that "the time required to teach the principles of coding has been reduced from ten lecture hours to two, and the training period from several months to a few hours."[179] On campus, it was found that graduate students were now able to prepare their own programs by themselves; the number of students doing so jumped from three to twenty-five after the introduction of TRANSCODE.[180] It was also claimed that beginners could use the official TRANSCODE manual to write their own correct programs without ever consulting an experienced programmer. In late 1954, J.F. Hart, the NRC representative at the Computation Centre, reported to his boss in Ottawa that "a very useful new routine has been devised for Ferut which in the view of the people at the Centre will enable many physical problems to be programmed to a large extent by the researcher submitting the problem."[181] He suggested that it would only take "an hour or so of instruction", and anticipated giving a lecture on the subject to his colleagues in Ottawa. He also wrote a short 50 page guide to TRANSCODE for use at the NRC.[182] And as late as 1956, in the *Computers and Automation* article Gotlieb invited people to mail their own programs to the Centre, waiving the usual $100 an hour machine fee so long as they would not profit personally from

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[179] Hume and Worsley, "Transcode: A System of Automatic Coding for Ferut", 251.

[180] Worsley and Hume, "A New Tool for Physicists", 20.

[181] L.E. Howlett to NRC, 28 October 1954, LAC RG77, Volume 211, File 15–17–13–C–4.

[182] J.F. Hart, "The Transcode Automatic Programme", Technical report (National Research Council of Canada, Division of Physics, 1955).

the arrangement.[183]

Unfortunately, programs submitted to the centre by mail did not always meet the hoped-for standards. As W. Fraser, the DRB representative put it, "debugging in varying degrees was usually required."[184] Hart agreed, noting that "the amount of checking is quite appreciable on some of these problems so that it will be necessary to establish a waiting list."[185] That said, Hume has recalled that with experience reading TRANSCODE tapes was remarkably easy.[186] Beyond fixing code, the Computation Centre staff had to prepare mailed programs to tape and find time to run them on the machine, which all took time. TRANSCODE programs required significantly more machine time to run than native machine code, and with the increasing demand placed on the machine, delays were inevitable.[187] The widespread impression by many clients was that their calculations could be turned around in a day, but the turn around time was closer to a week or more. As the number of requests increased it placed the most experienced programmers in Canada in the awkward position of spending a greater fraction of their time at routine work requiring little skill, such as punching tapes and mailing results. As Fraser admitted, the more demanding analysis and programming for which he'd been trained was being shifted to the problem originators, despite their novice status. In effect, TRANSCODE transferred a portion of the intellectually challenging work of programming outside of the Computation Centre, and "provided an opportunity to some of our scientists to make their first use of computers and to find out through their own experience some of the advantages and disadvantages connected with using them."[188] The Computation Centre went from a

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[183] Gotlieb, "Free Use of the Toronto Computer, and the Remote Programming of it", 20.

[184] Fraser, "Experience of the Defence Research Board in Mail Order Computer Service", 373.

[185] J.F. Hart to L.E. Howlett, 7 October 1955, LAC RG77, Volume 211, File 15–17–13–C–4.

[186] J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R. Williams.

[187] Any program expected to run longer than 20 minutes required special scheduling. See Computation Centre, "TRANSCODE Manual", 54. On those occasions that TRANSCODE submissions drew considerably more than their share of machine time, they were recoded manually to native machine code by somebody at the Computation Centre.

[188] Fraser, "Experience of the Defence Research Board in Mail Order Computer Service", 374.

closed shop to a open shop: access to the machine went from those people in immediate contact with it to almost anyone with enough interest to master the TRANSCODE manual.

Perhaps the most outstanding case of this occurred in 1955 when a special remote operation of Ferut was arranged between the Computation Centre and the University of Saskatchewan at Saskatoon. Earlier that year, W.R. Bruce, a Saskatoon physics Ph.D. student travelled to Toronto to use Ferut for computations necessary for his dissertation.[189] He took a numerical analysis course that was offered around the time he was there, but learned how to write programs for Ferut by reading Prinz's original guide, with a little help from others at the Computation Centre.[190] TRANSCODE would have been too slow for his calculations, so Bruce wrote his programs in machine code, with as many speed optimizations as possible. As he did not require more than six significant digits in the results, he trimmed down other Ferut library routines when greater accuracy would take too long. Finally, he eliminated some mathematical functions entirely in lieu of methods that used direct table lookups; again this was possible because the number of significant digits was minimal. It also demonstrates that as late as 1955, thinking in terms of desk calculations was not yet uncommon.

However, adapting tables and desktop methods for electronic computers was not always the most convenient means. Monte Carlo methods, which demand large quantities of random numbers to seed the calculations, were at the core of Bruce's work. Hand computation usually relied on published random number tables, but on Ferut there was simply not enough storage to make this economical. In any case, the Ferranti Mark I had a hardware random number generator. However, as both Bruce and the programmers in Manchester discovered, the generator was both insufficiently ran-

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[189] W. Robert Bruce, "Monte Carlo Calculations of the Scattering of X-rays in Low Atomic Number Materials.", Ph. D thesis, University of Saskatchewan (1956). A version of this research was later published: W. Robert Bruce and H.E. Johns, "The Spectra of X Rays Scattered in Low Atomic Number Materials", *British Journal of Radiology* Supplement No. 9 (1960).

[190] Bruce, W. Robert, conversation with author, Toronto, 18 July 2005.

dom and unpredictable.[191] As a result, he wrote his own superior routine based on a similar routine written for the IBM 701.[192] All told, it took a few months to get his programs working optimally; to compute the results took at least 110 hours, and the machine time cost about $9,000, which was covered at least in part by the National Cancer Institute of Canada.[193].

To return to the TRANSCODE story, while in Toronto Bruce and Gotlieb worked up a plan to connect potential computer users at the University of Saskatchewan to the Ferut in Toronto. When Bruce returned to Saskatoon, he gave a campus wide series of lectures on programming Ferut using TRANSCODE to anyone interested. This included the expected physicists, but also a few people from the veterinary science department. Enthusiastically, they all began writing their own programs and Bruce checked them for errors to avoid problems in Toronto. The first trial run was held during the third week in December, 1955, using a teletype line between Saskatoon and Toronto normally used by Trans Canada Transport. The programs in Saskatoon were punched to teletype tape, and around 8pm were transferred to teletype machine just down the hall from Ferut where they were printed. These tapes were then run through the machine. The results were printed to tape and sent back up the line to Saskatchewan, finishing around 2am. The first ten programs included "three in nuclear physics, six on the northern lights or aurora borealis and one in animal husbandry."[194] The first set were related to Bruce's work and X-ray research with the betatron at the University of Saskatchewan. The second set included a study of the effect the Northern Lights had on radio reception, and the third was a statistical analysis related to artificial insemination. It was estimated that in one night, scientists in

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[191] The latter point may seem oxymoronic, but a predictable algorithm for generating pseudo-random numbers is much preferred when debugging programs. Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 136.

[192] D. L. Johnson, "Generating and Testing Pseudo Random Numbers on the IBM Type 701", *Mathematical Tables and Other Aids to Computation* 10, no. 53 (Feb 1965), 8–13.

[193] Bruce and Johns, "The Spectra of X Rays Scattered in Low Atomic Number Materials", 19,57.

[194] "University Tests Teletype, Computer System to Speed Up Research", *Saskatoon Star Phoenix* (December 1955).

Saskatoon saved about 1000 man hours of time had they been stuck with desk calculators.[195] Despite being limited to relatively simple problems to avoid occupying too much telegraph and machine time, the experiment's success led to several months of Thursday night regular remote usage from Saskatoon.[196]

The entire scheme was repeated in 1957 between Toronto and the University of Alberta in Edmonton. In May of that year the Department of Physics at the University of Alberta hooked up a direct teletype line, donated by Canadian National Telegraph, to Ferut in Toronto. Don Betts, a theoretical physicist, was sent to the Computation Centre for a few weeks to learn TRANSCODE. When he returned, he taught it to other members of the physics department and a few undergraduates, who then wrote their own programs. The official opening on May 9 was attended by several dignitaries, including the president of the NRC, E.W.R. Steacie, whose agency had covered the costs of the teletype time. The arrangement continued throughout the summer and "worked tolerably well except when there was a thunderstorm anywhere between Edmonton and Toronto!"[197] Shortly after in October the University of Alberta purchased their own computer, an LGP-30, and the connection was no longer needed.

Remote programming remains an intriguing story, certainly a first in Canada and one of the first in the world, and it is further evidence that TRANSCODE enabled the transfer of programming knowledge across vast distances away from the physical machine. As Gotlieb remarked, in Toronto they never kept track of the problems and "all we ever saw was the teletype code."[198]It also had implications broader than the computational needs of a few scientists. In contemporary terms well understood by

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[195] "Electronic Computer Intended for Defense Gets Peaceful Tryout", *The Globe and Mail* (December 24 1955), 4.

[196] There are a few claims that a complete loop was arranged at one point, with the teletype tape running directly into Ferut, and the results tape right back down the telegraph lines, without any operator intervention at all. This may be apocryphal, as at least one person has suggested that the teletype and Ferut tape formats were not completely compatible. Bruce has suggested that it may have been a short experiment. Bruce, W. Robert, conversation with author, Toronto, 18 July 2005.

[197] Cited in Smillie, "The Department of Computing Science: The First Twenty-Five Years", 9.

[198] Calvin C. Gotlieb, interview by Henry S. Tropp, Computer Oral History Collection, edited transcript of tape recording, 29 June 1971, UTARMS B2002–0003, Box 8, Folder 1.

newspaper readers: "The use of a central brain would overcome many of the problems created by decentralization of business."[199] This speaks to the geopolitical reality of Canada: a widely dispersed population, often limited to and limited by centralized power structures.

Ultimately, TRANSCODE was not a perfect solution. Despite the lofty claims, it does not appear that many people could go from complete computer novice to able programmer without a little instruction or a lot of practice. The knowledge transfer was not without human intervention. In particular, program checking remained an art that could only come with time, despite the convenient checking features offered by TRANSCODE.

3.5 The Future of Ferut and TRANSCODE

Speedcoding and Autocode were influential technologies. In relative terms, TRANSCODE was not. In 1958, Ferut was decommissioned at Toronto, and replaced with an IBM 650, an event that will be covered in the next chapter. As Ferut went, so did TRANSCODE. Hume and Worsley had made no attempt to write a machine independent programming system; the consequence of this was an instruction set and coding practice tied heavily to the Ferranti Mark I hardware. The B-line use, variables, input and output, and other operational characteristics were all bound to the Mark I. While not an obvious advantage in the early 1950s, a decade or so later machine independence became an important characteristic for programming languages. "There must be reasonable potential of having a source program written in that language run on two computers with different machine codes without rewriting the source program."[200] The reason was cost. The price of writing programs was beginning to exceed

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[199] "Electronic Computer Intended for Defense Gets Peaceful Tryout", *The Globe and Mail* (December 24 1955), 4.

[200] Jean E. Sammet, "Programming Languages: History and Future", *Communications of the ACM* 15, no. 7 (1972), 10.

the price of buying and operating hardware. Computers could be physically replaced much easier than a time-consuming code rewrite. For this reason, by the end of the 1950s it was quite common for a programming language to appear on many different computers to ensure that programs could be transferred from one to another.

As for TRANSCODE, technically it might have been possible to write an new program to translate TRANSCODE programs into appropriate IBM 650 machine code. Programmers could then transfer their skills and programs to the new computer without interruption. But a translator program would not have been easy to write. Features found in the Mark I hardware and TRANSCODE would have been difficult if not impossible to replace, but they might have been generalized to some degree, as Brooker had done with his Autocode index variables. There had also been plans before Ferut was replaced to write an algebraic compiler system for the Mark I, similar to Autocode, but the project never got off the ground.[201]

With the arrival of the IBM 650, the notion became a non-issue. There was already a wide variety of programming systems and languages for the IBM 650, but three are worth mentioning.[202] The most basic, and the most widely used, was SOAP (Symbolic Optimal Assembly Program) from IBM. In more recent parlance, SOAP was an assembler, one step above raw machine code. The second was IT (Internal Translator), an algebraic language that was translated first to SOAP and thereafter to machine code. Intended for numerical scientific computation, it was popular at many universities that installed an IBM 650.[203] It also inspired many successors, and one, FORTRANSIT attempted to combine the best of FORTRAN and IT. FORTRANSIT offered a version of the increasingly popular FORTRAN which was only found on the more powerful

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[201] J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R. Williams.

[202] In May 1959, there were at least 29 programming systems available for the 650. Robert W. Bemer, "Nearly 650 Memories of the 650", *Annals of the History of Computing* 8, no. 01 (1986), 69.

[203] Alan J. Perlis, "Two Thousand Words and Two Thousand Ideas-The 650 at Carnegie", *Annals of the History of Computing* 8, no. 01 (1986), 42–46. In some ways IT could be called the first universal computer language given the vast number of IBM 650s installed across North America.

and more expensive IBM 704. FORTRANSIT translated FORTRAN source code to IT and then again to SOAP and to machine code.[204] The three programming problems that plagued an earlier generation of computers were now almost irrelevant. The IBM 650 used decimal rather than binary, eliminating any awkward notation. Floating-point operations were available as an optional hardware unit or via subroutines. Finally, though the IBM 650 still used a magnetic drum for storage, the 'Optimal' part of SOAP was to manage and optimize transfers to and from the drum. Ultimately, all three languages were at least as suitable as TRANSCODE for the task at hand, eliminating any need to expand or expend the effort to continue it. In particular, as an algebraic language, it was much easier to read and write programs with FORTRANSIT than TRANSCODE. Though nobody could have predicted it in 1958, FORTRAN would soon be the *lingua franca* of scientific programmers.

But it was obvious in 1958 that the IBM 650 was turning out to be an immensely popular machine, with an active community of users, especially universities and colleges. In Canada, nearly twenty other organizations had plans to install one by the end of the decade (see Table 4.1). A substantial collection of useful routines was available from IBM and other users. There was little need to continue developing TRANSCODE and rewrite it for the 650 given that most Canadian programmers had relatively easy access to a machine right across the country. As isolated as the Computation Centre had been with the Ferranti Mark I, once affiliated with the IBM 650, it now was a member of one of the largest computer user communities. The importance of this can be overvalued, as will be shown in the next chapters. In the meantime, Watson had launched a new fight on the political front to reform the relationship between the university and the Computation Centre.

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[204] B.C. Borden, "FORTRANSIT: A Universal Automatic Coding System for the IBM 650", in "Canadian Conference for Computing and Data Processing, Proceedings", 349–359.

Chapter 4

The Growth of Computing, 1955–1958

"The growth of teaching activities of the Centre is particularly gratifying, for without this function the Centre could well be placed elsewhere than in the University."

– W.H. Watson, Director of the Computation Centre, 1955.[1]

With the spectacular success of Ferut and TRANSCODE, the staff of the Computation Centre had mastered modern computing by 1955. Which is not to say that the rest of the university or the rest of Canada had achieved the same level of command of electronic computers. But Canadian scientists could count on the efficient and smoothly running Computation Centre. It had proven its worth to Chalk River, the DRB, the NRC, and Ontario Hydro. Yet the Centre's relationship with the university was less assured. Despite Watson's claim in this chapter's opening quotation, the academic ties between the University of Toronto and the Computation Centre were weak in the middle of the 1950s. Ferut, and the Centre, remained a service centre for outside users for several more years; as a result, there was little time left for teaching and research. Watson was fully aware of this, but had a plan to strengthen the relationship.

In the meantime, the Computation Centre's dominant position as the centre of

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[1] William H. Watson, "Report of the Director of the Computation Centre", in University of Toronto, *President's Report* (University of Toronto, 1955), 114.

modern computing in Canada was already starting to slip away. The patterns of computer usage were changing across the country. Ferut had been literally one of the first products of a commercial computer industry that was barely underway when the Ferranti Mark I was shipped to Toronto.[2] Worldwide, computer sales had grown continuously since those first tentative sales from a handful of custom built calculating tools to thousands of mass produced machines by the end of the decade. In Canada, there were no domestic companies selling Canadian-built general purpose computers, but most American computer companies made their offerings available to Canadians.[3] Large international corporations such as IBM, UNIVAC, and Burroughs competed against the likes of smaller Canadian companies such as Computing Devices of Canada, who acted as distributors for smaller manufacturers from the United States.[4] The price of an electronic computer fell from half a million dollars in the late 1940s, to a third of a million dollars in the early 1950s (about the cost of the Ferranti Mark I) to less than $50,000 for the LGP-30 from Librascope/General-Precision.[5] The Canadian market for electronic computers was much smaller than in the United States, and so there was a predictably high level of competition between salesmen. By the end of the 1950s there were about thirty computers operating in Canada. Inevitably, this had an impact on the Computation Centre, which was no longer the only proprietor of high-speed computing power in Canada. Many previously satisfied customers decided to buy their own computers, or purchase time at other computer centres closer to their own operations, perhaps in Ottawa or Montreal.

Against this backdrop it is possible to explore the arrival in 1958 of the IBM 650

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[2] As mentioned in chapter 2, it was the second commercial computer ever purchased, after the Census Bureau's UNIVAC.

[3] The only possible exception to this is Ferranti-Canada. See page 274 for a more thorough explanation of Ferranti-Canada's history.

[4] Bleackley and La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years*, 23–30.

[5] The cost of a fully configured LGP-30 would be over $100,000, but a basic version could be had for half that. M.H. Weik ed., *A Survey of Domestic Electronic Digital Computing Systems*, BRL report no. 971 (Aberdeen Proving Ground, Md.: Ballistic Research Laboratories, 1955), 93.

to replace Ferut. It was not a simple or straightforward upgrade from one computer to the next. Technologically, it was only a minor step forward in terms of speed and storage capacity, and some features found on the Ferranti Mark I were optional on the 650 and had to be specially ordered. However, the IBM machine was much more reliable and the large community of 650 users around the United States and Canada had already developed a great variety of programming options and a large library of routines to draw upon, providing sound technical reasons to choose the 650. More importantly, income from the sale of Ferut machine time was dwindling, and to rent the 650 would actually cost the Centre $3,000 less per year than to continue to operate Ferut. This raises the question of why it was not acquired sooner. Why the delay? In fact, the idea had been suggested as early as 1955, shortly after the first 650s were available. In all fairness, the rental price was considerably higher in 1955 than 1958, but as will be revealed, the deferral had more to do with the academic ambitions of the Computation Centre than the costs.

4.1 Defining an Academic Computing Centre

In August 1955, the University of Wisconsin hosted a conference dedicated to "The Computing Laboratory in the University."[6] The talks covered a broad range of material important to computing in higher educational institutions, including applications of computing in science and industry, of future personnel demands and curriculum needs, and of organizing and financing a computing centre or laboratory. One of introductory talks opened with the apparently unprovocative statement: "It is now quite generally accepted that every university should have an up-to-date computation laboratory complemented by strong programs in numerical analysis and computer tech-

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[6] Hammer, *The Computing Laboratory in the University.*

nology. This fact seems to be generally accepted even by academic purists."[7] Whether or not this was true for 'every university' when the proceedings were published in 1957, reviewer after reviewer agreed that the proceedings were indispensable in understanding how a school could and should use computers and deal with the problems of owning such an expensive, if versatile, research tool.[8]

The director of a typical university computing centre faced four problems. The first was operating the computing centre on a day-to-day basis. This included equipping a centre with up-to-date hardware, maintaining the equipment, and managing the support staff and program library. The second problem was financing, a vital problem when the price of a large-scale computer could run as much as a hundred times the salary of a human operator.[9] The first generation of modern computers were built with the financial assistance of the government, military, or industry. But by the mid 1950s computing centres were expected to be far more self-sufficient, generally achievable by selling computer time to outside organizations. It was therefore necessary to establish the cost of computing. A third problem was to provide instruction in computer technology, programming and numerical methods. Many university computing centres offered courses to the university's students, professors, and to other interested parties from on or off campus. In general, computer training was an important issue for the entire computing community but delivering their lessons in a way that satisfied academic purists was another matter. Finally, a computing centre often resided beyond the boundaries of traditional faculties and disciplines, which made it a constant headache for administrators and a tempting target for other departments looking

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[7] J.H. Curtiss, "The New Significance of Computation in Higher Education", in Hammer, *The Computing Laboratory in the University*, 11.

[8] See Franz L. Alt, "The Computing Laboratory in the University", *Journal of the American Statistical Association* 53, no. 282 (Jun 1958), 624–625; and William Viavant, "The Computing Laboratory in the University", *American Mathematical Monthly* 65, no. 5 (May 1958), 376.

[9] The Ferut, for example, cost $300,000 to purchase at a time when the annual salary of an average Computation Centre staff member was close to $3,000. Memorandum: Computation Centre Staff, as of 1 December 1949, UTARMS B1988–0069, Box 1, Folder 2. For a university uncertain about the future of electronic computing, tens of thousands of dollars could be spent to hire dozens of human computers and desk-calculators, rather than hundreds of thousands on an electronic computer.

to grab at the purse strings, valuable technology, and associated prestige. It was important for a computing centre to navigate these waters carefully, avoiding internecine squabbles and maximizing its value to the university by establishing a solid vision for academic computing.

At the University of Toronto, these problems fell on the shoulders of W.H. Watson and C.C. Gotlieb. Since 1952, Watson had chaired the university's Computation Centre Advisory Committee and served as Director of the Centre. Gotlieb, who had been hired by E.C. Bullard in 1948 as the Acting Director was given a new title under Watson: Chief Computer. He continued to manage the day-to-day operations of the centre.[10] The two tackled the four aforementioned problems throughout the 1950s, sharing the load as expected: Gotlieb kept the Computation Centre running efficiently and was one of a handful of instructors who organized and taught computing courses, while Watson worked with the university administration and the NRC and DRB to ensure continued financial health and to determine a proper range of activities for the centre.

The most important priority inside the Computation Centre was keeping Ferut running smoothly, an unforgiving duty given the machine's unreliability. Fortunately, under the terms of the installation contract, maintenance was provided by Ferranti *gratis* for the first year of operation, until October 1953.[11] Four full-time maintenance engineers were required to look after the machine. When it came time to write a new maintenance contract, Ferranti demanded just over fifty-thousand dollars (one sixth of the original purchase price) per year to cover the engineer's salaries and a stock of spare parts. Though the figure came as a shock to the University of Toronto comptroller and the Board of Governors, they had little choice in the matter to guaran-

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[10] When initially appointed, neither Watson or Gotlieb drew a salary from the Computation Centre, and subsisted instead on their positions in the Department of Physics, as chair and assistant professor, respectfully. S.E. Smith to Board of Governors, 27 January 1953, UTARMS A1968–0007, Box 110, Folder 4.

[11] A.G. Rankin, Proposed Contract with Ferranti Electric Limited for Maintenance of Mechanical Computer, 14 July 1953, UTARMS A1973–0025, Box 5, Folder 5.

tee continued operation of the Computation Centre.[12] By that time, Ferut was running continuously 105 hours per week, from 9am Monday morning to 5pm Friday afternoon, with a few hours set aside each week for preventive maintenance. Roughly 80% of the remaining time was available for programmers.[13]

Ferut was upgraded on a few occasions, as machine instructions were added or changed to improve the checking facilities and the overall user experience.[14] In 1954 Ferut was modified to include a standard IBM card reader and punch unit, which permanently set it apart from its only sibling, the Manchester Mark I.[15] The new input and output system, known as Ferib, required changes to the computer circuitry and machine instruction set, and added a small magnetic drum necessary to buffer and convert the data between the serial nature of Ferut and the parallel storage of punched cards.[16] Four new routines were added to the library, and one of the advantages of the new system was that punched cards offered decimal input and output. However, debugging programs was more difficult because of the timing characteristics of Ferib, which could only operate at full speed.[17] The purpose of the upgrade was "to bring the output speed into balance with the computing speed but also to make possible the direct use of cards originating outside the Computation Centre."[18]

Over the summer of 1956, Ferut was upgraded again, with a new magnetic drum.[19] The Mark I could access a maximum of 256 tracks on the drum, but when Ferut was

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[12] A.G. Rankin to W.E. Phillips, 7 July 1953, UTARMS A1973–0025, Box 5, Folder 5. The expensive maintenance fee was a thorn which stuck for many years, and was held up as an incentive in the late 1950s as justification to build a new computer and use university staff to maintain it.

[13] Calvin C. Gotlieb, "Running a Computer Efficiently", *Journal of the ACM (JACM)* 1, no. 3 (1954), 124.

[14] FERUT Library Supplement, UTARMS A2005–0021, Folder January 1954.

[15] After Ferranti shipped Ferut to Toronto, it improved the Mark I slightly, renamed it the Mark I*, and sold eight of the new units. Thus the only machine identical to the Ferut was in Manchester.

[16] Input and Output with FERIB, UTARMS A2005–0021, Folder February 1955.

[17] The extant documentation suggests that overall the entire Ferib system was no less awkward to use than the standard Ferut teletype equipment.

[18] Calvin C. Gotlieb, "Equipping a University Computing Laboratory", in Hammer, *The Computing Laboratory in the University*, 173. It is unknown how much the Ferib facility was needed or used.

[19] William H. Watson, "Report of the Director of the Computation Centre", in *President's Report* (University of Toronto, 1956), 104.

installed in the fall of 1952 only a fraction of these were available. New tracks were added as time passed and 249 tracks were available by June 1954, which was the limit of Ferut's drum.[20] Though only six shy of the theoretical maximum, in August 1956 all Ferut operations ceased for two weeks so that a new drum with a full complement of 256 tracks could be installed.[21] These upgrades ensured, in Watson's words, "a satisfactory computing machine," at least until the entire computer could be replaced, though there were no specific plans at that point to do so.[22]

The smooth operation of a computing centre demanded more than hardware maintenance and upgrades. A library of subroutines was just as essential, and its importance not to be underestimated. A library represented a sum of computing knowledge that a beginner or experienced programmer could draw from, without having to resort to first principles. For example, the Ferut input system inherited from Manchester that J.N.P. Hume modified was a crucial library routine that solved many of the basic problems of getting a program into storage and managing storage transfers.[23] As well, any contemporary university computing centre library needed to provide a variety of mathematical and scientific functions and routines that supplanted the hardware with features otherwise unavailable, such as floating-point arithmetic. In the Computation Centre, routines were normally written when needed for a specific project, and then generalized and stored in the library if future uses were expected. Anything that could be done to simplify programming saved both time and money, which explains the growth of automatic coding systems in the mid 1950s. Toronto's major contribution to this endeavour was TRANSCODE, which transformed the Computation Centre in many ways.[24]

However, libraries required a non-trivial investment in time and labour to create

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[20] FERUT Library Supplement, June 1954, UTARMS A2005–0021, Folder June 1954.

[21] Revised Supplement, October 56, UTARMS A2005–0021, Folder October 1956.

[22] Watson, "Report of the Director of the Computation Centre", 104.

[23] See section 3.3.

[24] See section 3.4.

and sustain them. As Gotlieb put it to the other attendees of the 1955 Computing Laboratory conference, a library "may not seem like equipment, but it is certain that an appreciable capital investment is needed to realize it."[25] The financial costs, when all factors were considered, could easily equal that of the computer itself. Such was the case, for example, with the ILLIAC at the University of Illinois. R.E. Meagher, of the Illinois Digital Computer Laboratory, also noted: "Our library at Illinois has cost perhaps almost as much as the ILLIAC," but it "extended the usefulness of the machine to many individuals who might otherwise find a large machine too much to study."[26] Moreover, a library was rarely static; problems never encountered before often required new routines. During Ferut's first year of operation, a total of 131 man-weeks and 143 machine-hours were used to rewrite and expand the Mark I library, which cost approximately $17,500, including machine time and salary.[27] Of course, this does not include the subsequent effort that went into writing, testing, and documenting TRANSCODE.

It was important to appoint a librarian to manage a collection and keep other programmers informed of changes. In the Computation Centre, both B.H. Worsley and Audrey Wallis served as the Ferut librarian in the early years. They issued regular supplements every few months to users regarding changes to the machine and to the library. Monthly meetings were held for all programmers in the centre to discuss possible new routines or changes to operating procedures.[28] It was equally important to try and maintain communications among neighbouring computing centres or those with a common computer. In general, in the first half of the 1950s there were many different and incompatible computers, and libraries could not be shared. In the second half of the decade, cooperative user groups arose around specific machines. SHARE

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[25] Gotlieb, "Equipping a University Computing Laboratory", 173.

[26] Ralph E. Meagher, "Equipping a University Computing Laboratory", in Hammer, *The Computing Laboratory in the University*, 184.

[27] Gotlieb, "The Cost of Programming and Coding", 14.

[28] Gotlieb, "Running a Computer Efficiently", 125.

was the first such collaborative organization of users to address "the inefficiency inherent in the fact that firms that had purchased an IBM mainframe still had to write their own programs to perform basic computing functions, a situation that resulted in a massive duplication of programming effort."[29] Its members consisted originally of IBM 704 users, mostly from the southern California aviation industry, though eventually SHARE expanded to include other IBM computers. Though there were attempts to transform SHARE into a professional society, it operated best as a mechanism for program exchange between users which permitted programmers "to forge a coherent body of knowledge." There were user groups dedicated to other machines and manufacturers as well, such as Univac Scientific Exchange (USE), which formed around the Remington Rand ERA 1103.[30] In the Computation Centre, they were well aware of the value of their connection to Manchester. The conduit, however, operated east-to-west; there does not appear to be an example of a transfer of knowledge or technique back to Manchester. Once the relationship was severed between the two universities, the Computation Centre was effectively isolated with the only Ferranti Mark I in North America. In other words, there was no need for a special user group.

Despite its location at the University of Toronto, until 1957 the majority of Ferut's time was consumed by outside customers.[31] The largest percentage of time was used by a block offered to the NRC, the DRB, and Atomic Energy of Canada Limited. In exchange for an annual $50,000 grant split between the NRC and DRB these agencies were granted 20 hours of machine time per month. Any machine time beyond the 20 hours was charged at $200 per hour, the same rate for all other users except other Canadian universities, whose staff and students were generally granted free access. Arriving at this rate was a complicated affair. Given the infancy of the field there

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[29] Atsushi Akera, "Voluntarism and the Fruits of Collaboration: The IBM User Group SHARE", *Technology and Culture* 42, no. 4 (October 2001), 710.

[30] Bruce H. Bruemmer, "Early Computer User Groups", *Annals of the History of Computing* 12, no. 01 (1990), 55–61.

[31] 1957 was the first year that University of Toronto staff and students used more than 50% of the machine time. See Table 4.2.

was no standard among computing centres. At first the Computation Centre charged $4 for every line of code their programmers wrote in course of solving a problem.[32] The figure was derived from adding the time the staff had spent over the course of the first year of operation writing new routines and adapting old ones for the library and dividing by their salaries. It did not take into account overhead, depreciation, or that library routines are generally trickier and take longer to write than the body of a program. Shortly before the arrival of TRANSCODE, this method was changed to an hourly charge, which was tracked and billed on a monthly basis of $200, which was closer to a standard commercial rate. This was the only other source of income for the Computation Centre and at $200 per hour it was able to operate Ferut in the black for most of its lifespan.[33] The importance of outside funding put the Computation Centre in an awkward position. Because most of the external work was contracted with deadlines, extra care had to be taken to avoid extended breakdowns or work stoppages. Expensive duplicates of parts were kept on hand to ensure that the computer could be repaired quickly and easily.[34]

Aside from the NRC, DRB, and AECL, which all kept a full-time programmer stationed in Toronto, the Computation Centre staff helped outside users write programs, at least until the arrival of TRANSCODE. The list of external companies buying time or help included Eastman Kodak and A.V. Roe Canada.[35] Both requested a variety of matrix related computations, including one to invert a square matrix of order 74 in 1953. These were quite close to the limit of Ferut's capability, and larger matrix

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[32] Gotlieb, "The Cost of Programming and Coding", 14–15,25.

[33] Statement of Income and Expenditure for the year ending June 30, 1957, Office of the Chief Accountant, 9 December 1957, UTARMS A1971–0011, Box 13, Folder 25.

[34] Gotlieb, "Equipping a University Computing Laboratory", 172.

[35] A.V. Roe Canada, or Avro Canada, was established in 1945 as a subsidiary of A.V. Roe in the United Kingdom. Three jet aircraft were designed in Canada at Avro in the late 1940s and early 1950s, including the Avro Arrow. The Arrow is rather infamous in Canada; had it been finished many believe it would have been the most advanced military aircraft of the day, but political controversy and the arrival of guided ballistic missiles put an end to the program in 1959 with only a few prototypes completed. See Palmiro Campagna, *Requiem for a Giant: A.V. Roe Canada and the Avro Arrow* (Toronto: Dundurn Group, 2003).

problems had to be turned away.[36] The next year a series of linear regression problems were computed for the Polymer Corporation of Sarnia and B.A. Oil of Toronto. There were few, if any, publications attached to this work, but if a useful routine was developed in the course of the problem it was added to the library. Not all of the uses were scientific and a few early experiments in data processing and business applications were undertaken. Late in 1953 annuity calculations were run for Manufacturers Life Insurance, and in 1954 an inventory control test was carried out for Imperial Oil Limited of Toronto. Before 1956 problems were also solved for faculty at McGill University, the University of Montreal, the University of Saskatchewan and the University of Manitoba.[37] Because the University of Toronto had the only large-scale computer in the country for many years, consulting companies used Ferut for demonstrations before their clients would commit to an investment of their own. One of these was a simulation of an electronic seat-inventory system that was run for Trans-Canada Air Lines (TCA) executives in August 1954.[38] This demonstration convinced TCA that such a system would be feasible, and it was followed by a second in October 1957 testing a communication line from Ferut to six remote 'Transactors' – a ticket agent's simplified interface to the seat inventory – stationed at the Royal York Hotel several kilometres away.[39]

The next major challenge for academic computing centres was training. An entire conference was dedicated to the subject in June 1954 and held at Wayne University, Detroit, sponsored by the Wayne University Computation Laboratory.[40] The sessions

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[36] Memorandum by the Director of the Computation Centre (W.H. Watson), October 1954, UTARMS B1988–0069, Box 1, Folder 2. Work on one problem for A.V. Roe involving a 40 by 40 matrix provoked a very simple theorem concerning the approximation of an inverted matrix that is arbitrarily close for left multiplication but far on the right. See Calvin C. Gotlieb, interview by Michael R. Williams, 6 May 1992, Transcript provided by Michael R. Williams, and Nathan S. Mendelsohn, "Some Elementary Properties of Ill Conditioned Matrices and Linear Equations", *The American Mathematical Monthly* 63, no. 5 (May 1956), 285–295.

[37] Watson, "Report of the Director of the Computation Centre", 113.

[38] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 129.

[39] Ibid., 133.

[40] Arvid W. Jacobson ed., *Proceedings of the First Conference on Training Personnel for the Computing Machine Field*, Wayne University Computation Laboratory (Detroit: Wayne University Press, June 22

were organized around four themes: projected manpower requirements in the computer field, the status and future of educational programs, the effect of computers on education, and the existing and potential collaboration between industry and educational institutions. There was little doubt that such a conference was necessary – the shortage of manpower in the field was already acute and many people from industry and academia recognized that as new uses were found for computers in the near future, the demand for a competent workforce would increase. Computer manufacturers typically provided training programs, but the conference attendees clearly believed that universities would ultimately be responsible for filling the shortage.[41] The notion of a university providing training (instead of a more academic education) was not received as poorly as one might expect. Many people rightly believed that advanced mathematical skills were necessary to write the programs which carried out scientific computation. Nevertheless, though specific machine training was to be avoided in favour of more fundamental lessons, it remained difficult to identify a specific new class of principles that stood out from established, if under-appreciated, fields such as numerical analysis or logic. One reviewer of the conference proceedings noted that a broad and thorough mathematical education was useful, but acknowledged that "much of the classical material on computation is obsolete," and had yet to be brought up to date.[42] In any case, it was generally felt that undergraduates with solid mathematical preparation should be able to bridge the gap and acquire the necessary computer skills once they entered industry or graduate school. The lack of a core set of fundamental principles upon which to base a new discipline continued to be a problem well into the 1960s.

At the University of Toronto, the Department of Mathematics remained involved in

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and 23 1955).

[41] It is interesting to note that only a third of the conference attendees represented institutes of higher education and the rest industrial, government, or military organizations.

[42] Franz Hohn, "The First Conference on Training Personnel for the Computing Machine Field", *The American Mathematical Monthly* 62, no. 1 (Jan. 1955), 12.

computer training only peripherally, either through the efforts of one faculty member, B.A. Griffith, or as the host of a course taught by someone from outside of the department. For instance, Griffith's first statistics laboratory courses during the 1947-1948 academic year survived for at least ten years.[43]But advanced instruction associated with more modern computing devices was picked up eventually by the Department of Physics. After Griffith ordered the IBM 602 and hired B.H. Worsley and J.P. Stanley, he sent the two to an IBM training centre to learn how to use the equipment. They in turn educated other members of the Computation Centre staff, on an ad hoc basis. Two years after Griffith's statistics courses were introduced, two relevant graduate courses were offered though the mathematics department for the 1949-1950 academic year: 'Introduction to Numerical Analysis', taught by Griffith and 'The Logical Basis of Digital Computers', taught by Gotlieb. Within two academic years the first was renamed 'Numerical Methods' and taught by both Griffith and Gotlieb, but the second course was dropped from the calendar only to reappear a year later in the Department of Physics. The following year, physics offered its own graduate course in numerical methods, led by Gotlieb and Hume, the third computing-related credit course. These courses attracted anywhere from five to twenty students per year, from engineering, aerophysics, mathematics and physics.[44] Informal means were also used to produce people with experience in computing methods. Starting in 1950, two or three students were employed at the Computation Centre each summer. They assisted with the electronics research and mathematical work, and though it was hoped their participation with the Computation Centre would continue, not all returned. Gillies and Mayberry studied multiple-word arithmetic routines for UTEC in the summer of 1949 but left to pursue graduate work at Princeton University.

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[43] A new arts building under construction on campus in 1960 was expected to contain two numerical laboratories with modern electric desk calculators. Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9.

[44] Computation Centre Progress Report, October 1, 1950 to September 30, 1951, UTARMS B1988–0069, Box 1, Folder 2, and Beatrice H. Worsley, "Computer Training at Toronto", in Jacobson, "Proceedings of the First Conference on Training Personnel for the Computing Machine Field", 72.

When Ferut arrived in the spring of 1952, there was little experience among the Computation Centre staff with an electronic computer. A few attempts had been made to write programs for UTEC, Worsley had spent time in the United Kingdom programming both EDSAC and the Mark I. Gotlieb travelled to Manchester for some lessons that spring, but only with a few more experienced hands borrowed from England, such as Strachey and Popplewell, was there sufficient programming knowledge to make plans for a programming course. The first took place over the final two months of the year.[45] The course was organized mainly for faculty and staff who were interested in immediately using the new computer, and was taught by Gotlieb and Worsley. It was followed in the spring with a short two-week course that was organized by Gotlieb and Hume. This course attracted students from within the university and external representatives from local business and industry. In June 1953, a more intensive two-week course was organized and taught by six of the Computation Centre staff members. The lessons included "machine design and computer logic as well as programming and numerical techniques," followed each afternoon with hands-on programming sessions at Ferut's console.[46] Of the thirty students, from disparate backgrounds and occupations, eight were adept enough to remain at the Computation Centre for the entire summer and make helpful contributions.

During much of Ferut's lifespan the Computation Centre had to fight a reputation inside the university as a service centre rather than an academic one. It was funded entirely by service income from external organizations and federal grants, an unusual position compared to other university departments. Its staff were not expected to produce scientific publications. Yet Watson worked to convince the faculty and administration that it was more than a service organization. As he explained in his submission to the annual university report in 1955, if not for the teaching, the Centre could have

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[45] Computation Centre Progress Report, 1 October 1951 to 30 September 1952, UTARMS B1988–0069, Box 1, Folder 2.

[46] Worsley, "Computer Training at Toronto", 71.

operated somewhere else – the NRC, the DRB, or as a private organization, for example.[47]

Not all within the administration were convinced that such training was a vital university function, though the president endorsed it in that year's Report. But none could argue with the Centre's success operating the only large-scale computer in Canada.

That success brought the Computation Centre to the attention of politicians and bureaucrats at the federal level in the mid 1950s. As the only authority in the country on modern computers, it was asked to contribute a report to the Royal Commission on Canada's Economic Prospects.[48] The theme of the commission was economic nationalism and levels of foreign investment and control over Canadian resources and business. Therefore, the point of Computation Centre's submission was to describe the "possible general effects on the national economy due to the rapid deployment of electronic computing devices."[49] The report, written by Watson and Gotlieb, emphasized that computers had already begun to affect business and industry in the United States, which would produce changes in the economic productivity in Canada. The two anticipated that Canadians would, in time, undergo great shifts in the white-collar sector, coinciding with improvements to national productivity and industrial production, thanks to changes in economic planning and the practice of engineering and science brought about by the computer. Because computing and engineering firms in the United States were already bringing many new techniques into Canada, Watson and Gotlieb recommended that improved computer training at all educational levels was imperative if Canadians wished to retain economic control. Though this advice was

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[47] Watson, "Report of the Director of the Computation Centre", 113–114. See the epigraph to this chapter for a direct quote.

[48] The Royal Commission was often known as the "Gordon Commission", named for the chairman Walter Gordon.

[49] William H. Watson and Calvin C. Gotlieb, "Submission to the Royal Commission on Canada's Economic Prospects", Technical report (Toronto: The Computation Centre, University of Toronto, October 1955), 1.

self-serving, they reiterated that the importance of computing to the economy was already well understood in the United States, where practices were roughly five years ahead of those in Canada. At a time when there were over 100 large and medium-scale computers south of the border, there were only three in Canada.[50]

Despite the overall sluggishness of the computer field in Canada, the Computation Centre had acquired a strong reputation outside its borders, much of it due to Gotlieb's tireless promotion. Because Ferut left Toronto isolated technologically, it was not possible to contribute via organizations such as SHARE, but general observations about academic computing were valuable. The few publications which it produced between 1948 and 1952 were tentative steps, but the Computation Centre's world debut was at the ACM meeting held in Toronto in September 1952. The staff were able to demonstrate two electronic computers, UTEC and Ferut, the Meccano differential analyzer, and the IBM 604 Electronic Calculating Punch (it had been upgraded from the 602A recently), all together a very respectable battery of computing power. Gotlieb attended next year's ACM meeting, where he presented a paper describing a year's successful operation of Ferut.[51] Worsley and Gotlieb were also among the minority of academics who attended the Conference on Training Personnel for the Computing Machine Field at Wayne University in 1954, and Gotlieb was invited to give a talk at the Computing Laboratory in the University conference the next year at the University of Wisconsin.[52]

The Computation Centre was paid perhaps the highest compliment by Morris Rubinoff, a Professor at the Moore School of Electrical Engineering at the University of Pennsylvania, when he wrote to Gotlieb in late 1955 for advice.[53] Rubinoff turned to his old friend and colleague for his opinion about how the Moore School should go about establishing a proper computing centre. As the birthplace of ENIAC and ED-

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[50] Aside from Ferut, two smaller machines had recently been sold to defence-related organizations, which will be described in the following section.

[51] Gotlieb, "Running a Computer Efficiently", 124–127.

[52] Gotlieb, "Equipping a University Computing Laboratory", 171–174.

[53] C.C. Gotlieb to M. Rubinoff, 30 December 1955, UTARMS B2002–0003, Box 2, Folder 15.

VAC, it would also be reasonable to expect the University of Pennsylvania and the Moore School to have a well-run computing centre. Yet ENIAC and EDVAC were not located on campus, having been relocated to Aberdeen Proving Grounds, leaving a differential analyzer as the school's only major computing machine for many years. Combined with the loss and dispersal of key personnel and obstructive university policies and regulations, the entire computing program languished for several years.[54] It was only in the second half of the 1950s that significant improvements were made to the academic program and it was only late in the decade that the computing centre could be built up. Gotlieb, of course, was flattered that Rubinoff would look to Toronto for advice, but he tempered his words with the wisdom that local conditions would have a greater influence than any comments he could make. As will be shown in the following section, a change in the local and national conditions in the coming years had a crucial effect on the Computation Centre.

4.2 The Changing Profile of Computing In Canada

In 1955, the Computation Centre was still the centre of modern computing in Canada, but by the end of the year at least ten computers were on order for various government, business, or academic organizations. The number of orders and the number of machines continued to climb throughout the decade, and it was not long before the University of Toronto could no longer claim to have the largest, most powerful, or fastest computer in Canada. Correspondingly, though the Computation Centre had once been the only concentrated hub of computing knowledge in the country, by the start of the 1960s there was a modern electronic computer in over half of the provinces, a variety of experienced computer consulting firms scattered across the country, and at least five computing centres at other universities making their own way with research

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[54] Aspray, "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s", 60-62.

and teaching. These changes would have a great effect on the operation, funding, and ambitions of the Computation Centre.

It was the advent of commercial computing, to borrow a chapter title from Ceruzzi's *A History of Modern Computing*, that permitted the expansion of computer activity in Canada.[55] John Vardalas has explored the handful of attempts to design and build computers in Canada from the late 1940s to the early 1960s, in particular Ferranti Canada and its successes and failures.[56] However, these were nearly all one-of-a-kind machines, not mass produced commercial machines. Though any organization contemplating owning a computer in the immediate post-war years faced the prospect of building their own, by 1952 it was possible to purchase one from a small collection of manufacturers; the first such transaction was completed in the summer of 1951 when a UNIVAC was installed at the United States Census Bureau. The UNIVAC computer was now a product of Remington Rand and it was followed quickly in 1952 by IBM's entry into the commercial computing field, the IBM 701 Electronic Data Processing Machine. The other major manufacturer of a large-scale computer was Engineering Research Associates (ERA), which began installing the ERA 1103 in the fall of 1953, after ERA was also purchased by Remington Rand. The three machines from two companies competed for the large-scale, scientific computation market. IBM did not sell the 701 but leased it for around $15,000 per month, which cannot easily be compared to the million dollar price tag of the UNIVAC and 1103, but few Canadian organizations could afford one all the same.[57]

However, there were smaller, less expensive computers. Instead of costly tube-based primary storage, many used magnetic drums that were slower, but generally reliable, and more economical. As a result, they were highly affordable; the base price for some of the popular models was under $50,000, though with peripherals and add-

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[55] Ceruzzi, *A history of modern computing*, 30–46.

[56] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence.*

[57] The broadest, most easily accessible and contemporary technical reference to these first machines is Weik, *A Survey of Domestic Electronic Digital Computing Systems.*

ons, the cost could double. The archetypal drum-based computer was the Computer Research Corporation (CRC) 102A, which was first sold in 1953 for around $100,000. Designed by engineers for engineers it sold modestly but after CRC was purchased by National Cash Register Company (NCR) in 1954, it provided NRC's entry into the field.[58] By the mid 1950s, drum technologies had improved sufficiently that a second generation of drum-based computers appeared. Three of the more prominent examples were the Librascope/General Precision LGP-30, Bendix G-15, and IBM 650. They were all modest machines, but suitable for organizations that could not afford to buy or lease a large-scale scientific computer.[59]

It should then come as no surprise that the second and third electronic computers in Canada came from this smaller class of machines. Specifically, A.V. Roe operated a 102A at Malton, Ontario, as did the Royal Canadian Air Force (RCAF) at Cold Lake, Alberta.[60] At Cold Lake, the Data Processing Department of Computing Devices of Canada Limited was responsible for the 102A and writing programs to solve scientific problems.[61] Their work at Cold Lake included analysis of weapons trials, solutions of systems of ordinary differential equations, digital simulations, and "a variety of problems involving matrix computations, statistical procedures, numerical integration and differentiation, the solution of non-linear equations and other mathematical procedures."[62] Among these were some calculations required during the design and

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[58] Thus, the 102A has three names: the CRC 102A, the NCR-CRC 102A, and the NCR 102A. To confuse matters, a decimal version known as the 102D was introduced later.

[59] Ceruzzi, *A history of modern computing*, 42–44.

[60] A.V. Roe had previous experience with a computing, indirectly via Orenda Engines which had an IBM Card Programmed Calculator (CPC), a half-way point between electromechanical calculators and fully electronic programmable computers. Bleackley and La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years*, 19.

[61] Computing Devices of Canada was founded in 1949 by George Glinski to build a real-time digital simulator for the Royal Canadian Navy. See Vardalas, *The Computer Revolution in Canada: Building National Technological Competence*, 58,324. According to Keith Smillie, who was a member of that Data Processing Department, Computing Devices was also the Canadian sales representative handling sales of the 102A.

[62] J.L. Howland and Keith W. Smillie, "Some Mathematical and Programming Techniques Employed in the Operation of a Scientific Computing Facility", in "Canadian Conference for Computing and Data Processing, Proceedings", 78.

testing of the Velvet Glove air-to-air guided missile.[63]

By 1958, the year Ferut was decommissioned at the University of Toronto, there were at least twenty-seven Canadian organizations that had installed a computer, or intended to install one in the near future. About three-quarters of them were profiled in an article describing the Canadian computing and data processing scene.[64] Though not a complete picture, Table 4.1, compiled from that article and other sources, reveals that the IBM 650 was the most popular choice in Canada. Though it was first introduced in 1954, the 650 outsold all other drum-based computers, with international sales numbering in the thousands. Its drum was one of the fastest, and because IBM positioned it as a business machine it appealed to IBM's pre-existing base of punched card customers. It could also be used for scientific work, and in the United States, the computer was common at many university campuses, largely because of the massive 60% discount offered to schools that agreed to use it in data processing or scientific computing courses.[65] In Canada, of the few universities that could afford a computer in the 1950s, all chose a drum-based computer, though not all chose the 650. Regardless, all were good choices for organizations looking to enter the computing field: they were relatively inexpensive, flexible, and popular. Because of the commonality, people were able to create user groups. The first, the Tape User Conference, was "an unorganized group of people who were interested in the aspects and applications of computer tape," and included many of the organizations listed in Table 4.1.[66] The more formal Computing and Data Processing Society of Canada (CDPSC) was founded in 1958 (see page 221).[67]

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[63] Keith W. Smillie, "Velvet Gloves and Latin Squares: Memories of Some Early Computing in Canada", in L. Gotlieb ed., *Canadian Information Processing Society Session 84 Proceedings* (1984), 323–326.

[64] H.W. Rowlands, "The Canadian Scene in Computing and Data Processing", in "Canadian Conference for Computing and Data Processing, Proceedings", 287–297.

[65] Ceruzzi, *A history of modern computing*, 43-44.

[66] Bleackley and La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years*, 20.

[67] The CDPSC's name was changed in 1968 to the Canadian Information Processing Society (CIPS).

The majority of Canadian organizations buying computers at the end of the 1950s were no longer strictly interested in scientific computation. The expected use of computers had expanded since the Computation Centre was created in 1948. At that time, the most likely source of problems was the Department of Physics at the University of Toronto and for half a dozen years most calculations continued to be related to engineering or scientific problems. But by the end of the 1950s, manufacturers, distributors, and insurance companies were taking an interest in computerized data processing. Many computer manufacturers had at least two product lines to address the business and scientific uses, recognizing that different users preferred different operating characteristics. On the one hand, a data processing machine should have good alphanumerical handling, of negligible importance to scientific computation. On the other hand, fast floating-point arithmetic was important to scientists and fast high-volume input-output was valuable for data-processing. Yet it was not unusual that a computer intended for one domain was used in another, and the distinction gradually disappeared. Nevertheless, computers were no longer only the tools of physicists and engineers, but also actuaries and accountants.

Two other events of 1958 can be used to illustrate the changing profile of computer activity in Canada. The first was the publication of *High-Speed Data Processing* by Gotlieb and Hume. Their book, part of a McGraw-Hill series in "Information and Data Processing", was the first Canadian textbook dedicated to computing.[69] Though the author's careers to that point had revolved around just one computer in an academic setting with little practical experience in the realm of data processing, the text was one of the first to deal with the application of computers to business. It proceeds as a reader might expect from an introductory course of the era, from the fundamentals of information representation and the internal organization of computers, through programming and code examples, to advanced applications of computers in insur-

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[69] Gotlieb and Hume, *High-Speed Data Processing.*

Table 4.1: Electronic Computers in Canada, c.1958

Computer	Primary Storage	Organization
ALWAC III-E	Drum	University of British Columbia
Bendix G-15	Drum	NRC, Mechanical Engineering Division
		RCAF Cold Lake
		Computing Devices of Canada
		University of Manitoba
Burroughs E101	Drum	NRC, Radio and Electrical Engineering Division
Datatron 205	Drum	Atomic Energy of Canada Limited
		McGill University (planned)
Ferranti Mark I	Williams Tube	University of Toronto (Ferut)
		NRC[68]
IBM 650	Drum	Canadair Limited
		Canadian General Electric Company
		Canadian National Railways
		Ford Motor Company of Canada
		Great West Life Assurance Company
		IBM Data Centre, Toronto
		Imperial Oil Limited
		KCS Data Control Limited
		Laval University (planned)
		Manufacturers Life Insurance Company
		Ontario Hydro-Electric Power Commission
		Orenda Engines Limited
		Prudential Insurance Company of America
		Royal Canadian Army Pay Corps
		Trans-Canada Air Lines
		Workmen's Compensation Board
		University of Ottawa (on order)
		University of Toronto
		University of Western Ontario (on order, 1959)
IBM 704	Core	Avro Aircraft Limited
IBM 705	Core	Confederation Life Association
		Drug Trading Company Limited
		Imperial Oil Limited
LGP-30	Drum	University of Alberta
		University of Saskatchewan
NCR 102A/D	Drum	RCAF Cold Lake
UNIVAC II	Core	London Life Insurance Company
		Sun Life Assurance Company of Canada

ance, accounting, planning, and scheduling. A six-page bibliography also provides a useful snapshot of the field in the late 1950s, as does an appendix that describes in detail many of most popular machines available at the time. Specific references to the Computation Centre are minimal with a few exceptions; in an early section entitled 'Logical Structure of a Computer', UTEC is used as an example of "an extremely primitive machine" to best study how the functional units of a computer come together as a whole. As well, in the final chapter, 'Automatic Programming', TRANSCODE is described in brief alongside other compilers and interpreters.[70] To best convey the principles of programming, rather than give instruction for any particular computer, a simplified hypothetical machine is introduced and used for most of the code examples.[71] Much of the book emerged from the notes of the night courses that Hume and Gotlieb had offered through the university's Department of Extension in recent years. Hume described that effort as partial motivation to prepare the text: "A lot of the work that I was interested in was the cleaning up of terminology. There were so many different words for the same thing and in our writing it was quite important ... to clarify the use of words: fields of records and files of records."[72] For their pioneering efforts, they were rewarded by being quoted in the sense section of twelve entries in the Oxford English Dictionary: block, character, datum, generator, housekeeping, in-line, interpreter, keyboard, logical, loop, matrix, simulate.[73]

The other event significant event of 1958 was the creation of the Computing and Data-Processing Society of Canada, marked by the first conference held at the University of Toronto June 9 and 10.[74] The first serious proposal for a Canadian computer

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[70] Gotlieb and Hume, *High-Speed Data Processing*, 67-72,298-300.

[71] One reviewer complained that the text focused too much on limited machines, rather than "the impressive ability of the larger machines" or "exciting improvements of the near future," but agreed it was a well balanced book. H. Campaigne, "Review: High-Speed Data Processing", *Mathematical Tables and Other Aids to Computation* 12, no. 64 (1958), 315–317.

[72] J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R. Williams.

[73] In the case of in-line and loop, their book is given as the earliest citation.

[74] "Canadian Conference for Computing and Data Processing, Proceedings".

user group came in 1955, and not from the Computation Centre but outside from those few organizations that were already active computer users.[75] The proposed association was not to be tied to a particular machine – aside from the 650 there were not enough of any one type in Canada to form such a group – nor was it intended to be an academic society, akin to the ACM. Instead, it would accept all computer users, regardless of background. There was little enthusiasm for the plan from the Computation Centre, which seems to have killed the idea for about two years.[76] Not until the fall of 1957 was Gotlieb was ready to admit that there was a "sharp increase in the number of Canadian companies committing themselves to electronic computers and data processors, and the feeling has grown that a conference of Canadian users of such equipment would have much to offer."[77] In a letter to other Canadian computing heavyweights, including A.V. Roe, Manufacturer's Life, KCS Data Control, the Ontario Hydro Commission, IBM and Remington Rand, he pointed out that although it was possible for Canadians to attend conferences and join societies in the United States, there were problems of particular interest to Canadians: the notion of a central computer serving large geographic areas, or the distinct Canadian taxation, tariff, and accounting practices, for example. The Computation Centre was prepared to host an inaugural conference, expecting participants from any Canadian organization with an interest in scientific computing and data processing. Though Gotlieb was involved at all levels in the planning, the remainder of the Executive, Program, and Publication committees consisted of people from the computer industry or whose organizations were already heavy computer users.[78]

Nearly four hundred people registered for the conference. The vast majority were from Toronto, or to a lesser degree, Montreal, but as expected they represented organi-

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[75] E.F. Codd to C.C. Gotlieb, 29 December 1955, UTARMS B2002–0003, Box 2, Folder 4.

[76] C.C. Gotlieb to E.F. Codd, 4 January 1956, UTARMS B2002–0003, Box 2, Folder 4.

[77] C.C. Gotlieb to Mailing List, 12 September 1957, UTARMS B2002–0003, Box 2, Folder 2.

[78] The sole exception was T.E. Hull, on the Program Committee, who was from the University of British Columbia.

zations from all walks: academia, consulting, distributors, energy, government, insurance, military, technology, transportation, and the computer industry itself. W.H. Watson opened the conference with a talk entitled 'On Learning to do Better' that began "No one who has thought about computing and data processing machines can fail to be impressed with the very great variety of purposes to which they may be applied."[79] This was well reflected in the conference program, with speakers and subjects as varied as the list of registrants, with the overwhelming emphasis on computer applications, rather than developments in hardware or programming techniques. The point of Watson's talk, however, was that this emerging diversity was not necessarily a strength, unless matched with training and research which met rigorous intellectual standards.

Watson had been laying the foundation for a strong academic department at Toronto to claim those responsibilities; his talk was but one stone in the structure. Perhaps better than anyone in his audience or his university, Watson knew that although the Computation Centre was the host of the conference, it was no longer the centre of computing in Canada. The rise in the number of computers in the country coupled with the expanding use of computers put the Computation Centre in a weak position. For the first time, it faced serious financial competition as service centre in Canada.[80] Not only were many customers abandoning the Computation Centre to buy their own computers, but other computing services were already or would shortly be available in Toronto and other major Canadian cities. As he pointed out at a March 1958 meeting of the Computation Centre Advisory Committee, even the stalwart support of the NRC and DRB might wane when a computer was available in Ottawa.[81] The DRB had, for instance, recently put its support behind a decision to

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[79] William H. Watson, "On Learning to do Better", in "Canadian Conference for Computing and Data Processing, Proceedings", 1.

[80] W.H. Watson to M. Woodside, 22 April 1958, UTARMS A1971–0011, Box 13, Folder 25.

[81] Computation Centre Advisory Committee (Administration), meeting minutes, 4 March 1958, UTARMS A1971–0011, Box 13, Folder 25.

install an IBM 650 at the University of Ottawa to improve computing access to defence scientists in the capital region.[82] Though the Computation Centre would still have a faster computer than most other organizations and a better run centre, distant users would almost certainly find it more convenient to use closer machines. The number of problems sent to Toronto would inevitably decrease.

There was irony in these developments not lost on Watson, who noted "We must recognize that we are in some measure a self-liquidating organization whose activity is to train the very people who will, by their services, remove demands for ours."[83] The obvious outcome of offering credit and extension computing courses was that students would take their new-found skills and knowledge outside of the Computation Centre. But aside from the 700 students that had attended one of the Computation Centre's courses, he was also referring to companies founded by former affiliates of the Computation Centre. Josef Kates and Len Casciato had left the University of Toronto after UTEC was cancelled, with an entrepreneurial appetite that was only satisfied when they formed KCS Data Control in 1954.[84] Another example was H.S. Gellman and Co., created in 1952 by Harvey Gellman, after he completed his Ph.D. at the University of Toronto and resigned from the Computation Centre.[85] Both were among Canada's preeminent computer consulting companies.

Unfortunately for Watson, a significant portion of the Computation Centre budget was derived from the service income of machine time sold to external customers, so much that a decline would impair the operations of the Centre. Watson had first predicted a scenario of declining income as early as March 1954. In a memo to the University of Toronto administration that forecasted the future of the Computation Centre, he warned that if the university could not "see its way to accept responsi-

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[82] J.H. Morgan, "Scientific Computation Within the Defence Research Board", in *Proceedings of the Third Conference of the Computing and Data Processing Society of Canada, McGill University, 2-3 June 1962* (Toronto: University of Toronto Press, 1963), 62.

[83] W.H. Watson to M. Woodside, 5 February 1958, UTARMS A1971–0011, Box 13, Folder 25.

[84] The name KCS was an amalgamation of their initials, with the third founding partner, Joe Shapiro.

[85] Strauss, "Harvey Gellman: 1924-2003", F11.

bility for operating the centre," then other computing centres would be created and service income would dry up.[86] His primary complaint was that the University of Toronto had experienced a failure of imagination and was not reacting to the needs of the Computation Centre, in terms of space on campus, staffing, or financing. The space in the McLennan Laboratory Building currently allocated to Ferut was inadequate, the number of staff members was half of what it should be in order to use Ferut to capacity, and the university did not contribute financially to the Centre. In fact, though it had an annual budget of around $140,000, the Computation Centre was a self-sufficient operation relative to the university. The $50,000 in annual grants from the NRC and DRB and the service income from the sale of machine time was all Watson could use to balance the salaries, supplies, rental and maintenance contracts, and other operating expenses. During Watson's first years as Director the Computation Centre ran close to a deficit. At the end of the 1953-54 academic period, the balance was just $330.[87] However, by the end of the 1956 period, a new fee mechanism had been implemented – charging per hour, rather than per line of code – and more organizations had learned of Ferut and TRANSCODE and began submitting programs. With these changes a surplus of about $46,000 had built up in a reserve fund.[88] Throughout these years, the university did not contribute a dollar of income though professors, staff and students were provided free machine time. All the while, the Computation Centre paid the university $12,000 per year for space and services such as electrical power.[89]

At the same time, Canadian organizations were turning away from the Computing Centre to acquire their own computers. Though the Cold Lake and A.V. Roe 102A installations were first, the most significant to follow this path was Atomic Energy of

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[86] W.H. Watson, The Computation Centre, University of Toronto (Confidential), 9 March 1954, UTARMS A1968–0007, Box 110, Folder 4.

[87] Computation Centre, Estimates for the Year Ending 30 June 1955, UTARMS A1968–0007, Box 121, Folder 9.

[88] G.L. Court to W.E. Phillips, 12 September 1956, UTARMS A1971–0011, Box 4, Folder 5.

[89] W.H. Watson to S.E. Smith, 5 March 1957, UTARMS A1971–0011, Box 4, Folder 5.

Canada Limited (AECL). Until 1956, AECL had been the primary outside user of Ferut and provided nearly one third of the service income.[90] Watson had been able to negotiate a contract with AECL for a one year period beginning June 1955 for 320 hours of machine time in exchange for $16,000.[91] Though the contract provided financial stability it was short lived. In 1956 AECL purchased a Datatron E205, a drum-based machine with an excellent architectural design and reputation, to handle its own computations. The end of the relationship between AECL and the Computation Centre caused a drastic loss of service income to the Centre.

Watson again went before the University of Toronto administration to argue that the university needed to contribute financially to the Computation Centre.[92] In a March 1957 letter to President Smith, Watson warned him that without a solid commitment from the university it would be inappropriate to press the NRC and DRB for larger grants to keep the Centre operating, especially as those agencies were using Ferut less and less. From 1956 to 1957, the combined machine time of the NRC, the DRB, and AECL dropped precipitously from 1243 to 786 hours (see Table 4.2). Some of this decrease could be attributed to AECL's purchase of the Datatron E205, but the total usage continued to fall to 714 hours in 1958 and to 150 hours in 1959. Fortunately for the Computation Centre, the annual grants from the NRC and the DRB were not in any immediate danger of disappearing, and perhaps Watson knew this. Yet he was only able to prevent the Centre budget from running in the red in 1957 by digging into the reserve fund built up in previous years. His frustration with the university and its lack of financial support was profound, and inflamed all the more so because in 1957 the percentage of programmer use of Ferut by University of Toronto staff and students had exceeded 50%. At no other point in Ferut's history had any one single group consumed more than half of the machine time. According to Watson, at

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[90] G.L. Court to W.E. Phillips, 12 September 1956, UTARMS A1971–0011, Box 4, Folder 5.
[91] A.G. Rankin to W.H. Watson, 25 April 1955, UTARMS A1968–0007, Box 121, Folder 9.
[92] W.H. Watson to S.E. Smith, 5 March 1957, UTARMS A1971–0011, Box 4, Folder 5.

the cheapest rate that the Computation Centre charged commercial users this was the equivalent of about $65,000 worth of computer time that went uncollected. He also pointed out to the president that there were many other benefits that the university received without compensation.[93] For example, staff members of the Computation Centre taught courses in the Department of Physics as part of their normal salary.

Table 4.2: Ferut and IBM 650 Usage (Hours), 1954–1959[94]

	1954	1955	1956	1957	1958			1959
	Ferut				Ferut*	IBM 650	Total	IBM 650
AECL, DRB, NRC	814	1042	1243	786	529	185	714	150
University of Toronto	124	366	872	1371	495	672	1167	1664
Outside Companies, Other Universities	641	596	533	449	92	126	218	30
Library	169	184	133	98	12	334	346	519
Available	625	440	364	365	70	500	570	876
Total Hours Usage	1748	2188	2781	2704	1130	1315	2445	2362

* First four months of 1958.

Why was the university now using more than half of the machine time? The obvious, if glib, answer is that no one else was. Because operations depended on service income, sales of machine time took precedence over university use. However, after 1955, though the hours of machine use remained relatively stable, as external use decreased university teaching and research use increased to occupy the same machine time. Between 1953 and 1957, roughly one new credit or non-credit computer related course was added each year; during the 1957-58 academic year alone, seven courses were attended by over 300 students.[95]One undergraduate course, 'Mathematics 1f: Numerical Methods' was now taught to first year Mathematics, Physics and Chemistry students as an introduction to computing techniques, accounting for the largest proportion of students in 1957-58.

Since the initial training courses in the early 1950s, the Computation Centre had

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[93] W.H. Watson to M. Woodside, 5 February 1958, UTARMS A1971–0011, Box 13, Folder 25.

[94] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9.

[95] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9.

also begun to reach out with a number of non-credit courses, intended for those who already had a degree. In the spring of 1954, Worsley and Gotlieb taught a special course devoted to programming Ferut to a collection of about two-dozen actuaries from eight local insurance companies.[96] In the next academic year, 1954-5, a new course was offered through the University of Toronto Department of Extension, 'High-Speed Data Processing'.[97] The number of students were surprisingly high: 51 students enrolled the first year, and more than twice as many signed up the second time. In response, a second extension course was added, 'Programming for Data Processing', which attracted fifteen students. Over the 1956-7 academic year, the last full year that Ferut was used, a third extension course was created, 'Engineering Techniques for Digital Computers', and together the three courses attracted over two hundred students. For several years, there were more than twice as many people enrolled in the extension courses as the credit courses, a sign of both the interest in the field and the lack of skilled students graduating from the university.[98] It was not until 1956-57 that 'Programming for Digital Computers', the first credit course dedicated to programming, was introduced for graduate students in the Physics department. Most relevant to the issue of computer time, many if not all of the courses in this expanding calendar required hands-on laboratories with Ferut. Instructors had learned quite early that "whilst the principles of machine methods of computing can be transmitted by lectures alone, the practice of coding can only be properly presented in laboratory sessions."[99]

A parallel problem appeared in the course of research conducted in the Computation Centre, where practical experience was essential for success in what might otherwise be considered theoretical realms. As Watson put it: "New ideas connected with the validity of proposed mathematics methods can not be gained without doing

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[96] Worsley, "Computer Training at Toronto", 72.
[97] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9.
[98] University of Toronto, *President's Report*, 114.
[99] Worsley, "Computer Training at Toronto", 72.

sufficiently large calculations," and that "One learns much from the failure of conventional mathematical methods applied to particular examples."[100]Regardless of the efficiencies made possible by TRANSCODE, learning how to use a computer, either as a beginner or as an experienced programming trying to devise and test new numerical methods, the university use of Ferut relentlessly increased. "This has required a good fraction of the time of the Computation Centre Staff to instruct learners and advise students in preparing work for the machine," and that "in order to do it well [we] have turned away work that might have increased our income."[101]

Towards the end of the 1950s there were an increasing number and variety of graduate students using Ferut in the course of their research, as shown in figure 4.1. By 1959, forty-nine students had completed a Ph.D. in connection with the Computation Centre, and in 1960, seventeen more had projects in progress. Clearly, the Department of Physics accounted for most of the doctoral research, with two-thirds of the total number of students during during the decade. Two reasons might explain this. First, there were more physics faculty members than any other associated with the Computation Centre. Second, during the 1950s physics was the only graduate department to offer programming courses, though students from other departments were welcome to attend.

The majority of all computer related dissertations at this time were cases of scientific computation. That is, most used the Centre as a means to another end. Interesting or valuable techniques might have been discovered in the course of writing programs to solve numerical problems, but only a small portion of graduate students in the 1950s were specifically attracted to studying the design or use of modern computers. The group includes Kates and Ratz's 1951 theses describing their work on UTEC, and

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[100] W.H. Watson, The Computation Centre, University of Toronto (Confidential), 9 March 1954, UTARMS A1968–0007, Box 110, Folder 4.

[101] [we] added. W.H. Watson to S.E. Smith, 5 March 1957, UTARMS A1971–0011, Box 4, Folder 5.

[102] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9, 31–33.

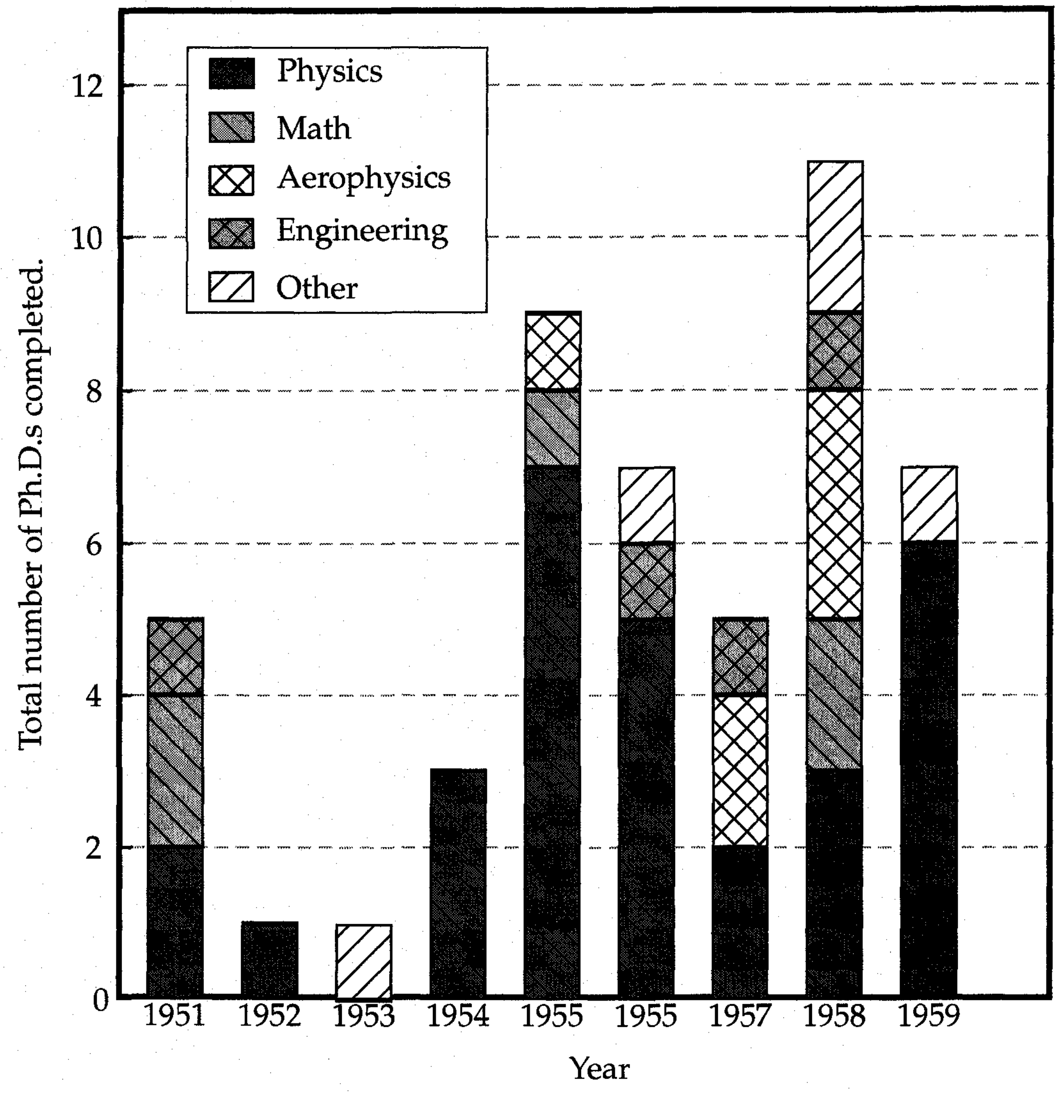

Figure 4.1: Computer Related Ph.D. Theses, 1951–1959.[102]

Perrier's analog computer of 1953.[103]

Before B.A. Griffith resigned from the University of Toronto in 1958, he supervised four mathematics students whose research involved computing. Two, K. Smillie and K. Okashimo, conducted statistical research in the Computation Centre, though their projects were in the category of computing as a means, rather than an end. Smillie, who used the IBM 602A for his project, worked with fisheries data supplied by the De-

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[103] Kates, "Space Charge Effects in Cathode-Ray Storage Tubes"; Ratz, "The Design of the Arithmetic Unit of an Electronic Digital Computer"; and Perrier, "An Electronic Analogue Computer for the Solution of Tenth-Degree Polynomials".

partment of Zoology and finished in 1952.[104] Smillie then spent two years at the DRB in Ottawa before he was hired by Computing Devices of Canada to help run the NCR 102A at RCAF Cold Lake.[105] Okashimo's thesis, finished in 1955, dealt with data from the Meteorology Service of Canada pertaining to water droplets.[106] Of the Griffith's other two students, both were staff members of the Computation Centre for several years, both wrote a thesis describing numerical methods appropriate for solution by electronic computer, and coincidentally, both finished in 1958. S.D. Baxter's work examined numerical methods for the solution of hyperbolic differential equations; it also included test programs written for Ferut.[107] After graduation Baxter was hired by the NRC and in the 1960s he was the director of the NRC's computing centre.[108] Griffith's final student was W.H. Kahan, who studied numerical methods for the solution of large systems of linear equations.[109] According to Griffith, his research methods and results were excellent, though it took arm twisting to get Kahan to actually write his thesis.[110]

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[104] Smillie was also assisted by human computers from the the federal Treasury Department and the Atomic Energy Project at Chalk River. Keith W. Smillie, "A Mathematical Treatment Of Certain Movement Of Fish – An Application of the Theory of Markov Processes", Ph.D. thesis, Mathematics, University of Toronto (1952).

[105] Howland and Smillie, "Some Mathematical and Programming Techniques Employed in the Operation of a Scientific Computing Facility", 78–87; Smillie, "Velvet Gloves and Latin Squares: Memories of Some Early Computing in Canada", 323–326. After a few years of employment as a government statistician, Smillie was hired as an Associate Professor at the University of Alberta, where he was a founding member of its Department of Computing Science in 1964.

[106] K. Okashimo, "The Numerical Integration of Integro-Differential Equations of Convolution Type", Ph.D. thesis, Mathematics, University of Toronto (1955).

[107] Stuart D. Baxter, "Numerical Methods for the Solution of Hyperbolic Differential Equations with the Aid of an Electronic Computer", Ph.D. thesis, Mathematics, University of Toronto (1958).

[108] In the mid 1960s Baxter was a member of the NRC Associate Committee on Computers, the purpose of which was "to recommend policy for awarding computer grants and to give guidance to Universities regarding computer equipment." Though not a founding member in 1963, Baxter served with K.F. Tupper, T.E. Hull, and A. Porter in 1965. NA RG77, File 6090-3.

[109] William M. Kahan, "Gauss-Seidel Methods of Solving Large Systems of Linear Equations", Ph.D. thesis, Mathematics, University of Toronto (1958).

[110] Griffith, "My Early Days in Toronto", 63. Kahan pursued a post-doctorate at Cambridge before returning to Toronto, where he was a founding member of the Department of Computer Science in 1964. Later that decade he was hired away by the University of California Berkeley. There he specialized in numerical analysis and the development of rigorous floating-point standards. Kahan is one of the most famous graduates to come out of Computation Centre. Among his many honours, he was the 1989 recipient of the ACM A.M. Turing Award. Considered the highest recognition in computer science, his citation reads: "For his fundamental contributions to numerical analysis. One of the foremost experts

The final explanation for the rise in university use of Ferut is that computing research by various faculty and Computation Centre staff members was also increasing. After the St. Lawrence Seaway backwater calculations, one of the largest programs was a series of self-consistent field calculations, carried out by Worsley.[111] The project was a collaboration between the Computation Centre and the Pure Physics Division of the NRC, the latter represented by J.F. Hart. The goal was to develop a program for Ferut that could be used to calculate atomic wave functions using the Hartree-Fock formulation.[112] Hartree himself consulted on the project in Canada until his death in 1958. Worsley wrote the Ferut program without the benefit of TRANSCODE, and in 1958 she was able to claim that in solving the equations, it was "the widest in scope and the most nearly automatic that had been attempted."[113] That is, it was the most flexible known routine and operator involvement was minimal during a production run. This made it possible to remove human judgement from the work, which had been necessary when Hartree first developed the technique and was limited to hand calculations. By use of certain optimizations Worsley was also able to triple the speed of calculation, which showed, as Hartree had argued, that it was possible to use a machine that was by then considered slow to achieve good results without sacrificing accuracy. However, it was still one of the most intensive routines run on Ferut, in the hundreds of hours, and the last major project before the machine was replaced. Wave function calculations for heavier atoms were simply too time-consuming and would have to wait for a more powerful machine.[114]

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on floating-point computations. Kahan has dedicated himself to 'making the world safe for numerical computations."'

[111] J. F. Hart and Beatrice H. Worsley, "Self-Consistent Field Calculations at the University of Toronto", in "Canadian Conference for Computing and Data Processing, Proceedings", 298–305.

[112] See Douglas R. Hartree, *The Calculation of Atomic Structures* (New York: J. Wiley, 1957) and Charlotte Froese Fischer, *Douglas Rayner Hartree: his life in science and computing* (Singapore, London: World Scientific, 2003).

[113] Hart and Worsley, "Self-Consistent Field Calculations at the University of Toronto", 302.

[114] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9.

4.3 Replacing Ferut

As early as 1955 Watson had been making plans to replace Ferut, not long after the staff of the Computation Centre had mastered the machine. By then Ferut was already starting to show its age: "obsolescence is not far off. In a very few years a new machine will be essential if computing research is to continue."[115] As Gotlieb complained to another university computing centre director, the high costs of maintaining an unreliable machine and an increasing load of more difficult problems meant that Ferut was already operating at capacity, when it was working at all.[116] A newer, faster, more reliable computer would be needed soon if the Computation Centre was to match the rising demands.

For the next five years, one computer sat at the top of the wish list: the ILLIAC II. The roots of this machine went back to the late 1940s, when the Digital Computer Laboratory at the University of Illinois built a modern computer based on von Neumann's design. The Laboratory was more successful than the Computation Centre, thanks to the support of a more generous benefactor – the United States Army Ballistics Research Laboratory. Known as ORDVAC, the computer was finished in 1951 and shipped to the Aberdeen Proving Grounds in March 1952. The Laboratory then constructed the first ILLIAC from the same plans but with University of Illinois funds; it was operating by the end of 1952.[117] The ILLIAC fell into about the same class of machine as IBM's first commercial electronic computer, the IBM 701, and was roughly ten times faster than Ferut.[118] The design of ILLIAC was well-regarded, and at least one copy was made, the Sydney ILLIAC (SILLIAC), at the University of Sydney in Australia.[119] At one point, the Computation Centre considered making a copy in Toronto,

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[115] Watson, "Report of the Director of the Computation Centre", 114.

[116] C.C. Gotlieb to P.C. Hammer, 28 June 1955, UTARMS B2002–0003, Box 2, Folder 15.

[117] Meagher, "Equipping a University Computing Laboratory", 181.

[118] Computation Centre, University of Toronto, November 1958, UTARMS B1988–0069, Box 1, Folder 11.

[119] Bennett, *Computing in Australia: The Development of a Profession.*

but by then the University of Illinois was readying itself to build a very high-speed solid state computer. Instead of vacuum tubes as the primary components, the ILLIAC II would be made with transistors, diodes, and magnetic cores. Though it was barely in the planning stages in 1955, replacing Ferut with a copy of such a machine was an attractive prospect for the Computation Centre.

Though of course the outcome is known already, the University of Toronto installed an IBM 650 when Ferut was removed and not an ILLIAC II, but the two machines could not be much more different. Though IBM started delivering the 650 to customers in 1954, it had begun life many years earlier in a proposal to extend the capabilities of the IBM 604 with a transitional machine to ease IBM's typical punched card customers into the computing era.[120] The 650 was by no means a speedy machine or even much faster than Ferut. Yet in Canada and the United States it was the most popular computer of the second half of the 1950s. By contrast, the ILLIAC II would be a unique machine, or nearly so, and in terms of raw computing speed was expected to be hundreds of times faster than the 650, if not more.

Both computers were discussed at the occasion that Watson first proposed the replacement of Ferut. In December 1955, the Computation Centre Joint Committee, the body of senior representatives from the NRC, DRB, and University of Toronto, met in Ottawa to consider the future of the Centre. After much discussion, the Joint Committee decided that both the IBM 650 and the ILLIAC II were worthy of consideration and directed Watson accordingly: "the possibility of renting an IBM 650 should be investigated," and that "detailed plans for taking up the invitation from the University of Illinois Computing Laboratory to participate in ILLIAC II should be explored at once."[121] Just three years after the collapse of the UTEC project, nobody on the Joint Committee was ready yet for the University of Toronto to move back towards

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[120] Pugh, *Building IBM: Shaping an Industry and Its Technology*, 178–182.

[121] Joint Committee on Computation Centre, agenda and minutes, 12 December 1955, UTARMS B1988–0069, Box 1, Folder 3. An earlier notion of copying the ILLIAC was dropped at this time.

computer research, design, or construction. Regardless, the ILLIAC II was the Computation Centre's favoured contender to replace Ferut. Watson and Gotlieb envisioned numerical calculations for which the current crop of tube-based machines would be inadequate. Unfortunately for them, the projected time-line at the University of Illinois called for the completion of the ILLIAC II no sooner than 1959 and a copy could not be made in Toronto until at least 1960. Assuming that Ferut would not last that long, an interim solution would be needed.[122] A temporary computer, as all involved saw it to be, would need to balance the immediate and long term needs of the Computation Centre until the ILLIAC II was ready.

Shortly after the December Joint Committee meeting, Watson drafted a memo summarizing the two options for the interim computer.[123] Though IBM offered a special educational discount, the rental cost for a basic 650 was nearly $75,000 a year for a single shift of operation.[124] The alternative was a Datatron E205, which could be purchased for about $200,000 or rented for $95,000 a year for a single shift. AECL had recently purchased a Datatron and expected to be using it at Chalk River within a year or so.[125] Both of these prices were beyond the means of the Computation Centre, and the unexpectedly high cost of what was to be a temporary computer forced a reevaluation of the merits of Ferut: perhaps it could be made to last until the ILLIAC II was ready. Though the Ferut service income had just begun to rise in 1955 after the first few lean years of operation, there was no guarantee that trend would continue; in fact, it was not long before the trend reversed and service income began to decline. The year 1955 ended without a firm decision regarding a replacement for Ferut.

By the summer of 1956, some headway had been made at Illinois on the ILLIAC II.

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[122] For comparison, at Manchester, the Mark I was turned off in December 1958, and dismantled the following June. Simon H. Lavington, *A History of Manchester Computers* (National Computing Centre, Manchester, England: NCC Publications, 1975), 24.

[123] Memorandum to the Joint Committee on the Computation Centre, UTARMS B1988–0069, Box 1, Folder 2.

[124] Ferut operated three shifts a day, five days a week, with regular breaks for maintenance procedures.

[125] W.H. Watson to S.E. Smith, 5 March 1957, UTARMS A1971–0011, Box 4, Folder 5.

Most important, a solid funding commitment from the United States Office of Naval Research and Atomic Energy Commission was in place and the project was officially launched as of 1 July 1956. The University of Toronto would also support it by providing a one year's leave-of-absence to R.W. McKay, Associate Professor of Physics, to travel to Illinois and help with the logical design and storage technology.[126] In January 1957 he was joined by K.C. Smith, a graduate student in the Department of Electrical Engineering, who would be employed on the project as a research engineer for a year and a half. Over the summer of 1957 W.H. Kahan was also sent to Illinois for two months to assist.[127] Gotlieb would also made several trips to the Urbana campus to help with planning, and Watson visited the project at least once. Toronto's financial contribution from 1956-57 was about $17,600, which was covered by the Computation Centre's reserve fund.

Also by the middle of 1956, several of the ILLIAC II's technical aspects had been outlined. The primary goal was to attain the highest computing speed possible. Therefore, it would be a parallel machine, with transistorized circuitry and a magnetic core for the high-speed store, though both technologies were still considered experimental and unstable. Reducing the magnetic core access time would be one of the more crucial research problems, and the proposed circuitry used transistors with extremely rare or even non-existent characteristics. The logical design of the machine was still an open question, but work was ongoing.

One early problem the ILLIAC II project faced was that the engineering team could build arithmetic circuitry that ran at about 0.1 microseconds, but the fastest magnetic core access time was 6 microseconds. This would leave the arithmetic unit starved for work, as a single computer cycle must be as slow as the slowest component. A number of solutions were proposed to solve the problem. First, McKay was leading a group attempting to build faster magnetic core storage, perhaps as fast as 2 microsec-

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[126] Progress Report on ILLIAC Project, 21 August 1956, UTARMS B1988–0069, Box 1, Folder 11.
[127] W.H. Watson to A.M. Zimmerman, 25 November 1957, UTARMS A1971–0011, Box 13, Folder 25.

onds. Another possibility was to use a non-magnetic core storage element that was much faster, at around 0.5 microseconds. Available in limited quantity, it would only be used during repetitive arithmetic or control operations.[128] No decision had been made regarding what technology would be used for this storage, but K.C. Smith was studying some of the options.[129] In June 1957, McKay returned to Toronto but continued his research into high speed magnetic core storage.

By that time, it had become obvious that Ferut would not survive until the ILLIAC II was ready. The high maintenance costs and unreliability doomed it in favour of the many other computers on the market that lacked these flaws. Sometime over the summer of 1957, Burroughs approached Watson with a new, more affordable five-year payment plan for a Datatron that fit within the Computation Centre's budget.[130] In September, Watson turned to IBM, looking for a competitive offer for a 650, but was taken aback by the response. In addition to the normal 60% educational discount, IBM attached two rider conditions. The first was that the Computation Centre would not be permitted to sell computer time to any organization other than the NRC or DRB. Undoubtedly, this was to prevent the Computation Centre from competing against IBM's own computing service in Toronto, but it would have left the Computation Centre insolvent. The second condition made a $10,000 fellowship from IBM to the university contingent on renting the 650. Watson had been negotiating the IBM fellowship separately for some time, "to be applied in promoting study and research in relation to computing machines under the auspices of the Computation Centre."[131] However, he was shocked when IBM attempted to make the fellowship conditional upon signing a contract for the 650. He informed the company that the conditions

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[128] Today, this would be known as a cache memory, a technique pioneered on the ILLIAC II.

[129] Status of the New Computer Project at the University of Illinois, 19 March 1957, UTARMS B1988–0069, Box 1, Folder 11.

[130] The Datatron had originally been sold by Electrodata, a small California based firm, until Burroughs purchased Electrodata in 1956.

[131] (Draft) IBM Graduate Fellowships in the University of Toronto, 21 November 1957, UTARMS A1971–0011, Box 13, Folder 25.

were unacceptable, and he was supported completely by the University of Toronto administration.[132] IBM dropped both riders as neither condition was raised again during negotiations.

The university comptroller, G.L. Court, analyzed the offers from IBM, Burroughs, and a third from Remington Rand.[133] The latter was willing to sell the UNIVAC 1103 (originally known as the ERA 1103, as mentioned above) to the university for about $300,000 – a considerable discount for what was normally a million dollar machine – but the annual maintenance fees were about $40,000. The high capital and maintenance costs eliminated the 1103 from the competition. However, the Datatron and the IBM 650 offers were more affordable and had to be considered closely. Technologically, Watson felt that that the two magnetic drum-based machines would provide more or less equivalent facilities. Both had a good reputation: the Datatron was slow but had an excellent architectural design, while the 650 was the second fastest drum-based computer.[134] The costs were now much closer than the earlier comparison in late 1955; the biggest difference was in the financing arrangement. IBM would rent the 650 to the Computation Centre for about $40,000 a year, and Burroughs would sell the Datatron on a five year low-interest plan for about $40,000 a year plus another $12,000 annually for maintenance. When Court was done with the figures, it turned out that renting the IBM 650, which did include all maintenance charges, would be over $3,000 cheaper to operate than Ferut. Though small, this saving sealed the deal more than anything else – as long as the the service income did not drop much further and the operating grants from the NRC and DRB continued, then the 650 would cost the university nothing. By the end of December, Watson entered final negotiations to install a 650 the following May. Whether it was a coincidence or something more sinis-

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[132] Correspondence between W.H. Watson and M. Woodside, 13 and 25 September 1957, UTARMS A1971–0011, Box 13, Folder 25.

[133] G.L. Court, Computing Equipment for the Computation Centre, 7 November 1957, UTARMS A1971–0011, Box 13, Folder 25.

[134] The fastest drum-based computer was the Bendix G-15. Ceruzzi, *A history of modern computing*, 44,66.

ter, that same week in December IBM sent the first $10,000 cheque to the University of Toronto to sponsor the aforementioned fellowship. IBM requested that the sponsor of the awards remained anonymous, suggesting that it wished to avoid any appearance of impropriety.[135]

On 11 April 1958 the Computation Centre ceased operations with Ferut and began preparing for the arrival of the 650. After roughly six years of service in Toronto, Ferut was shipped to the NRC in Ottawa where it was restarted and operated in the Division of Chemical Engineering for several more years.[136] The 650 arrived, as scheduled, in mid May and Gotlieb was happy with the new computer, at least at first: "It is an impressive machine, and I make no apologies for the change from Ferut."[137] The arrival of the IBM 650 did not have the same dramatic impact that the Ferut had in 1952, but it was an improvement. In terms of speed, the standard 650 was not much faster than Ferut, and because the 650 was a drum based machine, program execution time depended greatly on it accessing the drum optimally. A poorly written program would run slowly, delayed as it waited for the next instruction or data to be read from the drum as it rotated. A well written program was organized with the rotational speed in mind so that delays reading or writing to the drum were minimized. SOAP helped, but it was not good at optimizing larger programs.[138] However, it was possible to upgrade the 650 with optional features. For example, the base model did not include index registers, or B-lines as they were known on Ferut. For their 650 the Computation Centre did order index registers, and a floating-point unit which made its arithmetic several times faster than Ferut's programmed floating-point routines.[139] Experienced and novice programmers alike would also have been grateful that the 650 used a dec-

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[135] The annual University of Toronto *President's Report* recorded the $10,000 benefactor as anonymous until 1965.

[136] C.C. Gotlieb to W. Mitchell, 15 April 1958, UTARMS B2002–0003, Box 2, Folder 4.

[137] C.C. Gotlieb to C. Popplewell, 23 May 1958, UTARMS B2002–0003, Box 2, Folder 15.

[138] George R. Trimble, "The IBM 650 Magnetic Drum Calculator", *Annals of the History of Computing* 8, no. 01 (1986), 24.

[139] IBM also provided floating-point routines for customers with a 650 who chose not to pay for the hardware unit.

imal notation instead of Ferut's awkward teletype code, and that it was much more reliable than Ferut.

Perhaps more important than the 650's technical features was the variety of programming systems and the large library of routines that already existed for the 650. The user group SHARE had formed around IBM 704 users in California, but there was a greater number of 650 users, many of them universities and schools taking advantage of IBM's educational discount. Twenty-one universities in the United States were using a 650 as of December 1956, roughly half of all schools with an electronic computer at the time.[140] The 650 remained the most popular academic computer in North America until it was supplanted in the early 1960s by the IBM 1620, a small, inexpensive solid-state computer first introduced in 1959.[141] The significance of the large number of IBM 650 installations was not lost on IBM. After it released FORTRAN for the 704 in early 1957, it decided that the 650 would be the next computer to run FORTRAN. IBM gathered a small group, separate from the original 704 FORTRAN team, to write the FORTRANSIT compiler for the 650 which it also released in 1957. FORTRANSIT could only compile a subset of the full FORTRAN language, but for the most part, the same program could now run on both the 650 and the 704, two dramatically different machines. This was a considerable advantage for the diffusion of both programming knowledge and IBM products, and soon further versions of FORTRAN were made available on other computers.[142]. It has been said that in the late 1950s, "far more computer people cut their teeth on FORTRANSIT than on FORTRAN – due, of course, to the greater number of 650s in the field and the scarcity of 704s."[143]

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[140] "Universities: Editor's Note", *Annals of the History of Computing* 8, no. 01 (1986), 35. In 1959 it was estimated that there were 56 universities in the United States with an IBM 650, two with an IBM 704, and one with the recently announced IBM 709. Louis Fein, "The role of the University in computers, data processing, and related fields", *Communications of the ACM* 2, no. 9 (September 1959), 14.

[141] T.A. Keenan, "Sixth Survey of University Computing Facilities", Technical report (Rochester, N.Y.: Computing Centre, University of Rochester, 1963), 9.

[142] David Hemmes, "FORTRANSIT Recollections", *Annals of the History of Computing* 8, no. 01 (1986), 70.

[143] Bemer, "Nearly 650 Memories of the 650", 68.

Much as the user group SHARE had formed around IBM 704 computing centres, many universities that operated 650s also cooperated, "exchanging software, documentation and other information."[144] The ACM also maintained a library of information about programming systems for major computers installed in North America. Published tables describing the records indicate that in the late 1950s there were more programming systems for the 650 than for any other computer.[145] To reduce the chaos users worked to agreed on programming standards, to ensure that as the number of useful routines grew it would be possible to "build on each other's work."[146] For instance, a group of midwestern universities in the United States standardized on a particular input/output arrangement that permitted sharing of utility programs and languages.

But did the Computation Centre take advantage of the broader community? Gotlieb has claimed that it did: "we had been, roughly speaking, programming only for ourselves. The 650 ... brought us in contact with the IBM world."[147] As mentioned in the previous chapter, with the many programming systems available for the 650, including SOAP, IT, and FORTRANSIT, there was little need to transfer TRANSCODE from Ferut to the IBM 650. In particular, FORTRANSIT made programs much easier to read and write than a low level language like TRANSCODE. Relatively speaking, the latter was not much better than programming in machine code.[148] Unsurprisingly, at the University of Toronto students using the 650 were taught to program FORTRAN

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[144] Bernard A. Galler, "The IBM 650 and the Universities", *Annals of the History of Computing* 8, no. 01 (1986), 38.

[145] See "Techniques Department", *Communications of the ACM* 1, no. 4 (1958), 7,8 and Robert W. Bemer, "Automatic programming systems", *Communications of the ACM* 2, no. 5 (1959), 16 for tables of programming systems.

[146] Galler, "The IBM 650 and the Universities", 38.

[147] Bleackley and La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years*, 12.

[148] By some historical quirk, the only formal paper to describe FORTRANSIT, aside from the manual, was published in the proceedings of the *First Canadian Conference for Computing and Data Processing*, the inaugural meeting of the Computing and Data Processing Society of Canada in 1958. B.C. Borden, of IBM Canada, spoke on FORTRANSIT from the user's perspective, explaining the advantages had by the programmer versus a more conventional coding practices without such a compiler. See Borden, "FORTRANSIT: A Universal Automatic Coding System for the IBM 650", 349–359.

using FORTRANSIT.

Yet as a whole, neither the 650 nor FORTRANSIT were a panacea, and the advantages of belonging to a user group or the IBM world had limitations. While computer teaching was made considerably easier, research driven programming was often still handled with machine code and SOAP in order to maximize program speed or size. A new library was necessarily created to hold the expanding list of useful subroutines.[149] All of the routines in the library – including a large and complex matrix manipulation routine – were written locally by the faculty, staff, or students for specific projects. None came from the wider community or a user group, but some were customized versions of IBM supplied SOAP routines, altered to suit the needs of the Centre or a particular problem. Interestingly, a handful of the routines were based on published scientific articles which described useful algorithms. For example, a least squares method developed by George Forsythe was used to create the routine FORSYTHEFITTING.[150] Computing knowledge that was beginning to circulate in a generalized form in scientific journals could be adapted for any machine, not just an IBM 650. Thus the value of belonging to a 650 user group or the IBM community as a whole should not be overvalued.

In any case, the 650 did not solve the Computation Centre's most immediate problem of decreasing service income. In 1958, Ferut was used more in its final four months by external organizations than the 650 was used in its first eight months. Of course, it takes time to learn how to use a new computer, but there was also more competition. There were at least two other comparable IBM 650s available in Toronto: at KCS Data Control and IBM's own service centre, which was also using FORTRANSIT. Beyond

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[149] Computation Centre, *Library Programs for the IBM TAPE 650 Electronic Data Processing Machine*, Revised January 1960 edition (Toronto, January 1960).

[150] George E. Forsythe, "The Generation and Use of Orthogonal Polynomials for Data Fitting with a Digital Computer", *Society for Industrial and Applied Mathematics* 5, no. 2 (June 1957). Forsythe, an American numerical analyst and computer scientist at University of California Los Angeles and Stanford University was responsible "more than any other man ... for the rapid development of computer science in the world's colleges and universities." Donald E. Knuth, "George Forsythe and the Development of Computer Science", *Communications of the ACM* 15, no. 8 (August 1972), 721–726.

that, Confederation Life had recently purchased a much more powerful IBM 705 that IBM also operated as a service centre, Remington Rand was installing a UNIVAC II, and Burroughs was expected to have a Datatron operating soon in the city.[151] The Computation Centre could not expect to compete against these operations, particularly without a sales organization to drum up new business. As expected, outside use of the Computation Centre fell to less than 10% of the total use in 1959.

In technical terms the IBM 650 was a marginal improvement over Ferut, but it was not a perfect replacement. By July of 1958, after just a few months of operation, Gotlieb was already a little pessimistic. "It turns out to be a very nice machine, and though for the while it seems capable of handling the work we have for it, we do aspire to something better."[152] Recall, however, that the 650 was always intended to be a temporary solution. The Computation Centre was still fully committed to the ILLIAC II and building a copy of it as soon as possible. By renting the 650 it gave the Centre flexibility until the ILLIAC II was ready. The contract with IBM could be cancelled with one year's notice, or the computer could be upgraded with new features or to another computer as IBM's product line evolved. Though the 650 did not solve the problem of declining service income, the silver lining was that it forced the Computation Centre to move away from its role as a service centre. The commonality of the machine eliminated the Centre's position as the best or even the only place to buy computer time in Canada. And at the same time, university use was increasing to the point that it was disingenuous to even consider the Computation Centre a service centre. Thus Watson was halfway to redefining the relationship between the university and the Centre. As will be explored in the following chapters, the greater aspirations that Gotlieb referred to were not limited to computer technology.

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[151] W.H. Watson to M. Woodside, 22 April 1958, UTARMS A1971–0011, Box 13, Folder 25.
[152] C.C. Gotlieb to F.C. Williams, 22 July 1958, UTARMS B2002–0003, Box 2, Folder 15.

Chapter 5

New Computers and New Identities, 1958–1964

"In my experience in the Computation Centre I have learned some amazing facts about the way in which quite substantial sums of money can be committed before the necessary homework has been done."

– W.H. Watson, Director of the Computation Centre, 1958.[1]

Watson made the above remarks in his opening address of the First Canadian Conference for Computing and Data Processing, held at the University of Toronto in 1958. His cautionary words were intended to guide the many attendees who were contemplating joining the modern computer age, and to warn them of the various complexities and pitfalls. But as this chapter will also demonstrate, these words foretold events in the Computation Centre in a way he failed to anticipate.

At the end of the 1950s, computing technology and practices had changed considerably from a decade earlier. The challenge for Watson (and Gotlieb, his successor as Director of the Computation Centre) was to react to these changes, and to redefine the relationship between the Computation Centre and the university. Some members of

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[1] Watson, "On Learning to do Better", 1–5.

the university administration remained unconvinced that a school should own and operate a computer, believing that this was best left to private enterprise. But was there an academic aspect to modern computing that was not being recognized? The decision to delay the acquisition of a replacement for the Ferut was related to this dilemma, as was the desire to push for the ILLIAC II. Again and again, the argument was put forth by Watson that valuable research could only be conducted with a high-speed computer, despite evidence that interesting and useful work could be done with a lesser machine. Nevertheless, the University of Toronto would again end up with the most powerful computer in Canada in 1962, and with it came recognition that this was something worthwhile for a university. After a fourteen year existence, the Computation Centre was renamed the Institute of Computer Science to acknowledge its increasingly interdisciplinary role. A particular definition of computer science did not accompany the name, and the full realization of Watson's plan was incomplete until 1964 when a new graduate Department of Computer Science was created. The IBM 650 and the ILLIAC II were means to this end, but ultimately, a third computer would prove to be the linchpin in the plan.

5.1 Redefining Academic Computing

From 1954 to 1958, the Computation Centre had gone from operating the only computer in Canada, to running the only large-scale computer, to renting one of several identical medium-scale computers in the Toronto region. When the ILLIAC II was built it was expected to be more powerful than any other computer in Canada for many years, but in 1958 the Computation Centre's 650 was merely on par with many other Canadian organization's computers – at least twenty had one or were planning to get a 650 by the end of the decade.[2] Perhaps when Gotlieb said they aspired to some-

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[2] To be precise, the IBM 650 came in many configurations, and the Computation Centre had one of the better arrangements. But it was still a common computer, even in Canada.

thing better, he was lamenting this demotion. It would certainly make the Computation Centre less competitive. Fortunately, Watson had a vision of the Computation Centre no longer "dependent on an amateur business effort against the professionals," but self-sufficient within the university.[3] He could not and did not want to compete with the other computer service organizations that had arisen across Canada. But the Computation Centre simply could not survive year to year on the whim of federal grants and the sale of machine time.

Instead, Watson firmly believed that the proper mission of the Computation Centre was scholastic, and not as a training or service centre. Of course, that had been a part of the Centre's mandate as far back as the first proposal in 1946. It had only fallen from view as the more essential tasks of acquiring a modern computer and learning how to use one took precedence. But even as the Director of the Computation Centre, Watson had only limited powers to redirect the Centre from a service organization to an academic one. Internally, he could make small changes to nudge things along. He was able, for example, to institute a new policy in 1956 that the Computation Centre would cease offering programming services to their customers, "except where there is some special research interest," and to begin referring clients who lacked programming skills to another computing service.[4] The inevitable result was a drop in service income, but staff could redirect their attention to university matters such as instruction and aiding research.

Beyond the walls of the Computation Centre, though computer related research and teaching continued to grow, it proved more difficult to convince the rest of the university not to ignore the Centre and recognize it as a serious academic home. Roughly a year after he took over as Director, in early 1954, Watson summarized his thoughts in a memo to the university administrators. He chided them for failing to recognize that computing was already having an effect on science and engineering, and warned that

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[3] W.H. Watson to M. Woodside, 22 April 1958, UTARMS A1971–0011, Box 13, Folder 25.
[4] C.C. Gotlieb to E.F. Codd, 4 January 1956, UTARMS B2002–0003, Box 2, Folder 4.

if the university withdrew from the field in any way, "we shall eventually regret the step."[5] He advised that the university should act to retain the "first class engineers, theoretical scientists and mathematicians with a flair for the practical," that would accompany a well-supported computing centre and would boost the national and international profile of the university. The Computation Centre had already lost Ratz when UTEC was cancelled, and Kates had threatened to leave the country as well.

President Smith turned for advice to K.F. Tupper, dean of Engineering and the man Watson had replaced as Director of the Centre.[6] Tupper disagreed with Watson on most counts, especially the idea that operating a computer would be perpetually a proper university activity. "The day may come when the University will back out of digital computation just as it has backed out of photographic service." He continued, "While I earnestly express the hope that mathematicians within the University will remain interested in this activity, I see no reason why they should not be able to buy machine time outside the University just as a research worker can buy photographic service outside."[7] He did not express much hope that mathematicians would ever take up the activity, pointing out that they were responsible for establishing the computing project back in 1946 but had taken little interest since. Tupper also made clear his distaste at the prospect of the university Computation Centre taking on calculations from industry, preferring that some "enterprising young mathematician" set up his own business to handle the work.[8] However, Tupper seems to have missed Watson's primary point: that without greater university support, the computer could not be used to its fullest potential and many research opportunities would be lost, and with it the university's reputation. President Smith took no action at the time.

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[5] W.H. Watson, The Computation Centre, University of Toronto (Confidential), 9 March 1954, UTARMS A1968–0007, Box 110, Folder 4.

[6] Both had also worked together at Chalk River in the 1940s where Watson was head of theoretical physics and Tupper was head of the Engineering division.

[7] K.F. Tupper to S.E. Smith, 8 April 1954, UTARMS A1968–0007, Box 110, Folder 4.

[8] Whether Tupper knew this or not, Kates, Casciato, and Shapiro formed KCS Data Control around this time; Gellman had also established his own computer consulting company.

In October 1954, Watson tried a new tack. In a second memo he pointed out that the Computation Centre was having difficulty meeting the demands of customers because of the limitations of staffing and space and the increasing use of Ferut by insiders and outsiders. He predicted that as these factors intensified, "we must expect to find our competitive ability declining unless we can change to meet the new circumstances."[9] For instance, he claimed that A.V. Roe had passed over the Computation Centre for large matrix calculations. He proposed that the university take advantage of its leadership position while it could and firmly establish itself "as the source of experts for Canada" by expanding the staff and acquiring a new high-speed computer. It would permit an increase in the quality and quantity of both teaching and research, and create, in effect, a computing centre of national or even international calibre. He did not expect the university to pay for the computer, but suggested that external organizations which had helped in the past – the NRC and the DRB – could be convinced to contribute to the costs of a new computer. Perhaps even a few new industry groups could assist, as many more of them were beginning to discover the benefits of modern computing. It is not surprising that coming so shortly after the arrival of Ferut, this plan for a new computer was also ignored by the university administration, as were his other pleas.

Watson also appealed to the Computation Centre Joint Committee for assistance, but his problems were rebuffed there as well. At a 1954 Joint Committee meeting, the members were satisfied with the performance of the Computation Centre and decided it was not to "provide services of a national computing agency" much beyond the current level of service provided to the NRC, DRB, and AECL. Thus no new funds (or a computer) were forthcoming.[10] President E.W.R. Steacie of the NRC felt this was not an area of responsibility for his organization, and the average industrial organization

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[9] Memorandum by the Director of the Computation Centre (W.H. Watson), October 1954, UTARMS B1988–0069, Box 1, Folder 2.

[10] Joint Committee on Computation Centre, meeting minutes, 2 April 1954, UTARMS A1968–0007, Box 110, Folder 4.

who needed computing assistance should seek it elsewhere. Steacie even cautioned the university against increasing the computing staff.[11] E.L .Davies, vice-chairman of the DRB, did note the importance of industry having access to the Computation Centre, such as in the case of A.V. Roe and its contributions to Canadian defence research and development. These were special cases though, and he too did not see the need to expand the Computation Centre establish a truly national computing facility. It is worth pointing out that around the same time as the Joint Committee meeting, the DRB had approved the acquisition of the NCR 102A at Cold Lake.

Though the Joint Committee was content with the performance of the Computation Centre, it was less impressed with the university's ambivalence towards the Centre. At the next year's meeting, Steacie pointedly questioned "whether the Computation Centre's main function is to do something that the NRC and DRB want done or something that the University wants itself to do in a field in which people should be training."[12] He urged the university to resolve an answer one way or another and made it clear he preferred the latter option. The president of the DRB, H.H. Zimmerman, agreed that it was time for the university to substantially increase its support of the Computation Centre's academic activities. University President Smith, who attended that 1955 meeting, could only reply that the university valued the academic instruction performed by the Computation Centre staff, and "expressed the readiness of the university to help with future plans."[13] Earlier that year, Watson had managed to extract an admission from President Smith that the Computation Centre was not merely a service centre. In Watson's submission to the 1955 University of Toronto *President's Report* he emphasized the past year's research accomplishments along mathematical lines and drew the reader's attention to the automatic programming project

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[11] Meeting of Joint Committee of Computation Centre, 2 April 1954, UTARMS B1988–0069, Box 1, Folder 3.

[12] Joint Committee on Computation Centre, agenda and minutes, 12 December 1955, UTARMS B1988–0069, Box 1, Folder 3.

[13] Joint Committee on Computation Centre, agenda and minutes, 12 December 1955, UTARMS B1988–0069, Box 1, Folder 3.

TRANSCODE, which he described, accurately, as the spectacularly successful result of an investigation into utilizing computers efficiently. He also stressed the rapid growth of teaching activities, and the significant number of people in the Toronto region who had gained practical experience with a large-scale computer thanks to the Computation Centre. President Sidney Smith echoed many of these comments in his own summary of the Universities activities, and then acknowledged that the Computation Centre's training and research were the best justification for its location within the university.[14] The university did permit McKay's leave-of-absence to conduct research at Illinois for the ILLIAC II, but otherwise, the official relationship between the university and the Computation Centre changed very little until 1957. In particular, no new space was allocated to Ferut and no significant changes were made in staffing.

That year, Watson renewed his attempts at reform. His ammunition was much improved as the university was now the primary user of the Centre. In March, he proposed for the first time that a new academic department be created to contain all computer-related instruction and research, while computer operations be left to the computing centre. In an April letter to President Smith, he pointed out that within the Computation Centre academic activities were occupying greater amounts of staff time, and "to regard the Centre as a mere service department is unfair to its staff and inimical to the best interests of the University."[15] He gave several reasons to justify a new department dedicated to computing. First, the new techniques afforded by computers were making inroads into many scientific fields that were previously impossible. In a single week, a thousand man-hours of calculating could be completed on a computer like Ferut. Because there were so many fields that benefited from computers, the university community stood to gain by bringing together the diverse group of individuals interested in modern computing methods to form a new academic unit. Second, he stated that the theoretical principles of the efficient use of computers was a valid

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[14] University of Toronto, *President's Report*, 35–36,113–114. Also see the opening quote of chapter 4.
[15] W.H. Watson to S.E. Smith, 5 March 1957, UTARMS A1971–0011, Box 4, Folder 5.

intellectual interest. Research and instruction was necessary for both undergraduate and graduate students. It was widely expected that Canada would soon be in need of professionals with a solid understanding of the potential applications of computers and who had mastered the necessary mathematics. Though he admitted that undergraduates deserved instruction in computing, he proposed a graduate department be formed first. It was more pragmatic, as a smaller graduate department would be easier to assemble. Also, Watson did not wish the university to train "mere operators," but to educate them. Though well aware of the programmer shortage problem, he envisioned a graduate department that could take in specialists from other scientific fields and guide them towards the theoretical principles of numerical analysis and data processing that could be applied to their own work.[16]

How reasonable were his claims and plans? There is little doubt that electronic computers were a boon to researchers from across the academic spectrum, at Toronto, in Canada, and world-wide. The successful application of Ferut in the fields of physics, astronomy, and engineering was well known, and Watson was able to include in his proposal was a page-long list of other departments on campus that had also begun using computers. Law, medicine, chemistry, classical and modern languages were all experimenting with computer assisted methods of organization, indexing, and translating.[17] Next on the list were "matters of general concern to the functioning of the University," such as scheduling classes and tests, accommodation, and various library problems.[18] Outside of the university, computers were also used in business and industry related operations research such as scheduling and inventory, which he felt were suitably academic.[19]

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[16] W.H. Watson to S.E. Smith, 24 April 1957, UTARMS A1971–0011, Box 23, Folder 3.

[17] W.H. Watson, Notes on fields where the application of computing and data processing is being studied abroad, 30 April 1957, UTARMS A1971–0011, Box 23, Folder 3.

[18] Library automation had not yet begun in earnest, but would in the 1960s. Ritvars Bregzis, Calvin C. Gotlieb and Carole Moore, "The Beginning of Automation in the University of Toronto Library, 1963–1972", *IEEE Annals of the History of Computing* 24, no. 2 (Apr–Jun 2002), 50–70.

[19] The Computation Centre had recent research experience with these sorts of problems, carried out on behalf of Imperial Oil. See J.H. Chung and Calvin C. Gotlieb, "Test of an Inventory Control System

Could or should the university bring together those faculty members interested in computing to form a new department? Watson admitted there would likely be "professorial resistance to change."[20] Not a single department on campus – aside from Physics, which he still chaired – would be entirely well disposed to the creation of competition in terms of students, staff, or budget. Financially, the Computation Centre was self-sufficient, but a new academic department would need to draw from the university's pool of funds. In his defence of the proposal, Watson pointed out that "the work of a computing laboratory intersects many other academic activities. It does not fit into the traditional structure of academic departments."[21] That is, it was different enough that the old disciplinary frameworks were insufficient and a new one was necessary to accommodate computer related teaching and research in the future.

Was this final claim valid? Was there sufficiently new activity to justify a new department? By most standards, there was not. Nobody, at the University of Toronto or at any other school in the United States or the United Kingdom, could point to a single body of axiomatic principles or knowledge that might form the substantial basis of a new computing discipline, at least not in the late 1950s. Nor did any school yet host an academic department focused exclusively on computing; all such activity was nominally confined to departments of mathematics, physics, or engineering, and supported by a computing centre or laboratory. A laboratory or centre did not represent an academic home any more than a wind tunnel or cyclotron represented an aerodynamic engineering or physics department.

In his argument, Watson suggested numerical analysis and data processing as two candidates that could be used to found a new department.[22] At other universities, computer engineering was considered a necessary component of graduate computer

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on FERUT", *Journal of the ACM* 4, no. 2 (1957), 121–130.

[20] W.H. Watson to S.E. Smith, 24 April 1957, UTARMS A1971–0011, Box 23, Folder 3.

[21] W.H. Watson to S.E. Smith, 24 April 1957, UTARMS A1971–0011, Box 23, Folder 3.

[22] Watson certainly did not mention any of the core elements of theoretical computer science – "automata and formal languages, computational complexity, or formal semantics" – as recognized in later decades. Mahoney, "Software as Science – Science as Software", 29.

studies and less emphasis was given to Watson's choices. But few schools had a particularly strong or universally accepted vision for academic computing. Many were more than happy to accept a heavily discounted computer in exchange for offering programming instruction to students. Typically, an educational discount from IBM or another manufacturer was conditional that a programming or data processing course would be taught, and many schools scrambled to assemble a few courses to be led by wildly inexperienced staff members.[23] There was plenty of computer related activity at North American universities in the 1950s, there was nothing cohesive enough to form a new discipline. Even Watson did not claim – yet – that a new department was needed to contain a new discipline or produce a new category of computer professional, but that traditional specialists needed a better class of computer education.

President Smith's thoughts, if any, regarding Watson's proposal are unknown. Shortly after Watson's letter arrived at his desk, Smith resigned from the University of Toronto to pursue a career in federal politics.[24] Luckily, before Smith left, Watson was able to secure from him a small transfer of $12,000 from the reserve fund into the Computation Centre's 1957-58 budget.[25] As each transfer from the reserve fund was handled on an individual basis, he was forced to appeal again the next year to Acting President M. Woodside. In early 1958 Woodside was able to transfer $10,000 to help cover installation costs of the IBM 650, but Watson's budget woes continued and in February he requested additional funds. This time, Woodside only acknowledged the request and admonished Watson that "if additional funds are to be provided for one section of the University, they must be taken from some other section or from some source which affects all divisions, such as, for example, salaries."[26] The university did not normally make financial contributions to the operation of the Centre, and in re-

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[23] Pollack, "The Development of Computer Science", 27.

[24] From September 1957 to his sudden death in March 1959, Smith served as Minister of External Affairs for John Diefenbaker.

[25] W.H. Watson to M. Woodside, 5 February 1958, UTARMS A1971–0011, Box 13, Folder 25.

[26] M. Woodside to W.H. Watson, 28 February 1958, UTARMS A1971–0011, Box 13, Folder 25.

sponse to this heavy-handed warning, Watson returned with a threat of his own: "if the Computation Centre has to turn its attention aggressively to business activities," then it would have to "restrict academic use of the machine in order to stay alive."[27]

Watson does not appear to have bothered forwarding the proposal for a new department to Woodside. Faced with an interim president likely unable or unwilling to consider such a change he bided his time until a new president took office. However, he did document his troubles. Around the time the IBM 650 was installed, he called a meeting of the Computation Centre Advisory Committee (Administration), which included A.R. Gordon and R. McLaughlin, deans of the School of Graduate Studies and Engineering. The implicit purpose of the meeting was to draw everyone's attention to the projected deficit of the Computation Centre, to the university's rising use of Ferut, and then connect the dots between these two points. Watson again complained that as more computers were installed across Canada, the financial situation inside the Computation Centre would only worsen unless the university increased its contribution. Though the committee agreed that "it would be not in the best interest of the University for the Computation Centre to deviate seriously from the present scheme of operation, namely to provide instruction and the opportunity to use computing in research," no solutions were forthcoming.[28]

With the arrival of a new president of the University of Toronto, Claude T. Bissell, Watson had another chance to propose an academic home for computing. In late 1958, he forwarded his original proposal regarding a new graduate department to Bissell, with an addendum describing recent events that he felt strengthened his argument since sending it to President Smith.[29] In particular, Watson noted that the new IBM 650 was already operating at around 300 hours per month, the maximum the Computation Centre could handle for the moment. Equally important was the recent interest

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[27] W.H. Watson to M. Woodside, 26 February 1958, UTARMS A1971–0011, Box 13, Folder 25.

[28] Computation Centre Advisory Committee (Administration), meeting minutes, 4 March 1958, UTARMS A1971–0011, Box 13, Folder 25.

[29] W.H. Watson to C.T. Bissell, 11 November 1958, UTARMS A1971–0011, Box 23, Folder 3.

shown by the Department of Mathematics to include more numerical analysis in their undergraduate program. Watson was also able to point to the increase in graduate student use of the Computation Centre, and the increasing variety of disciplines (see Figure 4.1). Finally, he emphasized the Computation Centre's expanding outreach to industrial and business organizations interested in computing, referring to the CDPSC conference, held the earlier that year, and the publication of Gotlieb and Hume's 1958 text, *High-Speed Data Processing*.

He also informed Bissell that he had called a Computation Centre Joint Committee meeting for December 1958 that would be attended by the heads of the NRC, DRB, and AECL. The purpose was to discuss the progress of the ILLIAC II and "to decide whether we should discontinue our association with the project or look forward to carrying out the original plan of placing a prototype of the Illinois machine in the University of Toronto."[30] After two years of research, with participation from members of the University of Toronto, the University Illinois had produced a 220 page report "On the Design of a Very High-Speed Computer" for the United States Atomic Energy Commission and the Office of Naval Research. The agencies had then awarded Illinois a three-year $1.2 million contract to build the described computer. By the time Watson called the Joint Committee Meeting, the designs of many ILLIAC II components were nearly frozen, and pilot models had confirmed that the new machine could have addition times of about 0.3 microseconds and magnetic core access times were down from 6 to 2 microseconds. Combined with other planned optimizations, the ILLIAC II would be about one thousand times faster than Ferut or the IBM 650, and ten times faster than any other operating computer in the world.[31]

There was a very small number of exceptions to this claim, in particular a few

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[30] W.H. Watson to C.T. Bissell, 11 November 1958, UTARMS A1971–0011, Box 23, Folder 3. As mentioned in section 4.3, the previous Joint Committee meeting in 1955 had authorized the Computation Centre to follow and even join the project without committing too many resources.

[31] Computation Centre, University of Toronto, November 1958, UTARMS B1988–0069, Box 1, Folder 11.

experimental high-speed computers also under construction at the time. The most famous, at least in North America, was IBM's Project Stretch, which many expected to be the fastest computer in the world when it was complete. The name 'Project Stretch' – often shortened to Stretch – was intended to suggest a computer that stretched many technologies to new limits.[32] IBM established Project Stretch in 1955 to build a high-speed computer for the United States Atomic Energy Commission (AEC). The AEC fixed the price at $4.3 million, but it is believed that IBM spent at least three times that on research and development.[33] Like the ILLIAC II, much of its speed came from transistorized circuitry and fast magnetic core storage. Unfortunately, after the first model was installed at Los Alamos in April 1961, the operational speed proved to be disappointing and programs ran at about half as fast as had been predicted.[34] Embarrassed by missing the projected speeds IBM sold Stretch at a loss and restricted sales to just eight customers with preorders. This made Stretch a failure in some eyes, but its development had a positive effect on many computer technologies, including magnetic core storage, transistors, modularized circuit cards, "multiprogramming, memory protect, generalized interrupt, interleaving of memories, lookahead, the memory bus, a standard interface of input-output equipment, and the eight-bit character called the byte."[35]

The ILLIAC II project was not as influential as Stretch, but the designers had to solve many of the same problems, and it was in the same class of high-speed computer. If a copy of the ILLIAC II could be built by the Computation Centre then the University of Toronto would own one of the fastest computers in the world. And if the $1.2 million dollar price tag at Illinois did not escalate when it came time to

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[32] Pugh, *Building IBM: Shaping an Industry and Its Technology*, 233. When the first model was finished and installed the product was designated the IBM 7030.

[33] Ibid.

[34] For the next year or so it was still the fastest computer in the world, until that title was claimed by the Ferranti Atlas in the United Kingdom. See page 261.

[35] Ibid., 236–237. As mentioned in chapter 2, the term 'byte' was defined by W. Buchholz, a University of Toronto graduate who was turned down for a job in the Computation Centre in 1948 and hired at IBM not long after.

copy it in Toronto, it would be at a fraction of the cost to buy a similar computer from a commercial manufacturer like IBM. But it was clearly beyond the rather poor means of the Computation Centre, which is why Watson called the December 1958 Joint Committee meeting: to discern the level of financial support he could count on from the NRC and DRB. A report to the Joint Committee that preceded the meeting was his first attempt to justify the need for such a high-speed computer for the Computation Centre. First, Watson pointed out that if the Centre was forced to continue to turn away work – due to an inferior computer – then Canada could not hope to have a strong school in numerical analysis. Without a high-speed computer that could handle any scientific computation that Canadian scientists could propose, then the expertise would not develop. Second, he suggested that "research on programming methods and applications which are mainly of a logical rather than a mathematical nature can be done only on a large machine," and only the ILLIAC II would be sufficient.[36]To some degree this was true, as recent developments in programming systems such as FORTRAN depended on a fast computer with great amounts of storage, but as FORTRANSIT demonstrated, a million dollar machine was not entirely necessary. Third, Watson noted that it should be less expensive to build a copy of the ILLIAC II than to purchase a commercial machine or even the original at Illinois. He expected significant savings by using the existing jigs, drawings, and test chassis. The price of an IBM Stretch was as yet unknown but would be well above the $4.3 million AEC contract.[37] And because the same staff that built the ILLIAC II clone would be involved in maintenance, it was fair to assume that the maintenance costs would be lower than a commercial contract. As a bonus, this would be done in conjunction with members of the Department of Electrical Engineering, who could furnish occasional upgrades

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[36] Computation Centre, University of Toronto, November 1958, UTARMS B1988–0069, Box 1, Folder 11.

[37] IBM had planned to charge $13.5 million, but lowered the price to $7.8 million when Stretch was slower than anticipated. And as it turned out, IBM would have refused to sell one to the University of Toronto in any case.

as part of their research. Finally, he suggested that the Computation Centre's past success making their computing resources available to other universities, government, military, and industrial research laboratories, and business organizations made it the logical home for such an exceptional machine in the future. Despite the overall increase in computer use by the University of Toronto, he believed there would be more than enough machine time available on the ILLIAC II to share with other Canadian schools and organizations.

It is now possible to explain Watson's insistence a year earlier that the university should move to create a new academic department. How could he approach the NRC and DRB and ask for a million dollar computer if the university could not see its way to establish a proper home for it? "Indeed without making some such effort we hardly qualify for the gift of the machine."[38] Watson was linking the future of the ILLIAC II project to the future of academic computing at the University of Toronto. Without one, the other could hardly expect to succeed. It was a brilliant plan, if it worked, to finally get the recognition from the university he desired and at the same time to recapture the prestige of claiming the most powerful computer in Canada. Indeed, he had sown these seeds at the 1955 Joint Committee meeting that first contemplated a replacement for Ferut. "Since the object of placing a machine in a University is to investigate new things, not to have the most advanced facility possible disqualifies the research group there from competing on favourable terms with groups abroad."[39] When it became clear that Ferut would expire before the ILLIAC II was ready, Watson made sure his sponsors knew that the IBM 650 was only filling the gap temporarily. As he wrote to the head of the DRB, H.H. Zimmerman, the Computation Centre's primary interest in the ILLIAC II was the research potential it offered: "if we were to have one in Canada, it would have to be justified as a research tool," and not "as a substitute for present

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[38] W.H. Watson to S.E. Smith, 24 April 1957, UTARMS A1971–0011, Box 23, Folder 3.

[39] Memorandum to the Joint Committee on the Computation Centre, UTARMS B1988–0069, Box 1, Folder 2.

machines in their present form."[40] That is, the machine was only warranted if the computer related research at the University of Toronto was expanded. The reverse was also true: such research could only be conducted with a computer such as the ILLIAC II.

For his plan to succeed, Watson would need full support from the NRC, the DRB, and the University of Toronto. Before the December 1958 Joint Committee meeting he turned to Bissell for a response to his proposal to create a new department, or some other confirmation that the university was at least willing to contribute financially and to improve its commitment to academic computing. Bissell could only warn Watson that there were more important obstacles in Ottawa, as he had recently spoken informally with NRC President Steacie about the pre-meeting report. Steacie had reservations about the machine – specifically the great cost – and was as displeased as his predecessor, C.J. Mackenzie, regarding the lack of integration of the Department of Mathematics in the activities on the Computation Centre.[41] Earlier that year, Bissell had invited D.B. DeLury, chair of the Department of Mathematics, to join the University of Toronto Computation Centre Advisory Committee (Administration). This was done at the suggestion of Watson who hoped that DeLury's interest in numerical analysis and statistics would benefit the Committee, but the addition was apparently not enough to satisfy the NRC.[42]

In Ottawa, Watson hit a wall of apprehension immediately. The current construction schedule called for the University of Illinois to complete their copy of the ILLIAC II in 1960 and finish running tests in 1961. At that time, Toronto could begin to build their own copy and finish within about a year. The estimated cost would be just over $1 million. At least one person at the meeting questioned both the price and dates as overly optimistic, but it would be at least two years before either could be finalized

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[40] W.H. Watson to A.M. Zimmerman, 25 November 1957, UTARMS A1971–0011, Box 13, Folder 25.
[41] C.T. Bissell to W.H. Watson, 10 December 1958, UTARMS A1971–0011, Box 23, Folder 3.
[42] D.B. DeLury to C.T. Bissell, 19 January 1958, UTARMS A1971–0011, Box 23, Folder 3.

and so the figures were set aside. Instead, Zimmerman concentrated on eliciting a clarification regarding the need for such a large computer. It would permit expanded scientific research, Watson replied, citing large aerophysics matrix operations on the order of about 1000. W.B. Lewis concurred with the view that an advanced machine was necessary for scientific research, and noted several similarly demanding problems in nuclear physics. Apparently satisfied with this answer, Steacie then demanded to know why there were so few people attached to the project, noting that few grants of the scale envisioned were awarded without a reputable leader who could ensure a positive outcome and a strong team. Watson reassured him that "this was a case where you did not get the men without the facility," arguing again that the ILLIAC II was the only way to guarantee the future of academic computing at the university.[43] They had lost people in the past, such as Kates and Ratz, but a new, advanced computer would attract new people and provide a stimulus for future computing research. Again, Watson linked the prospects of academic success to acquiring the ILLIAC II.

The committee did agree that the Computation Centre was the right place to host the project, if it went forward. The tipping point for the group was the Centre's past success with such a broad variety of functions – research, training, and a computer service – but the individual members could not guarantee funding from their respective agencies.[44] According to Zimmerman, the DRB was not in a position to offer a large capital grant, having a present policy that precluded such awards to any one project. Lewis pointed out that the AECL was not a granting body, though he did support the project and indicated that the AECL might agree to a work contract if the Computation Centre could ensure cheaper high-speed computation than a commercial computing service. Fortunately, Steacie was able to offer a glimmer of hope. He

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[43] Computation Centre Advisory Committee, meeting minutes, 12 December 1958, UTARMS B1988–0069, Box 1, Folder 2.

[44] As an alternative, the committee briefly considered the possibility of preordering a Stretch computer. Lewis did not support this plan for technical reasons, and the much larger price-tag was enough to deflect the idea quickly enough.

noted that the size of NRC grants had increased by a factor of eight over the past five years, which made a large award possible. However, as he and the rest of the committee agreed, without a more specific budget and schedule, no firm decisions could be made. Instead, the Joint Committee advised Watson to continue to participate in the project at Illinois when possible, and prepare a full breakdown of the costs that could be used to evaluate a more formal application.

Caution is the best word to describe Ottawa's response to the proposal, but Watson returned to Toronto quite positive about the meeting's outcome and directed his staff to write a more formal proposal to build a copy of the ILLIAC II. The 40-page document with a detailed construction plan and budget was finished in January 1960 and sent to all interested parties.[45] The design of the computer was now fixed or nearly so. The floating-point addition time was set at 0.25 microseconds and the high-speed magnetic core storage of 8192 52 bit words had an access time of 2 microseconds per word. It would also use a 32,000 word drum and a magnetic tape for secondary storage. For comparison, Project Stretch had a floating add time of 1 microsecond and the 30,000 word magnetic core access time was 2 microseconds.[46] For increased speed, the ILLIAC II also employed 14 very high-speed registers for indexing (similar to a B-line on the Ferranti Mark I) and temporary storage (similar to cache memory, developed more recently). It had about 100 machine instructions, and was expected to provide a multiprogramming system to permit the execution of two or more programs at the same time.[47]

It is interesting to see how this report positioned ILLIAC II among the other high-speed computers, claiming it comparable only to Project Stretch in the United States, and Atlas, a collaborative project underway between Ferranti and Manchester Univer-

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[45] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9. The report also provides a fascinating snapshot of activity inside the Computation Centre up to then, summarizing the research, teaching, staffing, and facilities.

[46] Stretch had multiple storage banks and a pre-fetch capability which meant optimal access times were as low as 0.2 microseconds. Williams, *A History of Computing Technology*, 391–392.

[47] See page 270 for more on multiprogramming.

sity in the United Kingdom. The Ferranti Mark I had not been the last but the first of several computers to emerge from this combined effort. F.C. Williams and T. Kilburn, who had designed the Mark I, began to work in 1951 on the Mark II, usually referred to as MEG for Megacycle engine. It included floating-point arithmetic, was about 20 times faster than the Mark I, and served as the prototype for the Ferranti Mercury computer, first sold in 1957. At the same time as MEG was in development, research was underway on two transistor based computers. Most important to this story was one begun in 1956 by Kilburn called MUSE, for microsecond engine, referring to the 1 microsecond cycle time. In 1959, when Ferranti agreed to support the project it was renamed the Ferranti Atlas, though like the other two supercomputers the Atlas would not be completed for three more years.[48]

To compare the three machines this way was a calculated move intended to take advantage of any latent insecurity that a reader might have harboured about Canadian science and technology when compared to that of the United Kingdom and United States. But both Stretch and Atlas were simply too expensive for the Canadians. It was well known that the price of the former would be over $4 million, and the latter was to sell for around £2 million.[49] To accentuate the competition among nations, the report also noted that at least two other groups were planning to copy the ILLIAC II, the Weizmann Institute in Israel and the University of Sydney in Australia.[50] More than anything, the situation highlights the relative lack of a commercial transistorized computer in the late 1950s that a university would find well-balanced: an affordable computer, yet powerful and close enough to the technological leading-edge that a

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[48] The Atlas was also influential as the first computer to provide virtual memory, possibly inspired by the flat memory model created by Brooker for the Mark I Autocode.

[49] Aside from a one built at Manchester, Ferranti only sold two copies of the Atlas, both in the United Kingdom. At Cambridge University, a simpler, experimental version of the Atlas was constructed from parts supplied by Ferranti, which was known as the Cambridge Titan. Lavington, *A History of Manchester Computers*, 36–38.

[50] Sydney would choose not to copy the machine, opting instead to buy an English Electric KDF9. Bennett, *Computing in Australia: The Development of a Profession*. More will be said of the Weizmann Institute's decision on page 268.

lifespan greater than a few years was not unfathomable. The only option was to build such a machine, but only for those with deep enough pockets.

The Computation Centre's report expressed certainty that it would cost no more than $1.2 million to copy the ILLIAC II. Nearly two thirds of that was dedicated to the solid state components that made up the high-speed circuitry. Roughly half of the machine was to be constructed by university staff and the remainder fabricated by sub-contracting. In this latter category was the magnetic core storage ($200,000), the magnetic drum ($35,000), magnetic tape drives ($100,000), input, output, and analog-to-digital converters ($125,000). The rest of the budget consisted of salaries, testing equipment and installation costs. However, when a contingency fund and the 10,500 square foot space it would occupy in the new Physics Building were both included, the total price climbed to nearly $1.6 million. For perspective, the Computation Centre's budget in 1959 was just over $130,000, of which the computer costs – in the form of IBM rental charges for the 650 and other equipment – was about $50,000. Setting aside the capital cost of the new computer, it is interesting to observe that the projected annual budget for the Computation Centre with the ILLIAC II was only about $1,000 less, even though the university would own the ILLIAC II and not rent the 650. The estimate did not include any change in the annual grants from the NRC and DRB or the sale of machine time, but there would be a rise in salaries to cover an increase in technical staff.[51] This was certainly a conservative estimate, as sales of machine time were guaranteed to increase with a computer such as the ILLIAC II in Canada. However, Watson needed to convince people it was better to build this computer than buy or rent one, so the budget may have been tilted to emphasize that the annual budget would not expand to match the increasing construction costs.

Unfortunately, the deadlines at the University of Illinois had continued to slip and the construction of ILLIAC II was now not expected to be complete until mid 1961,

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[51] Even with the 650 gone, the Computation Centre would still owe IBM about $14,000 annually in rental charges for off-line and punched card equipment.

followed by six months or so of testing. The delay was not a significant problem in Toronto, as the NRC had not yet guaranteed the funding. When the project did start, it would be supervised directly by R.W. McKay and K.C. Smith. Smith was nearly finished his Ph.D in the Department of Physics.[52] The two would hire technical assistance when needed. Assuming that the NRC would award the grant shortly, McKay and Smith expected they could finish the Toronto copy by 1964. This new schedule, as of January 1960, called for the first orders for parts to be placed later that year. Construction of the arithmetic unit would begin in 1961, followed by control, store, and input-output, to be completed by 1962. Testing in 1963 would be completed the following year. Construction was thus split over four years, which was a substantial increase beyond the one year Watson had estimated in 1958. As mentioned, roughly half of the machine was to be built from sub-contracted but fairly standardized parts, but the remaining half was to be constructed by university staff. This decision mirrored one made by the Illinois group, who had found that it was preferable to train their own technical staff rather than draw up detailed engineering specifications and agreements for subcontractors. The savings in terms of time and money was significant, but more importantly, this plan automatically created a cadre of informed support staff. They could be counted on for maintenance and upgrades that typically consumed a large portion of the annual budget for a commercial computer, but would now be handled internally.[53] K.C. Smith, for instance, was expected to take up a position in the Department of Electrical Engineering when the project was finished.[54] If the computer could be paid for up front, an aspect to be examined in a moment, then the annual budget would change very little.

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[52] Kenneth C. Smith, "Flux Reversal in Ferrites", Ph.D. thesis, Physics, University of Toronto (1960).

[53] Because the ILLIAC II consisted largely of reliable solid state transistors and magnetic core storage rather than more problematic vacuum tubes, the annual maintenance costs were expected to be lower than for Ferut or the IBM 650.

[54] The Computation Centre also hoped to partner with a Canadian company to provide one or more of their engineers with experience in the construction and testing of an advanced digital computer, though the report did not suggest which company.

However, the report failed to include the costs of developing systems routines, programming languages, and a program library. Using the ILLIAC II would have been akin to the arrival of Ferut: a return to programming in relative isolation but for a few other universities who copied the same computer. On the one hand, this reinforces an argument of section 4.3, that computing was still perceived in local terms and that the benefits of belonging to a large community of users can be overestimated. On the other hand, it would be the most powerful computer in Canada for many years. This fact was used to rationalize the staggering capital expenditure, but it also explains the lack of concern regarding the small size of the community. One of Watson's justifications was that advanced research could only be pursued with such an advanced computer. With an expected lifetime of about a decade, and "even with the projected growth of requirements, it should be adequate for a long time and for a wide class of problems."[55]

Much like the first proposal to establish the Computation Centre in 1946, a laundry list was presented of scientific fields in Canada that were expected to benefit from access to the new computer: nuclear physics, astrophysics, and geophysics, analysis of artificial satellites, oceanographic studies, and molecular spectroscopy. Underlining this roll of fields was a new theme that postwar physical science was expanding and producing masses of data that had to be processed efficiently, which could only be done with larger computers. In a way, Watson and the Computation Centre had found a way to make data processing palatable to the scientific sponsors. Operational research and industrial engineering were two other fields expected to make heavy use of computers for the foreseeable future, and both demanded fast computers with large amounts of primary and secondary storage. Finally, the report pointed out that only the University of Toronto possessed the academic strength and diversity, even with-

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[55] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9. Ultimately, the original ILLIAC II's lifetime was just five years. It was considered operational in 1962 and retired in 1967.

out a special department, to support all of these kinds of research. Of course, the rest of Canada would also benefit from access to an advanced computer.

As to financing the staggering capital expenditure, the report offers no clue as to how it would be done. This was the most important item of discussion at the February 1960 Joint Committee meeting, attended by various heads of the NRC and DRB, Watson, and F.R. Stone, a vice president of the University of Toronto.[56] Watson opened the meeting, proposing that the costs of the project be split fifty-fifty, about $800,000, between the university and grants. Zimmerman repeated his stand from the previous Joint Committee meeting, that the DRB could not contribute in any way to the capital costs, but could be counted on to provide continued operational assistance.[57] Steacie, apparently satisfied with the report, was prepared to offer a total of six hundred thousand dollars: $200,000 would be provided through a $50,000 capital grant over the four year construction period and the remaining portion was to come from the Banting Fund. This source, also known as the "Santa Claus" Fund, was originally a special war-time NRC fund that was nearly exhausted.[58] The NRC was directing the remaining $399,970 in the Banting Fund to the ILLIAC II project, to "'help in the establishment of a first-rate university computation centre,"' and to support "'a new field of research with great possibilities."'[59]

For the first time in the history of the Computation Centre, a substantial financial

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[56] Computation Centre, Memorandum of Discussion at the offices of National Research Council, 19 February 1960, UTARMS B1988–0069, Box 1, Folder 2. The full list of attendees at that meeting is President E.W.R. Steacie and vice-president B.G. Ballard of the NRC, Chairman H.H. Zimmerman and Chief Scientist G.E. Field of the DRB, and Watson and Stone from the University of Toronto.

[57] According to Zimmerman, the DRB was moving away from funding any project not directly related to defence.

[58] The Santa Claus Fund was created in 1940 though a series of large private donations that were accumulated to fund Canadian scientific research and development during the war. It was administered by the War Technical and Scientific Development Committee. At inception, its value was more than that of the annual NRC budget, and it was used for a variety of vital projects, including radar and explosives research. In 1941 it was renamed the Sir Frederick Banting Fund, to honour Banting after his recent accidental death. Wilfrid Eggleston, *National Research in Canada: The NRC, 1916-1966* (Toronto: Irwin Clarke, 1978), 162-164,175,199

[59] Quoted in Ibid., 417. There was $1 million in the fund to disperse at the time: $100,000 was given to the Arctic Institute and half a million dollars went to McMaster University to fund the construction of the first university nuclear reactor in the British Commonwealth.

contribution was forthcoming from the University of Toronto. According to Stone, a new building for the Department of Physics, known as the McLennan Physical Laboratories, was underway and expected to be finished in 1961 or 1962. It would house the ILLIAC II, and $450,000 of the building costs had been included in the ILLIAC II budget. This contribution would not apply towards the actual computer itself and so the university had also managed to raise an additional $350,000 to meet its half of the $1.6 million project commitment. Though this was not yet approved by the Board of Governors, Stone felt the commitment was secure.[60] This left a shortfall of about $200,000. Because the federal contribution did not reach fifty percent, Steacie was willing to try to find additional funds. If the government increased the NRC budget in the future, then the NRC might cover the remaining portion, but there was no guarantee. Watson felt this was acceptable as several of the expenditures could be deferred for a few years.[61] Convinced of the strong support from Ottawa, the University of Toronto Board of Governors authorized the construction of a copy of ILLIAC II in early April, 1960.[62]

With the financing assured, McKay and Gotlieb made their way to the University of Illinois Digital Computer Laboratory in September 1960 to see for themselves the progress on the computer. As strange as it may seem, since K.C. Smith had returned from Illinois in 1958, there had been little contact with the ILLIAC II group, with one exception – Watson had made a single trip in late 1959 to Illinois in advance of his final proposal to the NRC and DRB.[63] At that time, Illinois expected the construction

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[60] Stone and Watson's accounting is suspect. Though Watson had proposed a fifty-fifty split, the university was offering to pay for less than a third of the cost of the computer itself. Construction of the McLennan building was to be handled through a separate capital expansion program of the university and space was already allocated for the Computation Centre. For more on the university expansion, see Friedland, *The University of Toronto: A History*, 422–426. Yet adding $450,000 to the ILLIAC II budget to help pay for the space in the new building appears deceptive and even underhanded, all the more so retrospectively, because construction of the McLennan Physical Laboratories was delayed for many years. C.C. Gotlieb to W.H. Watson, 31 January 1962, UTARMS B2002–0003, Box 2, Folder 5.

[61] F.R. Stone to C.T. Bissell, 26 March 1960, UTARMS A1971–0011, Box 31, Folder 9.

[62] F.R. Stone to F.T. Rosser, 30 March 1960, UTARMS A1971–0011, Box 31, Folder 9.

[63] W.H. Watson to E.W.R. Steacie, 1 December 1959, UTARMS A1971–0011, Box 31, Folder 9.

to run from January 1960 to October 1961, and operations to begin by April 1962; Watson wanted to parallel this schedule in Toronto, roughly one year behind. But by the time McKay and Gotlieb arrived, though construction was underway the schedule had slipped even further. Some blueprints were finished but many circuits had yet to be designed, and recently some avenues of work had been abandoned as alternatives were considered. A new deadline for completion of the major components was December 1961, but McKay and Gotlieb were not convinced: "In view of the all the delays to date it is optimistic to say that they will meet this target date."[64]

A close look at their report suggests disappointment with the lack of progress, but the delays may have been a blessing in disguise. Gotlieb managed to acquire an independent study prepared for the Weizmann Institute, which was also planning to build a copy. It concluded that the total cost of building and installing the computer was more accurately about $1.7 million (not including the $450,000 that the University of Toronto had allocated to the McLennan Physical Laboratories). The price of the transistors intended for the arithmetic and control units had not fallen as much as anticipated, which lead to an increase in the cost estimate of about $100,000.[65] In addition to this cost, the Weizmann Institute report found it was necessary to adjust upwards the price of the input-output units, air conditioning, and labour. Though Illinois was considering replacing the transistors with cheaper ones, this was only going to happen if it did not affect speed significantly. Because of the delays and sharp rise in costs, McKay and Gotlieb began to reconsider if the ILLIAC II was still an affordable choice in Toronto and if it would still be significantly better than a less expensive commercial machine. There were now doubts about the entire project. The two visitors could only recommend that the University of Toronto wait another nine

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[64] Report of the the Visit By Professors R.W. McKay and C.C. Gotlieb to the Digital Computer Laboratory of University of Illinois, 13,14 September 1960, UTARMS B1988–0069, Box 1, Folder 11.

[65] There were about 29,000 transistors relevant to this calculation. The original unit price, $20, had fallen to $18, not $15 as they had hoped, and it was still possible that the price would increase before they could place an order. This was a risk of choosing a design that relied on provisional transistors rather than existing ones.

months before committing any money, but to not give up hope.

Watson was far less optimistic. In a letter to President Bissell, he revealed the "drastically changed situation as regards the scheduling of work and the estimated cost of the machine . . . that we can scarcely hope to carry out our original plan."[66] Watson was not entirely ready to give up and suggested that by sacrificing speed, some $300,000 could be saved by choosing less expensive transistors. He set K.C. Smith to study the possibility, and presented these circumstances in a positive manner by claiming it was an excellent chance to bring together the Computation Centre and the Departments of Electrical Engineering and Physics and to expand the university's research in digital electronics. In reality, this was a stalling tactic until a new scheme to use the NRC and university's money could be concocted that might preserve his hopes for an academic department. A month later, such a plan was delivered to Bissell: the Computation Centre should instead obtain a commercial machine, the fastest and most expensive it could afford. That it was impossible to proceed with the ILLIAC II was clear. Redesigning the ILLIAC II to accommodate slower and less costly transistors would take too long and was antithetical to the aim of the machine in the first place. Why copy one of the world's fastest machines but use inferior components and increase the likelihood of an undesirable outcome. Despite Watson's optimistic letters to Bissell about interdepartmental collaboration, he knew that the university lacked the skills and knowledge to undertake a redesign within a reasonable time-frame. There is no doubt that Watson and the rest of the Computation Centre were disappointed: "If the plan to install a copy of the machine being built at the University of Illinois has to be given up and we have to depend on what we can afford to rent or buy with our $1 million we shall not have the machine that should be installed in the new laboratory for computing research."[67]

Yet the Weizmann Institute built not one, but two modified copies of the ILLIAC II.

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[66] W.H. Watson to C.T. Bissell, 17 October 1960, UTARMS A1971–0011, Box 42, Folder 19.

[67] W.H. Watson to C.T. Bissell, 16 November 1960, UTARMS A1971–0011, Box 42, Folder 19.

Known as the GOLEM A, the two machines adhered to the same architectural plan as the ILLIAC II, but were only ten percent as big physically and used only twenty-five percent as many transistors. Unlike Toronto, the Weizmann Institute development group could use their "expertise in circuit design utilizing commercial components to make such significant engineering improvements."[68] The leader of the team, S. Ruhman, had studied computer engineering at the University of Pennsylvania and had further developed his skills as a circuit designer at Packard-Bell. Toronto simply did not have an experienced production engineer who could have redesigned ILLIAC II in a similar fashion.

It is prudent to question Watson's position that a one million dollar machine was necessary to conduct computer related research. His argument was that research trends were tending towards the necessity of large, fast, and correspondingly expensive computers. He cited multiprogramming as an example. The aim of multiprogramming is for a single computer to appear to run two or more programs simultaneously. The predominant mode of computing at the time was batch processing, which was to run many similar programs consecutively before moving on to other tasks. Multiprogramming is normally an illusion, accomplished when the computer runs a slice of one program while the other programs pause and wait for their slice to run. A fast computer with the appropriate technical characteristics can be made to switch between each program slice quickly enough to give the impression that all are running simultaneously.[69] Great efficiencies can be had in this situation, especially if a program is already waiting for data on input or output channels and the other programs could be processed in the meantime. However, special operating system routines are necessary to manage the switches between programs, a research area that Watson felt was ripe: "Whereas in the past the computing machine in operation might be likened

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[68] Gerald Estrin, "The WEIZAC Years (1954-1963)", *Annals of the History of Computing* 13, no. 04 (1991), 337.

[69] A true parallel or multiprocessing computer contains more than one central processor and can execute programs simultaneously.

to playing a single musical instrument, the most advanced designs today ... provide for an internal performance like an orchestra with the machine helping to write the orchestration as it goes along."[70] Multiprogramming was by no means a simple affair for the hardware architect or the programmer, and in the early 1960s it had also caught the attention of those working with advanced hardware. Watson was right to point to this as an area that could only be studied by those with access to such technology.

It must be said that considerable research could be conducted in an academic department devoted to computer research without one of the most powerful computers in the world. Having a mediocre computer like the IBM 650 was not necessarily the liability that Watson implied. Because of IBM's generous educational discount the 650 was a common machine at universities around the late 1950s, and was the foundation of many computer science departments that emerged in the 1960s.[71] The 650 was the training ground for the first generation of computer scientists, including some of the most famous and influential: Donald Knuth, Herbert Simon, Allen Newell, Alan Perlis, and George Forsythe.[72] Despite the speed and storage limitations of the 650, or perhaps even in spite of them, important investigations into compiler design, information processing, and artificial intelligence were undertaken. It was disingenuous for Watson to argue as early as 1955 that the future of academic computer research would lie only with very high-speed machines. Even in 1960 this was a disputable claim. Other Canadian universities were operating academic computing centres with lesser computers and not one aimed to replace them with an advanced computer like the ILLIAC II. But none had plans as ambitious as Watson to establish the finest research department in Canada dedicated to computing.

To be fair, by the fall of 1960 when the ILLIAC II project fell apart in Toronto,

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[70] W.H. Watson to C.T. Bissell, 16 November 1960, UTARMS A1971–0011, Box 42, Folder 19.

[71] In the opening years of the 1960s, the equally affordable and mediocre IBM 1620 played a similar role.

[72] A January 1986 special issue of the *Annals of the History of Computing* was dedicated to the IBM 650 and considerable attention was given over to the importance of the 650 to universities.

the Computation Centre had wrung most of what could be had from their 650. A decision on a new computer could not be delayed if it might take years to deliver. The 650 had been, after all, a temporary choice and Watson was looking to replace it with an advanced computer that would last at least another five years, preferably even as many as ten. In retrospect, expecting a computer to last a decade was overly optimistic.[73] The rate of technological change in the computer field from 1960 to 1970 was phenomenal. A vast variety of machines were produced both large and small, from supercomputers like the Control Data Corporation (CDC) 6600 to minicomputers like the Digital Equipment Corporation (DEC) PDP-8. Though these computers had their roots in the 1950s, it is unlikely that Watson could have anticipated any of them.

5.2 Transforming the Computation Centre

The 1960s marked the end of an era when a university needed to design and build their own computer. "The development of a computer in a reasonable time that can be useful and dependable in instruction and research (as are the commercially available ones) is *not* a research effort; it *is* a major development effort requiring as much, if not more know-how in fabrication techniques and practices as in theory and design."[74] A few schools would continue to develop computers, such as the University of Illinois, which extended the ILLIAC program though to ILLIAC IV in the mid 1970s.[75] Manchester had yet to finish the Atlas in collaboration with Ferranti, but these approaches were no longer appropriate for most universities. Few had the resources, desire, or need when so many commercial machines were available ways.[76]

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[73] The ILLIAC II was retired after only five years, although the GOLEM A operated from 1964 to 1974.

[74] Fein, "The role of the University in computers, data processing, and related fields", 10.

[75] R. Michael Hord, *The Illiac IV, the first supercomputer* (Rockville, Md.: Computer Science Press, 1982).

[76] Interestingly, the arrival of cheap microprocessor based computers in the 1970s inspired a few universities to return to computer design, and build their own microcomputers for student use. For example, the University of Toronto produced a microprocessor board in 1979, and the University of Waterloo developed the MicroWAT and SuperPET. D.D. Cowan and J.W. Graham, "Waterloo microcomputer systems for the 1980's", in *ACM '82: Proceedings of the ACM '82 conference* (ACM Press, 1982),

However, there were very few options for a university looking to acquire an advanced computer. Though drum-based computers were widely available and popular, they were an inexpensive, interim technology – a bridge between vacuum tubes and transistors. Many knowledgeable users were waiting for commercial solid state machines to arrive and provide a dramatic improvement in speed. Though transistors were invented in 1947, it was nearly a decade before a transistorized computer was built. It is no great surprise that the United States military and government were two of the primary drivers pushing the new technology. In 1958 the United States Air Force specified that from then on it would only purchase transistorized computers for a new Ballistic Missile Early Warning System (BMEWS). That same year, an American company named Philco had produced the first commercial transistorized computer. Originally an electronics company, earlier in the decade, Philco had developed a new transistor that was used in an experimental MIT computer in 1954 and a special computer named SOLO for the United States National Security Agency around 1957. Philco then released a commercial computer called the S-2000 in 1958.[77] The S-2000 performed and sold well but Philco was unable or unwilling to compete strongly with other manufacturers and by 1962 had pulled out of the field. In the late 1950s IBM was not yet the titan of the electronic computer industry and was slow to embrace transistors for commercial machines. Aside from Project Stretch, it was not until 1958 that IBM management enacted a new policy that no new tube-based computers would be announced, a decision some have attributed to the Air Force's BMEWS requirement.[78]

Before exploring which computer was chosen to replace the ILLIAC II, it is important to recognize that there were several research and development projects under way around this time to build a transistorized computer in Canada. None were ever

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13–17. Projects like these also ended when commercial microcomputers were sufficiently powerful and plentiful; the University of Waterloo turned to the IBM PC rather than build another micro.

[77] It was briefly preceded by the S-1000. Ceruzzi, *A history of modern computing*, 65-6.

[78] IBM's engineers preferred the more familiar and cheaper tubes over what they felt was untested solid-state technology. Pugh, *Building IBM: Shaping an Industry and Its Technology*, 230.

considered for the University of Toronto, but the timing of the projects and various design criteria would have eliminated each from serious contention for the Computation Centre, strengthening the observation that there were few options for the university. Between 1957 and 1962 the Defence Research Telecommunications Establishment (DRTE) of the DRB built a transistorized computer as a means of investigating solid-state components and to satisfy DRB computational needs.[79] Though a prototype of an arithmetic unit was ready in 1957, construction of the DRTE computer took place between 1959 and 1962. Known fondly as the Dirty Gertie, it performed very well; one function was to track artificial satellites in orbit.[80] There never was any communication between the DRTE and the Computation Centre about computer design or programming, though there was limited contact between Ferranti-Canada and Manchester.[81] No commercial version or a successor of the DRTE computer was ever produced.

Ferranti-Canada, located in Toronto, built several electronic computers throughout the 1950s and into the early 1960s, mostly transistorized.[82] The first was called DATAR, for Digital Automated Tracking And Resolving. It was a combined product of the Royal Canadian Navy's (RCN) post-war strategy of military self-reliance and Ferranti-Canada's attempt to establish itself as an electronics research and development group. It was more than a single tube-based machine, but an entire network of computers that handled real-time anti-submarine tracking and display among multiple warships. The project was launched in 1948 and progressed through to a successful demonstration in the summer of 1953 on the waters of Lake Ontario. However,

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[79] Petiot, "Dirty Gertie: The DRTE Computer", 43–52.

[80] Petiot repeats the speculation that the DRTE computer also found use for Cold War code breaking.

[81] Calvin C. Gotlieb, interview by Michael R. Williams, 6 May 1992, Transcript provided by Michael R. Williams.

[82] John Vardalas has written extensively about the history of Ferranti-Canada. See Vardalas, "From DATAR to the FP-6000: Technological Change in a Canadian Context", 20–30; Norman R. Ball and John N. Vardalas, *Ferranti-Packard: Pioneers in Canadian Electrical Manufacturing* (Montreal: McGill-Queen's University Press, 1994); and Vardalas, *The Computer Revolution in Canada: Building National Technological Competence.*

the RCN's inability to convince the American and British navies to buy into DATAR sunk the project for Ferranti-Canada. Its engineers were able to sustain their acquired technological knowledge by contracting with the Canadian post office to build the first computerized mail sorter. The experimental transistorized computer was completed in 1956, but again, a full-scale version was never completed, this time a result of political turmoil at the federal level.

Around the same time, the development group at Ferranti-Canada constructed a seat reservation computer for Trans-Canada Air Lines (TCA), parts of which had been demonstrated on Ferut in 1954 and 1957.[83] The entire reservation system was known as ReserVec, but the general-purpose transistorized computer that processed the transactions was called Gemini. It consisted of two identical machines running in parallel to share the load. When finished in 1963, it could process 100,000 reservations a day, a very favourable comparison to the more famous American Airlines SABRE reservation system, which did not go online until 1964 and handled about a quarter the number of daily transactions. Although Gemini was a general-purpose computer, a commercial version was not sold. But in 1962 Ferranti-Canada was ready to start selling a general-purpose commercial computer, when it contracted with the New York Federal Reserve Bank (FRB) to build one. From 1959 to 1961, the FRB had run a pilot project testing a special-purpose check-sorting computer built by Ferranti-Canada. Satisfied by the results, when Ferranti-Canada proposed a general purpose variant in 1962, the FRB accepted the proposal, and the FP-6000 was born.[84] It was a mid-level machine but offered multiprogramming at a far more economical price than IBM's Project Stretch, Ferranti UK's Atlas, or the ILLIAC II. The engineering design was a remarkable technological achievement, but only a few FP-6000's were sold. And although there was a strong group of programmers developing libraries,

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[83] See page 209, and Dornian, "ReserVec: Trans-Canada Air Lines' Computerized Reservation System", 31–42.

[84] Ferranti Canada had recently merged with Packard Electric to become Ferranti Packard, hence the initials 'FP'.

languages and applications for the FP-6000, it could not compete with IBM, or any other large North American computer company. Ultimately, the project was pulled from underneath the feet of Ferranti-Canada when the parent company, Ferranti UK, sold all of its non-military computer operations to International Computers and Tabulators (ICT) in 1963.[85] This ended Ferranti-Canada's involvement in modern computing, and the company returned more or less to its traditional market of electrical transformers. There was little to no collaborative contact between the Computation Centre and Ferranti-Canada, though the two groups would have been aware of the other's work.[86]

Though IBM did not embrace transistors for its mainstream products until 1958, it had been using solid-state circuits in Project Stretch since 1955. Thus it was able to move quickly when the new transistor-only policy was enacted and within two years was able to announce and deliver two of the most important computers of the 1960s, the IBM 1401 and IBM 7090. Both used Stretch's Standard Modular System (SMS) with transistor cards and both had magnetic core storage, but were quite different machines aimed at different audiences. The 1401 was relatively inexpensive and massively popular computer (IBM manufactured and delivered well over ten thousand) making it an unofficial successor to the IBM 650. The preponderance of the 1401 knocked many competitors from the industry who were unable to match IBM's engineering, manufacturing, and support.[87] And like the 650 it was a smaller machine intended for business applications. The 1401 was so modest a computer that it could even be used as a peripheral to handle input and output for a larger computer. Around the same time IBM introduced a small and inexpensive scientific computer known as the IBM

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[85] The FP-6000 was the basis of the ICT 1900 series, one of the most important 'British' computers of the 1960s. Martin Campbell-Kelly, *ICL: A Business and Technical History* (Oxford, New York: Clarendon Press, Oxford University Press, 1989).

[86] In the 1960 ILLIAC II proposal, the idea of collaborating with a Canadian company with "digital engineering experience" was considered. This may have referred to Ferranti-Canada, a logical choice, but no corroborating evidence can be found. Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9.

[87] Pugh, *Building IBM: Shaping an Industry and Its Technology*, 265–268.

1620. It too was a solid state machine with magnetic core storage. It sold well, particularly at universities starting a computing program in the early 1960s, but was not nearly as significant a machine as the 1401.[88]

The IBM 7090 resided at the opposite end of the spectrum. It was a large, expensive and powerful scientific mainframe, and prices started around $1.5 million, or $30,000 per month. The 7090 series of mainframes, which includes the 7094 and 7094-II, were the workhorse computers of the 1960s for many scientific and engineering firms, such as the aerospace and defence industries.[89] They came about after IBM placed a bid on a US Air Force BMEWS contract in 1958 with the intention of supplying its recently announced tube-based 709 scientific computer. But to accommodate the Air Force's new transistor-only policy IBM agreed to produce an architecturally identical transistorized version dubbed the 7090. The deadline imposed by the Air Force was to install one by 1960, which IBM only just met.

The 7090 series was also a popular large-scale academic computer in North America in the first half of the 1960s, at least for those few universities that could afford one. In 1963 the top three most common computers in American and Canadian schools were the IBM 1620, IBM 1401, and LGP 30.[90] In Canada, only one university could possibly afford to install a 7090 in the early 1960s – the University of Toronto. The timing of the 7090's development and delivery helped keep it from consideration by the Computation Centre until the ILLIAC II's costs started to soar and delays continued in late 1960. By that time, Watson and Gotlieb were looking for a new computer, and though they actively sought out alternatives to the 7090, in the end there would be little choice. The ILLIAC II, IBM Stretch, Ferranti Atlas, and Philco 2000 Model 212 were dropped from deliberation for reasons of cost. The Stretch was well beyond the means of the university, as were the Atlas at an estimated £2 million and the Philco at $1.6

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[88] For instance, one of the better histories of IBM, Pugh's *Building IBM*, fails to mention the IBM 1620.

[89] The 7094 included four additional index registers over the 7090; upgrading to the 7094-II roughly doubled the speed.

[90] Keenan, "Sixth Survey of University Computing Facilities", 9.

million plus a $80,000 annual maintenance charge.[91] Though these were the advanced computers that Watson and the Computation Centre longed for, they were simply too expensive. With about one million dollars to spend, three lesser machines were more appropriate: the CDC 1604 at $1.25 million, the UNIVAC 1107 at $1.05 million and the IBM 7090 at $1.09 million.[92]

For an unknown reason, the 1604 was removed from the list and by March 1961 the decision came down to the UNIVAC or the IBM computer. Aside from the similar purchase price, their annual maintenance fees were nearly the same at around $40,000, but Watson was able to furnish the university administration with a long list of reasons, both technical and otherwise, to choose the 7090. The 7090, for example, was marginally faster and had a relatively easy upgrade path, though he felt the UNIVAC had a better arithmetic unit. The 7090 offered a new parallel input-output data channel that provided very high performance, especially for scientific applications that required high volume data input-output, as Watson had anticipated. He also pointed to the far greater amount of programming resources available for the 7090, which was compatible with the tube-based 709 and 704 computers, and could draw upon program exchange organizations such as SHARE. On the non-technical side, Watson emphasized that the long and positive relationship between the university and IBM would likely end if the UNIVAC 1107 was chosen. The Computation Centre was still renting punched card tabulating equipment from IBM at a discount and enjoying IBM's annual $10,000 fellowship.[93] He also suggested that if the university administration ever acquired an IBM 1401 for business purposes, which he felt prob-

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[91] The estimated cost of the Atlas in 1960 Canadian dollars would be about $2.8 million, based on historical exchange rates. For the Philco estimate, which included the educational discount, see A.F. Parker to C.C. Gotlieb, 17 February 1961, UTARMS A1970–0013, Box 4, Folder 2.

[92] W.H. Watson to F.R. Stone, 4 April 1961, UTARMS A1970–0013, Box 4, Folder 1. These prices included the educational discount. A fourth, unspecified, computer was also dropped from consideration due to relatively poor performance.

[93] That Watson was concerned about the fellowship implies that the connection between it and the selection of the IBM 650 in 1957 was more important than was acknowledged at the time.

able, then it would be compatible with the 7090 for reserve power.[94] Because the 7090 had been in production for the past year, one could be installed and operating by the start of the 1962-63 academic year, before the copy of the ILLIAC II would have been completed or a UNIVAC would be available. Finally, Watson warned that if Toronto went with the UNIVAC computer, "one can predict with confidence that IBM will install the 7090 at the University of Ottawa where the manpower and problems would inevitably come from departments of the Federal Government. The consequence of this for the future support of the Computation Centre here could be serious."[95] Of course, it was unlikely that the University of Ottawa could afford the 7090. However, if IBM felt computations from the federal scientific agencies would make an Ottawa-based computing centre profitable enough, it could offer the University of Ottawa a cooperative ownership plan. The precedent existed: in Toronto only a few years earlier IBM had operated a service centre using a 705 owned by Confederation Life. But Watson's warning was probably too extreme; IBM never saw the need to operate a 7090 in a computing centre in Canada.

That Watson now believed that the 7090's large library and user base was an important advantage is difficult to reconcile with the fact that the ILLIAC II would have placed the Computation Centre in the opposite position, with no library and a minuscule user base. As it is inconceivable that Gotlieb and the rest of the Centre staff were ignorant of this, either the value of a large community of users and a preexisting library of routines was less significant than expected (and therefore, Watson's argument in favour of the 7090 was equally weak), or the perceived value of owning a machine as advanced as the ILLIAC II outweighed this factor. Perhaps the members of the Computation Centre were blinded by their long association with the ILLIAC II project, or felt that developing a library of routines was a worthy, if time consuming,

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[94] The university did, in fact, acquire a 1401 by the beginning of 1964. It was installed in Simcoe Hall and was used as a peripheral for the 7090 and for university accounting and student records. Beatrice H. Worsley, "News from Southern Ontario", *CDPSC Quarterly Bulletin* 4, no. 2 (January 1964), 7–8.

[95] W.H. Watson to F.R. Stone, 4 April 1961, UTARMS A1970–0013, Box 4, Folder 1.

endeavour. Gotlieb stated in a contemporary article that given a choice between a different programming systems for the Centre, he preferred a newer system under active development rather than an older and well-tested but stagnant one.[96] Given the diversity of the computer field, with few universal standards – even FORTRAN varied from one machine to another, or from one version to the next on the same machine – his position was that it was best to choose the most ascendant system and with an actively growing community. This may help explain the willingness of the Computation Centre to undertake to develop a library for the ILLIAC II, in order to be on leading edge.[97] On the other hand, if a 7090 was to be installed, it seems the Centre was equally willing to join SHARE and participate fully in that organization. Indeed, before the 7090 arrived in Toronto, Worsley was appointed the Centre's SHARE representative, and helped organize SHARE XIX, the first SHARE meeting outside of the United States. Held in early September 1962, only three months after the 7090 was running, it was attended by 800 participants.[98] There were only three Canadian members of SHARE at the time – the University of Toronto, the IBM Data Centre in Toronto, and the Ontario Department of Highways, with a 7090, 704, and 7040, respectively.[99]

Finally, although Watson was able to point to a savings of at least $300,000 for the 7090 compared to the ILLIAC II, there were still a few financial concerns. Despite the assistance from the NRC and the Banting Fund, the University of Toronto was still $130,000 short of the total installation cost.[100] Watson attempted to balance this

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[96] Calvin C. Gotlieb, "Software Problems", in "Proceedings of the Third Conference of the Computing and Data Processing Society of Canada, McGill University, 2-3 June 1962", 200.

[97] Gotlieb has indicated in retrospective interviews that he and the rest of the Computation Centre came to recognize that the lack of a large programming community around the ILLIAC II would have been to their detriment had they stuck with the plan to build it. See Calvin C. Gotlieb, interview by Henry S. Tropp, Computer Oral History Collection, edited transcript of tape recording, 29 June 1971, UTARMS B2002–0003, Box 8, Folder 1. However, no contemporary evidence has been found to indicate that the decision not to build the ILLIAC II was determined by anything other than costs escalating beyond affordability and the delays in Illinois.

[98] C.C. Gotlieb to W.H. Watson, 21 November 1961, UTARMS B2002–0003, Box 2, Folder 5.

[99] Beatrice H. Worsley, "News of Toronto and the Toronto section", *CDPSC Quarterly Bulletin* 3, no. 2 (January 1963), 12.

[100] Office of the Vice-President (Administration), Memorandum, Purchase of Computer, 27 April 1961, UTARMS A1970–0013, Box 4, Folder 1.

shortfall in a number of ways. First, he noted that the annual maintenance charge for the new computer was $11,300 less than the rental for the 650 (which also included maintenance); the savings over a few years could be diverted to cover the cost of the 7090.[101] Second, there was a good probability that for the first time in many years, the Computation Centre service income would increase. There were many Canadian organizations eager to purchase time on the 7090 whose scientific computing needs were substantial but not enough to justify acquiring their own. Watson was able to confirm that the DRB, KCS Data Control, H.S. Gellman and Imperial Oil had expressed interest, the latter so far as to agree to a monthly contract.[102]

In early 1962 the University of Toronto Board of Governors approved the purchase, and plans were made to install the IBM 7090 on 27 June of 1962. It is important not to underestimate the significance of the 7090 in the Computation Centre. At a time when most other Canadian universities were getting by with ageing drum based computers or perhaps a small IBM 1620, the University of Toronto had the most powerful and expensive general-purpose computer in the country.[103] A special inauguration ceremony was held in October 1962, unlike the arrival of the IBM 650. As a gauge of the significance, invitations were sent to the heads or representatives of the NRC, the DRB, AECL, IBM, Ontario Hydro, the Ontario Research Foundation, Confederation Life, Manufacturers Life, Crown Life, Trans Canada Airways, Canadian Imperial Bank of Commerce, Ferranti-Packard, KCS Data Control, H.S. Gellman and Co., the University of Toronto Board of Governors, and, almost absent-mindedly, the faculty and staff who would actually be using the new machine.[104] At the ceremony, Presi-

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[101] This was creative accounting. Normally, the operating and capital budgets were kept separate.

[102] W.H. Watson to F.R. Stone, 17 April 1961, UTARMS A1970–0013, Box 4, Folder 1. In November 1962, after the 7090 had been operating for less than half a year, Gotlieb was able to report sufficient income had been raised that the remaining balance could be paid by the end of the year. F.R. Stone to the Secretary of the Board, 6 November 1962, UTARMS A1971–0011, Box 60, Folder 11.

[103] For the first year of operation, it was expected that any faculty or student of any Canadian university could have free machine time, provided it was used for teaching or research. Computation Centre, Memorandum: Off-Site Users of the IBM 7090, 1962, UTARMS A1970–0013, Box 4, Folder 5.

[104] Guest List of Inauguration of IBM 7090 Computer, 3 October 1962, UTARMS A1971–0011, Box 60, Folder 11. Needless to say, not all of these dignitaries attended the ceremony.

dent Bissell offered the expected thanks to the NRC and DRB, and extolled his school's lengthy leadership in Canadian computing. The university was undergoing a growth period, and opening new buildings had become common, but this was a million dollar machine, and as his notes remarked "we in the University are still impressed by that sum."[105] Or, as Gotlieb put it: "It was this that made the president of the university really aware of the Computation Centre for the first time."[106]

One person who did not attend the ceremony was W.H. Watson. Over the summer of 1961, he took a sabbatical year that became a resignation.[107] He moved to Palo Alto, California, where he was hired as a senior consulting scientist at Lockheed Missiles & Space Company until 1969.[108] Despite the distance, he had remained in close communication with the university administration and Gotlieb regarding the status of the 7090 installation and the Computation Centre operations. Before his influence waned he helped instigate two final changes.

The first was the more significant of the two. Aided perhaps by the new-found attention on the expensive computer, Watson was finally able to put forward a successful proposal to create a new academic division dedicated to computing. There were about half a dozen faculty members strongly associated with the Computation Centre, but all belonged to departments of increasingly orthogonal fields. C.C. Gotlieb, J.N.P. Hume, R.W. McKay, and B.H. Worsley belonged to the Department of Physics,

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[105] President's Notes for Inauguration of the IBM 7090 Computer, 3 October 1962, UTARMS A1971–0011, Box 60, Folder 11. For an overview of the expansion of the University of Toronto around this time, see Friedland, *The University of Toronto: A History*, 401–459.

[106] Calvin C. Gotlieb, interview by Henry S. Tropp, Computer Oral History Collection, edited transcript of tape recording, 29 June 1971, UTARMS B2002–0003, Box 8, Folder 1.

[107] Gotlieb has alleged that in the early 1960s two physics professors manoeuvred to have Watson removed from the department as they were unhappy that an outsider was still running 'their' department. Calvin C. Gotlieb, conversation with author, Toronto, 24 November 2005. H.L. Welsh succeeded Watson as chair of physics, though not of the Computation Centre. A 1962 staff notice indicated that "rapid growth of the Centre demands more of Watson's time. He will continue as professor in the Department of Physics," but when Watson did not return from his sabbatical, Gotlieb was put in charge of the Centre. "Announcements", *University of Toronto Bulletin* (January 1962), 4.

[108] In 1972 Watson retired to Victoria, British Columbia, where he died 9 November 1987 a few weeks shy of his eighty-eighth birthday. E.R. Pounder, "William Heriot Watson 1899-1987", *Transactions of the Royal Society of Canada, Series VI* 1 (1990), 595–598.

W.H. Kahan to the Department of Mathematics, and K.C. Smith to the Department of Electrical Engineering.[109] There were others on campus with weaker ties to the Centre, who had used or "had their students use Ferut or the IBM 650 for substantial calculations."[110]In 1960 there were nearly thirty faculty members on that list from the Departments of Physics, Geophysics, Mathematics, Aerophysics, Chemical and Electrical Engineering, Astronomy, Chemistry, the Faculty of Medicine, Biometrics, Banting and Best Department of Medical Research, and the Ontario College of Education. But it had grown difficult to conduct computing research without a proper academic home. Physics had supported these activities for nearly a decade, thanks to Watson's dual leadership of the two divisions. Under his umbrella, most of the above faculty members were relatively free to continue their computing work, but graduate students did not have the same blessing. Those who were interested in computing research could only pursue it by registering in one the departments best suited to their undergraduate specialization and fulfilling that department's academic requirements. Those requirements would preclude most students from spending their time studying computing and dilute their experience.

Rather than expend the effort to create a new department, Watson proposed that the university establish a new Institute dedicated to computing within the School of Graduate Studies (SGS).[111] This was an increasingly popular tool at the University of Toronto at the time. "The 1960s would see the creation of numerous multidisciplinary centres and institutes ... They were a means of integrating knowledge among the established disciplines."[112] Many, like the Centre for Medieval Studies, the Centre for Linguistics, and the Centre for Culture and Technology, all created in 1963, were

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[109] Worsley was originally appointed an Assistant Professor of Mathematics in 1960 before her appointment was transferred to the physics department in 1961.

[110] Computation Centre, ILLIAC II Proposal, January 1960, UTARMS B1988–0069, Box 23, Folder 9.

[111] D.B. DeLury and W.H. Watson to C.T. Bissell, 20 June 1961, UTARMS A1971–0011, Box 52, Folder 8. D.B. DeLury, chairman of the Department of Mathematics, co-signed the letter to President Bissell, but Watson was without question the prime mover.

[112] Friedland, *The University of Toronto: A History*, 479. The entirety of chapter thirty-four, 'Multidisciplinary Endeavours' pp. 479–498, of Friedland's book is given over to this subject.

graduate centres. It permitted students and faculty to conduct research more easily in an interdepartmental area that was not otherwise provided by the recognized specializations.[113] The Institute would operate similarly, but was not a full graduate department. Students interested in computing still had to register in a graduate department, but their courses and research could be better managed by a faculty member cross-appointed to the Institute. Because it was held together with interdisciplinary cross-appointments, no new funding was needed to create the Institute. As evidence of the interdisciplinary nature of computing research, Watson pointed to the three disciplines with strong academic ties to the Computation Centre: mathematics, engineering, and physics, but also listed those with weaker ties, including language departments, economics, and the library as university units that would also benefit from the arrangement. Ideally, the new Institute would be ready to accept students by the 1962-63 academic year to best coincide with the installation of the 7090. His biggest problem was what to call the Institute. "The best I can suggest is 'Computer Science'."[114]

Watson already had President Bissell's attention thanks to the million dollar 7090. The latter was ready to accept the plan and glad that it would "stimulate graduate work and research", but remained wary that Institutes "have a tendency to acquire administrative machinery and to request supporting funds," that is, become full departments.[115] Before signing off on the proposal, Bissell turned to the longtime dean

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[113] Many Centres and Institutes were so successful that undergraduate departments were created and absorbed the graduate centres. This included the Centre for Linguistics, and eventually, the Institute of Computer Science, though the complete details of that story are absent from this dissertation.

[114] W.H. Watson to C.T. Bissell, 16 November 1960, UTARMS A1971–0011, Box 42, Folder 19. Why Watson felt this was the best and from where he picked the term up are unknown. The earliest and most widely available reference connecting the phrase computer science to a new discipline is almost certainly Fein, "The role of the University in computers, data processing, and related fields", 7–14, as noted in Ceruzzi, "Electronics Technology and Computer Science, 1940-1975: A Coevolution", 266-267. The term was not yet attached fully to that meaning then. In 1959 Pergamom Press in New York began publishing a series of texts as part of its series "International tracts in computer science and technology and their application." The first example cited in the Oxford English Dictionary is from 1961. Regardless, Watson was not suggesting a name that would have been unusual. On the other hand, a particular definition of computer science was many years away, as shown below.

[115] C.T. Bissell to A.R. Gordon, 27 June 1961, UTARMS A1971–0011, Box 52, Folder 8.

of SGS, A.R. Gordon, and asked if he felt there was sufficient justification for another graduate program. Gordon, who had more knowledge of computing, was satisfied: "There is probably more justification for an Institute of Computer Science than there is for some of the institutes that have been formed."[116] Despite his enthusiasm, the bureaucratic wheels ground slowly. It took so long to grind the June 1961 proposition through the committees and councils that at one point Bissell wrote to Gordon to ensure things hadn't been forgotten.[117] In November 1961, Gordon was able to report back that SGS was prepared to establish the new Institute of Computer Science, "a device to serve as a focus for a technique which is a real interest to many departments."[118] His recommendation moved through the University of Toronto Senate smoothly that month, returned to the president's office and thence to the Board of Governors in January 1962.[119] The Computation Centre's name was officially changed to the Institute of Computer Science as of 1 July 1962 just a few days after the IBM 7090 was scheduled for installation.

Parallel to Watson's proposition to establish the Institute of Computer Science, he moved to create a post-graduate diploma program in the university extension department. This was not an academic push, but a pragmatic attempt to help fill the shortage of programmers in Canada, "an emergency which the University of Toronto cannot ignore."[120] Too many otherwise excellent students were graduating with insufficient training and experience at computing and data processing at the university level. As early as 1958 educators had noted that "The normal expansion of computing activities requires general education of future businessmen, engineers and scientists", and concluded that in Canada "our present curricula and enrolments are extremely inadequate and will require drastic improvements."[121] Although the number of Canadian

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[116] A.R. Gordon to C.T. Bissell, 28 June 1961, UTARMS A1971–0011, Box 52, Folder 8.

[117] C.T. Bissell to A.R. Gordon, 17 October 1961, UTARMS A1971–0011, Box 52, Folder 8.

[118] A.R. Gordon to C.T. Bissell, 6 November 1961, UTARMS A1971–0011, Box 52, Folder 8.

[119] J.F. Brook to V.W. Bladen, 1 February 1962, UTARMS A1970–0013, Box 4, Folder 3.

[120] W.H. Watson to D.C. Williams, 7 June 1961, UTARMS A1970–0013, Box 4, Folder 3.

[121] George S. Glinski, "Computer Education in Canadian Universities", in "Canadian Conference for

universities with a computer was increasing in the early 1960s, dramatic improvements in computer related teaching had not yet materialized across the country. Even at the University of Toronto, with a decade long head-start, only graduate students in physics, mathematics, or engineering could obtain substantial programming experience. For students not inclined towards graduate studies, the diploma would be an alternative route to a similar base of knowledge.

Though Watson was less enthusiastic about the diploma than the Institute, it was a secondary solution to the same problem: academic recognition of computing. He noted that the University of Cambridge used diplomas in a similar fashion, which at least gave his scheme "a veneer of academic respectability."[122] The University of Toronto Senate tentatively approved of the Diploma Course in Computing and Data Processing at a January 1962 meeting.[123] However, concerns that the newly created Institute of Computer Science had no ability to perform the necessary registration and secretarial duties meant that it would be administered through the Faculty of Arts and Sciences, rather than through the Department of Extension.[124]

With the new Institute of Computer Science Watson finally had some academic recognition for computing, though it was still a part-measure; not a department or even centre, but an institute.[125] The great cost of the 7090 ensured that Watson would not overreach this time when he proposed the institute and the diploma. There is little doubt that the university approved of both because neither would cost very much, financially or otherwise. There was no new administrative bureaucracy accompanying the Institute, and the diploma would be handled by pre-existing structure in the Faculty of Arts and Sciences. Their establishment would not threaten any other main-

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Computing and Data Processing, Proceedings", 27.

[122] W.H. Watson to D.C. Williams, 7 June 1961, UTARMS A1970–0013, Box 4, Folder 3.

[123] Meeting of the Executive Committee of the Senate, agenda, 4 January 1962, UTARMS A1970–0013, Box 4, Folder 3.

[124] C.T. Bissell to R.Ross, 12 January 1962, UTARMS A1971–0011, Box 52, Folder 8, and C.C. Gotlieb to W.H. Watson, 6 April 1962, UTARMS B2002–0003, Box 2, Folder 5.

[125] The hierarchy was strict. A department or a centre was a degree granting body, but an institute was not.

stream department or discipline. The diploma course was no more complex than a short repackaging of pre-existing graduate and senior undergraduate courses from the Department of Mathematics and Physics. Arguably, the Institute of Computer Science was even less significant a change. It did not offer new courses, register students, or employ faculty members: "Graduate students wishing to specialize in computers will enrol in a department appropriate to their interests and undergraduate training. Their programme of studies will be the responsibility of the department in which they enrol. Staff members of the Institute having cross-appointments in other departments will be available for help in arranging courses, selecting thesis topics, and supervising research."[126] It was in some ways nothing more than a different name for the old Computation Centre, with added prestige but few new academic capabilities. As mentioned above, the university would only agree to purchase the 7090 despite a $130,000 shortfall if Watson could provide reassurances that a rising service income would cover that sum in the next few years. Therefore the Institute of Computer Science could not afford to set aside its role as a service centre so that staff might concentrate wholly on academics. It is also telling that for several years, in the annual University of Toronto *President's Report* the Institute of Computer Science's position remained near the end of the Report, among the other laboratories, and not forward alongside other academic departments.

Was there any value in the new name? The Institute of Computer Science was the first official use of the phrase 'computer science' to describe an academic activity at the University of Toronto. This lent gravitas to the phrase, but the fact that the new Institute functioned much the same as the old Computation Centre made it no easier to identify what was meant by computer science. The University of Toronto Calendar was not helpful. The Institute claimed to represent "a wide range of subjects related to computers, including programming, numerical analysis, logical design, and

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[126] Computer Science, 1962, UTARMS A1970–0013, Box 2, Folder 3.

applications to science, engineering, medicine, business, and the humanities."[127] This broad list made no attempt to identify a particular core or framework of academic enquiry that the new Institute could focus on. It was nonspecific and speculative.

Yet this was not unusual. In the early 1960s there was no harmony as to what computer science was, even among those who had begun to use the title 'computer scientist'. If it was a science (a large assumption), what was the cornerstone? "Unlike most other areas of enquiry, there was no natural arena such as an atom, tissue or crystal lattice to serve as a source of observations."[128] Obviously, it would have something to do with modern computing, but this was an insufficient guideline. Was the principal domain computer design, application development, or computational techniques? Engineering, physics, or applied mathematics? A combination, or something else? There was considerable disagreement as to what should be a part of the embryonic discipline, and what should be excluded. The tendency at many schools was to embrace the aspects of computing that its faculty was most familiar with. For example, those with a history of computer engineering tilted their course offerings and research in that direction, and thus their definition of computer science. Other schools with pronounced programs in numerical analysis or computer applications did likewise. At still other universities, interdisciplinary approaches were common, recognizing that there were many academic divisions that claimed some part of computer science, but not one that could categorically claim them all.[129] The resulting cacophony was not resolved successfully into one coherent voice until the 1970s.

Yet in some ways the problem was irrelevant: "The first published statements about 'computer science' revealed a perception that a science was being born, and it needed to be established on organizational and administrative grounds; the question of just what it 'was' could be answered later."[130] The first computer scientists

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[127] Computer Science, 1962, UTARMS A1970–0013, Box 2, Folder 3.
[128] Pollack, "The Development of Computer Science", 31.
[129] Ibid., 29.
[130] Ceruzzi, "Electronics Technology and Computer Science, 1940-1975: A Coevolution", 266.

could only answer their self-defining question when they could set their own agenda instead of reacting to others. The concept of an agenda from Michael Mahoney's work on the history of computing can be explained as "what practitioners of the discipline agree ought to be done, a consensus concerning the problems of the field, their order of importance or priority, the means of solving them, and perhaps most importantly, what constitute solutions," with an important corollary that "New disciplines emerge by acquiring that autonomy."[131] Clearly, there were problems in the early 1960s establishing an agenda for computer science. The process was hindered by the lack of a suitable structure within the university that would provide the base from which an agenda might grow to become a discipline. As prospective computer science professors and students were typically bound to physics, engineering, or mathematics departments, the early 1960s witnessed the appearance of many divisions, institutes, centres, and departments of computer science to better carve autonomy from the rest of a campus.

The Institute of Computer Science was not well positioned to accomplish this. Though faculty members could and did set their individual research agendas, they had only minimal control over their students and the overall determination of computer science. Graduate students still had to enrol in another department and complete its academic requirements. Students could be supervised by cross-listed Institute faculty, but the requirements of their home graduate department took precedence. To a lesser degree, the faculty members of the Institute faced the same problem. Although Gotlieb and Hume were members of the Department of Physics, neither had any remotely recent publications in the field; only the benevolence of Watson, chair of physics and director of the Computation Centre, permitted such laxity.[132] Despite

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[131] Mahoney, "Computer Science: The Search for a Mathematical Theory", 619.

[132] Hume had many other interests at the time. From 1959 to 1965 he and another physics faculty member, D. Ivey, co-wrote, co-hosted, and otherwise contributed to a television series for the Canadian Broadcasting Corporation that became known as the *Nature of Things* in 1960. In continuous production now for over 45 years, the series is the longest running general science television show in North America.

these failings, the establishment of the Institute created momentum. It was a force that people could gather behind and help push towards an independent discipline.

The IBM 7090 was part of that momentum. By turning to a commercial computer instead of continuing to construct the ILLIAC II, it was acknowledging, or anticipating, that the study of computer hardware was not a vital or viable aspect of computer science and would remain a part of engineering. As early as 1959, proponents of a new computer science discipline had argued that the study of computers could and should de-emphasize computer equipment in favour of more abstract investigations. While almost paradoxical, they believed hardware was merely the common link between various related research areas and not the focal point itself. Research in several of these areas, such as switching, coding, or information theory, could even be conducted without access to a computer, "just as a first-rate program in certain areas of physics can exist without a cyclotron."[133] This was not a universal point of view. Another definition of computer science, presented by Herbert Simon, Alan Perlis, and Allen Newell in a letter to the editor of *Science* in 1967, was simply "the study of computers", which explicitly included electrical engineering as it pertained to the study of computer hardware.[134] Nevertheless, as the agenda of computer science was settled, by the mid 1960s hardware was considered an optional, or elective, subject for an undergraduate computer science program; by the late 1960s it was dropped altogether.[135]

When the 7090 was installed and the Institute of Computer Science was created, this issue was far from resolution in the broader community or locally. At Toronto,

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[133] Fein, "The role of the University in computers, data processing, and related fields", 11.

[134] For discussion see: Ceruzzi, *A history of modern computing*, 102–103; for the original letter see: Allen Newell, Alan J. Perlis and Herbert A. Simon, "Letters: Computer Science", *Science* 157, no. 3795 (September 22 1967), 1373–1374.

[135] For evidence of this purge, see the preliminary and final drafts of "Curriculum 68", a report intended by the ACM to set down guidelines as to a proper undergraduate computer science curriculum. The former included electronics, while the latter did not. S. D. Conte et al., "An undergraduate program in computer science – preliminary recommendations", *Communications of the ACM* 8, no. 9 (1965), 543–552; and William F. Atchison et al., "Curriculum 68: Recommendations for academic programs in computer science: A report of the ACM curriculum committee on computer science", *Communications of the ACM* 11, no. 3 (1968), 151–197.

hardware and engineering were never far from computer science. Despite the failure of the UTEC and ILLIAC II projects to take hold, computer science has enjoyed a long and relatively close relationship with the Department of Electrical Engineering. Cross-appointments were common over the next decades; similarly, students often took courses in both departments.[136] In 1982 that relationship was further recognized and strengthened when together the two departments moved into the refurbished Sandford Fleming Building.[137] But when the ILLIAC II project was cancelled, the scope of the Institute narrowed to exclude the design of computers and emphasize the use of them.[138] Shortly after the 7090 was ordered from IBM, Gotlieb organized monthly meetings to prepare for its arrival.[139] A delegate had to be assigned to represent the university at SHARE meetings, a new user guide to the computing resources on campus had to be prepared, and the group had to choose which operating and programming systems would be supported. Though similar decisions accompanied the arrival of the 650, "the scale of this effort is much larger. Part of this increase is of course due to the larger machine, but much of it is simply a measure of the increased concentration on software."[140]

After some discussion, FORTRAN was selected as the programming language of choice at the Institute.[141] This was a pragmatic decision rather than one based on an ideological agenda. In the latter case, ALGOL (ALGOrithmic Language) would have been the proper choice: it was international, more rigorously designed, and "intended

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[136] For example, K.C. Smith was cross-appointed in both departments in the mid 1960s. Another example is E.S. Lee, an electrical engineer who maintained close ties to computer science. He helped operate an IBM 1620 in the engineering faculty in the early 1960s, and was cross-appointed to the Department of Computer Science in 1965.

[137] White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000*, 256.

[138] Hardware was never mentioned in any proposal to create the Institute or Department of Computer Science which followed.

[139] Announcement of IBM 7090 Installation, May 1961, UTARMS A1970–0013, Box 4, Folder 1, Minutes of the U. of T. 7090 Meeting, 26 May 1961, UTARMS A1970–0013, Box 4, Folder 1.

[140] Gotlieb, "Software Problems", 202.

[141] The FORTRAN monitor was also chosen as the basis for the operating system.

from the start to be independent of any particular hardware configuration."[142] In contrast, FORTRAN was predominant in North America and particular implementations were generally machine specific with their own peculiarities and idiosyncrasies.[143] Though some FORTRAN standards were emerging that a version might adhere to, this was voluntary.[144] ALGOL routines were expected to be universal; for many years, the *Communications of the ACM* (CACM) insisted that all algorithms submitted for publication were written using ALGOL. In response to this principle, at least one half-hearted attempt was made by the Institute to accommodate ALGOL.[145] However, the language was never widely used at the University of Toronto, and it must be said that both IBM and SHARE distributed routines in FORTRAN. Despite initial success in Europe, for a variety of reasons ALGOL was eventually supplanted by FORTRAN. Although ALGOL represented an effort to control the direction and agenda of the study of programming languages, FORTRAN had the important advantage of arriving first. For example, the first important programming textbook of the era was Daniel McCracken's 1961 *A Guide to FORTRAN Programming*.[146] FORTRAN was also the first widespread language taught to students at Toronto, via FORTRANSIT on the IBM 650.

There were more changes still to come in 1962. With the departure of Watson, Gotlieb assumed command of computing at the University of Toronto. When Watson

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[142] Ceruzzi, *A history of modern computing*, 94.

[143] John W. Backus, "The History of FORTRAN I, II and III", *Annals of the History of Computing* 1, no. 01 (1979), 21–37.

[144] FORTRANSIT, for example, came close to the original FORTRAN language. FORTRAN II, of 1958, was an improved version of both the original language, and a standard that many other compilers aimed for, such as FORGO for the IBM 1620. The FORTRAN IV language was the result of a more deliberate attempt to formalize the peculiarities and eliminate machine dependencies. William P. Heising, "The Emergence of FORTRAN IV from FORTRAN II", *Annals of the History of Computing* 6, no. 1 (1984), 31–32.

[145] The Director of the Institute of Computer Science, University of Toronto, *President's Report* (University of Toronto, 1963), 125.

[146] Daniel McCracken, *A Guide to FORTRAN Programming* (New York: Wiley, 1961) and see Calvin C. Gotlieb, "Review: A guide to FORTRAN programming", *Computing Reviews* (Jan-Feb 1962). To be clear, the first 1951 edition of Wilkes, Wheeler, and Gill's book was much earlier than McCracken's text. Wilkes et al., *The Preparation of Programs for an Electronic Digital Computer*. However, McCracken's FORTRAN book was the first important programming textbook following the widespread adoption of automatic coding.

went on leave, Gotlieb was promoted from Chief Computer to Acting Director of the Computation Centre, and then to Director of the Institute of Computer Science once Watson's absence became permanent. That the title Chief Computer survived until the 1960s is a sign that the university had been stubbornly unable to recognize computing as more than mere calculation. That same year, Gotlieb acquired another new title when he was chosen to succeed Alan Perlis as the Editor-in-Chief of the CACM, one of the two flagship periodicals of the ACM.[147] University President Bissell was enthusiastic about Gotlieb's new role, and agreed to help defray the costs of hiring an assistant.[148]

5.3 A Department of Computer Science

Just two months after Bissell officially opened the new 7090 facility and less than half a year after the Institute of Computer Science was established, Gotlieb started to push the university for a graduate Department of Computer Science that would split the academic duties off from the Institute. If successful, this would grant Gotlieb and his colleagues far greater autonomy, but the initial list of justifications were little different than those used by Watson to establish the Institute. Computer science, Gotlieb declared, "has developed to the stage which justifies such a centre, that it is strongly interdisciplinary and does not properly belong to any existing department, and that faculty, students, and equipment are available to ensure that original research can be done."[149] Like Watson had done in earlier proposals, he pointed to other major universities in the United States that had accepted the new discipline as legitimate, adding

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[147] C.C. Gotlieb to C.T. Bissell, 18 May 1962, UTARMS A1971–0011, Box 52, Folder 8. The CACM was founded in 1958. Its sister periodical, the quarterly JACM, was older and specialized in longer scientific articles, whereas the monthly CACM focused on shorter pieces and more pressing news. From 1966 to 1968 Gotlieb was editor-in-chief of the JACM.

[148] C.T. Bissell to C.C. Gotlieb, 24 May 1962, UTARMS A1971–0011, Box 52, Folder 8.

[149] C.C. Gotlieb to A.R. Gordon, 7 January 1963, UTARMS A1970–0013, Box 2, Folder 3.

that several were now awarding graduate degrees.[150] Later that summer, Gotlieb added the Universities of Alberta and Western Ontario as Canadian schools that were advertising their own computer science degrees to potential students, a sly way to convince the University of Toronto administration that it risked losing face. After all, how could the school with the oldest computing program in the country fall behind such upstarts? However, he still did not describe what computer science was, or why it might rightfully be declared a discipline. Unconvinced, Dean Gordon of SGS struck a committee that would consider a more detailed proposal.[151]

In July 1963, Gotlieb produced a six page report for the committee, outlining his claims that: computer science was a discipline; computer science could stand alone as a graduate department; that the university had sufficient resources to support his proposal; and that a respectable graduate curriculum could be easily assembled. More clearly than Watson, Gotlieb was finally able to explain why computer science was not merely an interdisciplinary meeting place, but an individual discipline.

First, he admitted there were a large number of subjects related to computer science that overlapped with existing disciplines: "numerical analysis and recursive function theory to mathematics; computer components to physics; system design and theory of automata to electrical engineering; and adaptive systems and artificial intelligence to industrial engineering and psychology."[152] The fact that over twenty different divisions of the university used the IBM 7090 in the past year was also a strong sign of the interdisciplinary interest in computing. But, he argued, there was a core that was exclusive to computer science: "programming, computer linguistics, theory of algo-

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[150] In his first letter to the administration, he referred to the Carnegie Institute of Technology (now Carnegie Mellon University) and the University of Chicago. In a later, more comprehensive proposal, he added MIT, Stanford University, Purdue University, and the University of Wisconsin. For a comprehensive list of schools offering an undergraduate and graduate computer science degrees in 1964 and planning them for 1968, see Finerman, "Appendix: Computers in Higher Education", in A. Finerman ed., *University Education in Computing Science,* ACM Monograph Series, 215–229 (New York: Academic Press, 1968), 215–229.

[151] J.E. Gordon to C.C. Gotlieb, 13 February 1963, UTARMS A1970–0013, Box 2, Folder 3.

[152] C.C. Gotlieb, A Proposal for the Establishment of a Graduate Department of Computer Science, July 1963, UTARMS A1970–0013, Box 2, Folder 3.

rithms, data processing, pattern recognition, and information retrieval."[153] That is, he was identifying an exclusive research agenda, though his list was still vague. The core of computer science remained difficult to define, and many other attempts of the era contained "references to such puzzling concepts as the 'theory of applications.'"[154]

A more convincing argument from Gotlieb was that although computers would always be important to scientific and engineering calculations, "in using computers we soon find cases where the method of attack is influenced more by the available computer methods than by the origin of the problem."[155] Translated, this meant computers were more than a means to an end – the study of computer techniques was valuable as an end itself. Despite the introduction of the Institute of Computer Science, it was still prohibitively difficult for students to study in this way. There was little question in Gotlieb's mind that Toronto had the necessary staff and resources to supervise graduate students who chose computer science; the university's long, though occasionally fitful, growth in the field made it an ideal location. Several recent factors helped ensure that the future was secure: the arrivals of the IBM 7090 in 1962 and of Professor T.E. Hull, an applied mathematician with a long interest in computing, in 1963, and the new space allocated to the Institute of Computer Science in the nearly-complete Physics Building.[156] By adding just three courses to the current six, an entire graduate curriculum could be established for master's students that would be both broad and deep when concluded with a separate thesis. Confirming that there was a demand for

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[153] C.C. Gotlieb, A Proposal for the Establishment of a Graduate Department of Computer Science, July 1963, UTARMS A1970–0013, Box 2, Folder 3.

[154] Pollack, "The Development of Computer Science", 31.

[155] C.C. Gotlieb, A Proposal for the Establishment of a Graduate Department of Computer Science, July 1963, UTARMS A1970–0013, Box 2, Folder 3.

[156] Hull had completed his Applied Mathematics Ph.D. under L. Infeld in 1949 at the University of Toronto. That same year he was hired to teach mathematics at the University of British Columbia (UBC), where he developed that University's electronic computer program in the second half of the 1950s and early 1960s. This included helping arrange for the first electronic computer on the West Coast, an ALWAC III-E installed at UBC in 1957. While on sabbatical in Toronto in 1963, Gotlieb lured him back, and Hull eventually succeeded Gotlieb as the second chair of the Department of Computer Science. Hull was also active in the computing field, for example participating on several NRC computing committees in 1960s and as one of the co-authors of the ACM's "Curriculum 68".

a graduate degree in computer science, Gotlieb included a list of twenty people from around the world who had enquired at the Institute for such a program in the last year alone.

The SGS committee that was struck to evaluate this claim was chaired by H.L. Welsh, also chair of the Department of Physics after Watson resigned. Given the long support of the department of physics, it is somewhat surprising that Welsh did not support the plan, feeling that it was yet premature and that computer science was not strong enough to offer graduate degrees. He might also have been protecting his own department – he was likely to lose several faculty to the new department, including Gotlieb, Hume, McKay, and Worsley. Yet he might just as easily have welcomed that change, hoping to purge the physics department of half-hearted physicists more interested in computing. In the end, at the final committee meeting, when Welsh recognized his was the minority position, he agreed to change his vote and made the motion himself to create the new department.[157]

With the SGS committee approval at the end of 1963, the proposal went before the SGS Council in 1964 and from there to the Senate, where it was approved in time for inclusion in the 1964 University of Toronto Calendar. The entry for the new department read: "The staff in Computer Science is interested in a wide range of subjects related to computers, including programming theory and techniques, numerical analysis, logical design, and applications to science, engineering, business, medicine, and the humanities. The university's IBM 7090 electronic computer offers an excellent facility for research in any of these areas."[158] From that point on, the Department of Computer Science represented all research aspects of computing and the Institute of Computer Science was responsible for the operational side of computing at the university. Gotlieb chaired both divisions of the former Computation Centre, and for several

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[157] See Thomas E. Hull, interview by Michael R. Williams, 12 June 1992, Transcript provided by Michael R. Williams.

[158] University of Toronto, *School of Graduate Studies Calendar 1964–1965* (University of Toronto, 1964), 61.

years the activities of the new department were chronicled in his annual report on the Institute of Computer Science. The other five members of the new department were T.E. Hull, J.N.P. Hume, W.H. Kahan, R.W. McKay, and B.H. Worsley. Both a Master's and Ph.D. degree were created.[159] One of the first students to enrol, S. Kumar, was awarded the first Ph.D. of the new department in 1968.[160]

It should be pointed out that this was not the first department of computer science in Canada. About two hours west of Toronto, in London, Ontario, the University of Western Ontario (UWO) announced the creation of an undergraduate Department of Computer Science in 1963, though students could not enrol in the Honours Bachelor of Science degree until September 1964.[161] The program required courses in "numerical analysis, numerical computing, logical design of computers, and non-numerical computing."[162] The computing effort at UWO was led by J.F. Hart, a University of Toronto graduate and experienced TRANSCODE programmer as the NRC representative in the 1950s. He helped bring an IBM 650 to UWO in 1959, and an IBM 7040 in the fall of 1963 to help usher in the new department, which he chaired for 27 years.[163]

At the University of Alberta, in Edmonton, Alberta, the Department of Computing Science was created in the Faculty of Science as of 1 April 1964.[164] Only a Master's of Science degree was available immediately, but it was followed shortly by a Bachelor of Science and in 1967, a Ph.D.[165] The University of Alberta had one of the oldest uni-

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[159] C.C. Gotlieb to J.G. Breckenridge, 18 December 1963, UTARMS A1970–0013, Box 2, Folder 3.

[160] See S. Kumar and Calvin C. Gotlieb, "Semantic Clustering of Index Terms", *Journal of the ACM* 15, no. 4 (1968), 493–513; S. Kumar, "Semantic Clustering of Index Terms", Ph.D. thesis, Computer Science, University of Toronto (1968).

[161] University of Western Ontario, *Report of the President* (University of Western Ontario, 1964), 25.

[162] L. Mezei, "News of Southern Ontario", *CDPSC Quarterly Bulletin* 3, no. 4 (July 1963), 11.

[163] J. McGregor, "Professor paved the way for blind students", *London Free Press* (August 11 2002).

[164] Keith Smillie, one of the founding faculty members has this to say about the variant of the title: "The choice of the name 'computing science' instead of the more common 'computer science' was deliberate in order to indicate that computing rather than computers was to be the foundation of the discipline. Another explanation attributed the name to a typographical error. Although both names appear in the correspondence regarding the formation of the department, the second explanation is undoubtedly suspect." Smillie, "The Department of Computing Science: The First Twenty-Five Years", 19.

[165] University of Alberta, *Calendar 1964–1965* (University of Alberta, 1964), 423,486. Thus the University of Toronto can lay claim to the first graduate department of computer science in Canada to offer a Ph.D.

versity computing programs in the country, aside from Toronto, having participated in the remote Ferut project in 1957, installed an LGP-30 in 1957, an IBM 1620 in 1961, and coinciding with the new department, an IBM 7040 in 1964.

A third university deserves mention for recognizing computer science in 1964. That year, the University of Waterloo created a Division of Computer Science within the Department of Mathematics in the Faculty of Arts.[166] Though computing courses had been offered at Waterloo since 1958, mainly to engineers, for those students explicitly planning a career in computing, as of September 1964 a Co-operative Bachelor of Arts degree was now available with a computer science option. Unlike the University of Toronto, which had created its new department to better manage computer science research, the Waterloo co-operative program emphasized training and tight connections with industry. A co-op student's degree was obtained by alternating every four months between on-campus studies and an off-campus internship. While students were expected to master the necessary mathematics, the course work was generally intended to provide the best possible experience in preparation for employment, rather than research.[167]

The University of Waterloo also had a policy that every student was to be given the opportunity to learn how to use computers – in the 1964/65 academic year, over 800 students were taking a computer related course. After having launched its computing program with an IBM 1620, in 1964 an IBM 7040 was installed. One of the outcomes of this approach was WATFOR (Waterloo FORTRAN), a phenomenally successful student-oriented FORTRAN compiler for the IBM 7040 written by four undergraduates over the summer of 1965.[168] Like other student-oriented compilers, it was

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[166] In 1967, mathematics was severed from the Faculty of Arts to create one of the world's only Faculty of Mathematics and at the same time, a full Department of Computer Science.

[167] J.W. Graham, "A Co-operative Course in Honours Mathematics with Actuarial and Computer Science Options", *CDPSC Quarterly Bulletin* 4, no. 3 (April 1964), 15–16.

[168] The four undergraduate were: Angus German, Jim Mitchell, Richard Shirley, and Bob Zarnke. They were supervised by Peter Shantz, a computer science lecturer, while the entire project was managed by J.W. Graham, Director of the Computing Centre.

ideal for the academic environment because it ran much faster than other compilers (important when hundreds of students were submitting programs each day) and it had superior diagnostic messages (important for novice programmers prone to mistakes, a category most students belong to). These features made WATFOR desirable to other academic and industrial computing centres, and a second version was written in 1967 for the IBM 360. Success with the 360, the most important line of computers in the second half of the 1960s enabled Waterloo to continue developing further versions as FORTRAN evolved and to implement other programming languages, such as COBOL or LISP, for the educational environment. The overall success was such that by the mid 1980s, it is estimated that millions of students around the world had learned how to program with a version of WATFOR.[169]. By then, Waterloo had acquired a reputation as one of the top schools for computer science, not just in Canada – where Toronto and Waterloo were the two brightest stars – but worldwide.

As can be seen, at all three of these other Canadian universities, an IBM 7040 was considered sufficient to found a computer science department, unlike the more powerful and more expensive IBM 7090 at Toronto. And yet, Watson's effective position in 1958 was that a computer science department was impossible if not matched with an incredibly fast computer such as the ILLIAC II, or the next best thing, the IBM 7090. This apparent inconsistency, from his promise of the late 1950s to the actual turn of events in the mid 1960s, is taken in up the following concluding chapter.

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[169] Scott M. Campbell, "'WAT' For Ever: Student-Oriented Compilers and Computing at the University of Waterloo, 1957-1967", Institute for the History and Philosophy of Science and Technology, University of Toronto (2001).

Chapter 6

Conclusion

"Computers are an essential tool in much fundamental research in other fields. All students of science should be at home with them. But there must be a group of students who see in computer science an exciting new field of intellectual stimulation. For in them will rest the promise of computer science."

– J.N.P. Hume, Professor of Computer Science, 1964.[1]

It may seem odd that up to this point, a specific definition of computer science has not been put forth, and in fact, none will be given. The reader may question if it is possible to study the origins of a discipline without reference to its precepts and doctrines. There are several defences to this criticism.

The first, and most obvious, is that to limit the scope of the story to a contemporary definition of computer science would result in an incomplete, inaccurate, and whiggish interpretation. Viewing history through the lens of the present does a great disservice to the events of the past. A history of computer science told in the same way would risk excluding material that is not relevant to today's practitioners and their specific disciplinary bias, but was relevant to yesterday's. For example, the design and construction of computer hardware has been excluded from most computer

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[1] J.N.P. Hume, "The Promise of Computer Science", in *Proceedings of the Fourth National Conference, University of Ottawa, 1964* (Toronto: University of Toronto Press, 1964), 7.

science programs since the 1960s, but to eliminate the UTEC and ILLIAC II projects from this narrative would have left out a large part of the story. The reverse instance – over-emphasizing certain historical aspects that do seem particularly relevant to contemporary computer science – is just as problematic. Today, a student is expected to master theoretical components of computer science pertaining to linguistics, complexity, and automata, but a computer science student at the University of Toronto in 1964 would not have encountered these subjects at any depth.[2] Thus an inclusive history of computer science can not begin with a preconceived notion based on current practice.

The second justification is that contextually, for the period in question, there was no consensus regarding a definition of computer science. As was explored in chapter 5, the discipline evolved in different ways at different universities with different guiding principles. Attempts to unify the discipline or identify its boundaries only got under way after many departments were established, including the Department of Computer Science at the University of Toronto. Until then there were at least as many definitions of computer science as there were schools studying it, and no one in particular can be used to explain the development of the departments. They are all irrelevant with the exception of the one used at Toronto, and as was shown, the creation of the Department of Computer Science in 1964 was not accompanied by a particularly articulate definition.

The final justification for failing to provide a definition is that this dissertation is not an attempt to unveil the origins of computer science. To untangle that entire web of social and technological factors would be phenomenally complex. Nor does this dissertation attempt to explain specifically the history of the discipline of computer science at the University of Toronto, though such a history would be fundamentally related to this one. By way of an analogy, in today's terminology, a hook is a software

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[2] In Michael Mahoney's work on the development of theoretical computer science, he shows that linguistics, complexity, and automata were not considered the core of computer science until the 1970s. See Mahoney, "Computer Science: The Search for a Mathematical Theory", 617–634.

or hardware device that is designed to permit the eventual end user of a program or computer to modify, direct, or add to its normal behaviour. A program that outputs numerical results in decimal might have a hook that would also enable base-16 output or Roman numerals.[3] A hook in this case might also permit a user to craft his own extension that enables other forms of output, such as binary or different formatting. Well-conceived hooks provide great flexibility and power, and in this sense this dissertation uses computers as hooks to explore the early development of computing at the University of Toronto, from instigation to academic recognition. A different story could be hung on some of the same hooks. Indeed, historian John Vardalas has done so in his book which explored the early external influence of the DRB on the nascent computing program at Toronto and the demise of UTEC.[4] Another story could explore the theoretical roots of computer science at Toronto with more explicit attention paid to the specific research programs of individuals, particularly in the 1960s.

But this is not that tale. Instead, it is a history of modern computing at the University of Toronto, from the introduction of computers in the late 1940s to the creation of an academic Department of Computer Science in 1964. Its purpose is to explore how various members of the university – faculty, students, and administration – determined the role of modern computing technology and practices within the university, and to not ignore the possibility that the technology was also a determinant. It was a surprisingly turbulent twenty years: the start and end points have very little in common in terms of the people or the technology. With one exception, nobody in chapter 1 appears in chapter 5.[5] The technological changes from beginning to end were equally profound, from desktop and electromechanical calculators to massive million-dollar mainframes. More importantly, the manner of use and purpose of computer technol-

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[3] This example has been borrowed from Eric S. Raymond ed., *The new hacker's dictionary*, 3rd edition (Cambridge, Mass.: MIT Press, 1996).

[4] Vardalas, *The Computer Revolution in Canada: Building National Technological Competence.*

[5] That exception is W.H. Watson. Until 1952 his involvement with computing at Toronto was peripheral and so are his appearances in the first two chapters. Of course, for the next ten years and three chapters his involvement was central.

ogy within the university evolved considerably during this time. A small statistics laboratory became a Computation Centre for the university and federally sponsored scientific research agencies. The Computation Centre's relevance to the rest of the country fell when less expensive and more reliable computers appeared on the market in the late 1950s just as the University of Toronto came to be the dominant user of the Centre. This was a critical turning point that would eventually lead to the university regaining the title of fastest computer in Canada, renaming the Computation Centre the Institute of Computer Science, and creating the autonomous Department of Computer Science. The division between the academic and operational aspects of computing persists today, though neither of these two functions existed in 1945, when this story begins.[6] And so computer science is a logical end point, but not the focal point of this story.

6.1 The Perils of Early Entry

Computing historian William Aspray has examined the history of five universities in the United States with early computing programs – MIT, Harvard, the University of Pennsylvania, Columbia, and Princeton – and concluded that being first is not a useful predictor of success. Unlike Toronto, "Not one of the five institutions was able to take advantage of its early entry in such a way as to continuously build itself into a leading department of computer science."[7] Therefore, that the University of Toronto was the first in Canada to found a graduate Department of Computer Science should not be seen as preordained. Though it was the first Canadian university to take modern computing seriously, this did not guarantee the outcome portrayed in this dissertation.

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[6] It must be said that in the 1970s and 1980s minicomputers and microcomputers afforded massive decentralization of computing power, and many faculties and departments opted to operate their own computing facilities. Regardless, the academic and operational aspects remained separate, and the Department of Computer Science has endured as a distinct entity.

[7] Aspray, "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s", 81.

An early entrant did have some advantages as a matter of course.[8] Until the mid 1950s, the five schools were able to exploit their pioneering positions to create brand recognition, increase their links to government and industry partners, establish standards and large networks of graduates, and attract personnel from the scarce pool of candidates. However, past that half way point of the decade, the early entrants were plagued by disadvantages. Because the technology was new and not well understood by outsiders, it was often difficult to acquire long-term financial support, both inside and outside of the university. The demand for large-scale electronic computers was also uncertain, especially immediately after the war; this impression changed only gradually until new uses were discovered. The schools that had invested heavily in first generation hardware could not afford to upgrade and expand their research programs when computer technologies improved a few years later. Finally, the early entrants had difficulty identifying a unique direction that could be aggressively pursued. Computer science, the discipline that would eventually occupy this aim, was a decade or so in the future, and there was no other academic stream to jump into. The five schools Aspray selected were unable to extend their advantages and overcome their disadvantages in time to create a strong department of computer science in the 1960s. That Toronto was able to do this had as much to do with good timing and fortune as good planning.

First, it is prudent to verify that the scope of early entry as defined by Aspray is not too narrow chronologically or otherwise that it would exclude the University of Toronto from comparison. After all, Toronto did not attempt to join the modern computing fraternity until 1948.[9] This was at minimum two to three years after Aspray's

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[8] Aspray's definition and analysis of early entry is adapted from M.E. Porter, *Competitive Advantage: Creating and Sustaining Superior Performance* (New York: The Free Press, 1985). Another useful work on early entry is Everett M. Rogers, *Diffusion of Innovations*, 5th edition (New York: The Free Press, 2003).

[9] For instance, Aspray does not include the University of Illinois and the ORDVAC and ILLIAC projects, perhaps because the two were derivative of von Neumann's IAS computer. Nor does he include non-North American universities, such as Cambridge or Manchester, home of the EDSAC and Mark I.

five chosen schools had active computing programs, and in some cases significantly later.[10] Consequently, Toronto had the opportunity to evaluate existing and future computer technologies before entering the field. After the Committee on Computing Machines toured computing centres in the United States in the spring of 1946, it was prepared to declare certain machines and techniques obsolete. It took another two years to convince the NRC and DRB to sponsor a computing centre at Toronto. There was no easily identifiable need for one, and no other group in Canada was looking to establish a computing centre, but successes in the United States and the United Kingdom were too important and exciting to ignore. In the end, the Computation Centre was the only Canadian entrant to the field for nearly a decade.

The Computation Centre also started from much the same position as other early entrants after the Centre failed to reject or avoid any obsolete technology. With the NRC and DRB grants in hand, five separate and simultaneous computing projects were begun, but only one of them – UTEC – can be seen as a legitimate attempt to break from the past. The statistics laboratory, the differential analyzer, the electromechanical punched card calculator, and the relay computer were outmoded technologies. Which is not to say they were not useful. Electronic computers were not generally ready for operational duty, and the IBM 602A powered the Computation Centre for the next four years. Yet if the Computation Centre had continued down the path to build a copy of the Bell relay computer, the later achievements of the Centre can be considered unlikely. It was only external intervention from the DRB that shook the Computation Centre back to a more reasonable course. Moreover, despite the ambitions of Kates and Ratz, the full scale UTEC plans were no more advanced than the other electronic computers under construction at the time.

As Toronto was beginning from a similar technological position it can be consid-

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[10] MIT's connection with computing begins with analog technology in the 1920s, although it did move to digital computing devices after the Second World War. Columbia's enviable association with IBM began in 1929. Harvard, Pennsylvania, and Princeton launched their programs at the beginning, middle, and end of the war, respectively.

ered an early entrant. Fortunately, while it shared many of the same advantages as the other early entrants, it did not suffer from all of the disadvantages. For one, after the Centre was established, the external financial support did not waver, simply because there was no significant competition for the federal dollars for many years, even as the demand for the computing services climbed. The DRB and NRC were conservative with their grants, and both expressed that if private enterprise demanded computing assistance in Canada, private enterprise should supply it. Nor were the DRB or NRC averse to stepping in on occasion to settle disputes, including the aforementioned relay computer debacle and when the full-scale UTEC was cancelled to be replaced by the Ferranti Mark I. These impositions might be regarded as a case of *deus ex machina*, as the interference had such a positive and stabilizing effect, forcing the Centre to expand gradually and cautiously, even against the will of the staff. But the Centre was not stuck with a nearly obsolete electromechanical computer (though it wanted one), was held back from building a full-scale UTEC (that it was unqualified to construct), and so when Ferut arrived the University of Toronto was fortunate to be one of the first schools in North America with a modern, stored-program electronic computer. More importantly, there was no exisiting obsolete technology around to impede further progress.

The lack of competition in Canada for many years was a considerable advantage, as it would be for any early entrant that is given a chance to consolidate its leadership position. It was nearly a decade after the founding of the Computation Centre that another Canadian university was able to conduct serious research or offer instruction related to modern computing. In the mean time, almost every large and interesting computational problem in the country made its way through the hands of the Computation Centre staff. Though a significant percentage of the computational work was completed at the behest of university staff and students, that done for the NRC, DRB, AECL, St. Lawrence Seaway Project, A.V. Roe, Eastman Kodak and others solidified the Centre's position as the national leader. The Centre was also able to set at least one standard during this tenure: TRANSCODE, the de facto programming system for the entire first generation of programmers in Canada. The Computation Centre did not have to fight to maintain its position or struggle to identify a direction for computing, as there was more computational work than it could handle. The Centre was the acknowledged centre of computing in Canada, and the only logical place to host the first all-Canadian computing conference in 1958.

That said, the University of Toronto and the Computation Centre did not have an entirely charmed existence. There was difficulty hiring or even retaining some of its better qualified candidates for faculty or staff positions, several of whom abandoned the country for greener pastures in the United States. It is a delicate art to balance among employing outsiders, nurturing homegrown talent, and networking with alumni. It is an art that Toronto failed to perfect until the 1960s. Unable to hire a reputable Director in the early stages, the university turned to the unproven Gotlieb to manage day to day operations, a fortuitous decision. But there was a long list of suitable personnel for the Centre who were either passed over for employment or departed of their own accord, including Buchholz, Gellman, Gillies, Kates, Ratz, Rubinoff, and Stanley. It is tempting to suggest that it was a case of luck that they were able to retain Gotlieb, Worsley and Hume in the 1950s and Kahan and Hull in the 1960s.[11] To be fair, the Computation Centre was a solitary operation in a country of great geographic size with a scattered population, making it difficult to discover and retain talent when compared to the United States.[12] The silver lining was that

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[11] Worsley eventually did leave in 1965, under cloudy circumstances, to work at Queen's University. Campbell, "Beatrice Helen Worsley: Canada's Female Computer Pioneer", 51–62. When the IBM 650 replaced Ferut, Hume lost most of his interest in computing until the Department was created several years later. In Kahan's case, after completing his doctorate in 1958 and post-doctorate in 1960, there were concerns that he would not return. C.C. Gotlieb to W. Kahan, 11 December 1959, UTARMS B2002–0003, Box 2, Folder 15. Hull was persuaded to move to Toronto only after a year's sabbatical there and the new department was created. Thomas E. Hull, interview by Michael R. Williams, 12 June 1992, Transcript provided by Michael R. Williams.

[12] Worsley, "Computer Training at Toronto", 72.

for a relatively small operation with parsimonious support from the host university, the Computation Centre was remarkably well connected to computer activity in the United States, and for a time, the United Kingdom. As the only Canadian academic computing centre, its members were forced to reach into to the United States to keep abreast of news. There they were welcomed with open arms to American computer societies, conferences, and periodicals. The Computation Centre's success in the 1950s can be attributed directly to its status as the only early entrant in Canada, and some good fortune that prevented it from being invested too heavily in older technology.

As the decade wore on, the competition increased in Canada along with the demands placed on the Computation Centre. Until 1957, the Ferut was used primarily by external customers: the AECL, DRB, NRC, and other businesses and universities. Around this time many of these same users began to purchase their own computers, a result of the rising availability of inexpensive and reliable commercial machines. This included former customers and other schools such as the University of Alberta, British Columbia, and Saskatchewan. As the Computation Centre's service income dropped, the usage statistics quickly reversed so that the university consumed two-thirds of the computing time in 1958 and over nine-tenths in 1959. That the percentage of university usage was rising is not necessarily evidence of an overall increase in academic activity; it could imply that other organizations had simply lost interest in purchasing computer time at the Computation Centre. After all, Ferut's reliability problems never went away, and its replacement was a very common and not very fast IBM 650. Yet by several measures academic activity in the Centre was climbing as the Toronto faculty and students made excellent use of the unsold machine time. The number of Computation Centre related publications, dissertations, credit and non-credit courses, and students were all increasing. This corresponded to a rise in the number of departments and disciplines conducting research with Computation Centre resources. Though the university found it gratifying that the Computation Centre was well used, it was not inclined to pay a commercial rate for the computer time (or any rate at all) which left the Centre without enough money or time for the staff to support the research and teaching programs optimally. As Watson warned Acting President Woodside in 1958, he faced the unwelcome prospect of restricting academic use of the machine and increasing business activities to balance the budget.[13]

These new conditions had eliminated the early entry advantage for Toronto. Other computing centres had faster computers, though no other Canadian university had a better one than Toronto's, and the positive links to government and industry were of less significance. The Computation Centre was no longer relevant as a service centre as it fell from the forefront of computer technology, though Gotlieb and Hume's 1958 book, *High-Speed Data Processing* was important in fixing computing nomenclature. But because the University of Toronto was now the largest client of its own computing centre, it helped refocus attention inward. The role of the Computation Centre as a part of the University of Toronto would need to be clarified if the Centre was to retain or even recapture its position of leadership in Canada. The outcome of this introspection was the creation of the Department of Computer Science in 1964.

6.2 Why a Graduate Department?

In several ways, a graduate department was inevitable at the University of Toronto. Certainly, this would not be unusual for a North American university at the time. Of those awarding computer science degrees, the majority offered a doctoral degree, and graduate programs were more common than undergraduate ones overall.[14] Pragmatism played a large part. By its nature, a graduate only department should be smaller and more flexible than one that includes undergraduate degrees. These were crucial considerations for computer science. With very few faculty qualified to teach a large

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[13] W.H. Watson to M. Woodside, 26 February 1958, UTARMS A1971–0011, Box 13, Folder 25.

[14] Finerman, "Appendix: Computers in Higher Education", 225–226.

undergraduate course, let along supervise graduate students, the size of a department could not be ignored. For those who were qualified, a job in the private sector could be lucrative compared to an assistant professorship, which made expanding a department difficult.[15] Just as important, the meaning of computer science was still evolving, and a successful department needed to be able to adapt to new conditions – as evidenced by the early entrants who failed to adjust in the 1950s.

These issues, and more, were put forth in a 1959 article by L. Fein in the CACM which summarized the current relationship between universities and computers in the United States.[16] Fein introduced the notion that academic departments were needed to represent the nascent discipline that he called the Computer Sciences.[17] He explicitly recommended the creation of independent graduate departments, "to allow a freedom of choice in policy that can respond to the rapidly changing situations ...without the constraints imposed by an existing structure designed to cope with situations that no longer exist." He argued the ideal manner to develop the new discipline was through research related activities that included "establishing terminology, axiomatizing a field, writing or editing books, journals, and other such material, and even helping to organize professional societies."[18] To form a graduate department of computer science, or at least a department that emphasized research and doctoral stream studies, was entirely normal and appropriate.[19]

Conformity to a norm does not sufficiently explain why Toronto created a graduate program, nor does practicality. Local conditions played a determining role in

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[15] Fortunately, one of President Smith's final accomplishments before he retired in 1957 was to raise academic salaries at Toronto to parity with the highest in the United States. While industry salaries might still be higher, it gave Toronto an advantage over other Canadian universities in this area, and helped ensure continued leadership. Friedland, *The University of Toronto: A History*, 414–415.

[16] Some of his research was conducted as a consultant to Stanford University. Fein, "The role of the University in computers, data processing, and related fields", 7–14.

[17] Fein's article was likely the first to recognize computer science as a new discipline, as pointed out on page 284.

[18] Ibid., 13.

[19] Suggesting, perhaps, that the historical cases at Waterloo and UWO could be more interesting. Why did they choose to provide an undergraduate program instead of a more 'appropriate' graduate degree?

computer science, just as Aspray suggests was the case at other schools in his analysis of early entry. He points to an encouraging institutional environment, long-term external support, and the ability to exploit regional advantages as influential factors. These help explain the relative lack of success of computer science at Princeton University. Because it focused on undergraduate education and the liberal arts, a leading computer science department did not fit well with this mission and attempts to establish one met resistance from other departments. The resulting computer science program that did form there was too small to attract top faculty or students.[20]

At Toronto, the roots of the graduate computer science program went back in time a decade or more, and resulting growth was very much a matter of local conditions. For one, there was a long and unquestionable preference for research rather instruction. Undergraduate teaching brushed too close to training, an unsuitable and unseemly activity for a university. "It is not a proper university function to train mere operators," wrote Watson in 1958, who argued that any "emphasis in instruction should be laid on principles and the theory of methods instead of training in routines."[21] Watson was a theoretician – recall his prior position at the Atomic Energy Project at Chalk River, where he had been the Head of Theoretical Physics – and many times advocated theoretical approaches to computing rather than practical ones. Watson would also have agreed with Fein that the proper means to develop a discipline was in the hands of rigorous intellectuals capable of organizing and setting down much needed theoretical principles.[22] Toronto did acknowledge the shortage of skilled programmers, creating the Diploma Course in Computing and Data Processing in 1962, but the prerequisite mathematical knowledge and course load put the diploma in the same class as a master's degree without a thesis.[23] The diploma was useful for engi-

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[20] Aspray, "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s", 83–84.

[21] W.H. Watson to S.E. Smith, 24 April 1957, UTARMS A1971–0011, Box 23, Folder 3.

[22] Recall his memorable words at the 1958 CDPSC conference, of substantial sums of money thrown at computers before thought was ever given to a problem.

[23] D.B. DeLury and W.H. Watson to C.T. Bissell, 20 June 1961, UTARMS A1971–0011, Box 52, Folder

neering or science graduates looking for computing experience, but by the time the department was established in 1964, it was becoming irrelevant as community colleges and other universities began to provide more appealing and practical courses. In 1968 it was time to abolish the diploma, on the grounds that "almost all applicants are seeking training in data processing," and "they are neither interested in nor properly prepared for the more scientific and mathematical aspects of computing."[24]

In contrast, the University of Waterloo did supply a degree for those preferring more practical studies, as expected from a university and faculty with strong ties to industry.[25] In particular, J.W. Graham, who was responsible for the development of computing and computer science at Waterloo more than any other person, previously spent five years working for IBM as a technical salesman. His students were still taught important concepts in numerical analysis, but training was an integral part of the curriculum. In 1963 Gotlieb justified his department's predisposition for graduate studies in the face of obvious national demand for trained programmers. He remarked that there also existed a demand for people with graduate degrees in computer science, especially at the fifteen other universities in Canada with a computer looking for academic staff.[26]That is, someone had to teach the trainers. It is not a coincidence that determining a discipline's agenda is easier at the helm of a graduate department.

The root of this attitude might well have been the environment at the University of Toronto. Possible departmental models for computer science include physics, mathematics, and engineering. All had strong graduate customs. The first, physics, was the

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[24] L. Mezei to T.E. Hull, 9 September 1968, UTARMS A1970–0013, Box 3, Folder 7. The diploma should not be perceived as a failure. Graduates of the program were routinely offered their choice of employment.

[25] For a history of the University of Waterloo, see James Scott, *Of Mud and Dreams: University of Waterloo, 1957–1967* (Toronto: Ryerson Press, 1967), and Kenneth McLaughlin, *Waterloo: The Unconventional Founding of an Unconventional University*, 1st edition (Waterloo, Ont.: University of Waterloo, 1997).

[26] C.C. Gotlieb, A Proposal for the Establishment of a Graduate Department of Computer Science, July 1963, UTARMS A1970–0013, Box 2, Folder 3.

most influential, and at Toronto had perhaps the oldest tradition of graduate research going back forty years; between the world wars it graduated the most doctorates in the university.[27] Mathematics had an excellent reputation during and after the Second World War, thanks to world-class mathematicians such as H.S.M. Coxeter and the benefits of an influx of European refugees. The department had a respectable number of graduate students, and the undergraduate division was proud of its success sending teams to the Putnam Competition.[28] In the 1950s the engineering departments housed a relatively stable body of over one hundred graduate students. There were difficulties growing this number, attributable to the lack of money for fellowships. A substantial Ford Foundation grant in the early 1960s provided the financial means for the graduate program to explode: by the end of the decade there were over 600 graduates enrolled.[29]

But why not a complete Department of Computer Science with a full spectrum of undergraduates, masters, and doctorate students, much like those other three departments? If smaller schools like Waterloo and UWO could have an undergraduate program in 1964 – or, for that matter, if there were American schools with a full slate like Purdue University or MIT – why was this not the case in Toronto?[30] The simple answer is that forming a graduate-only department was the path of least resistance. It would have minimal effect on budgetary allocations, and had the lowest threshold for administrative approval.[31] All a graduate-only department would require was the blessing of the deans and associate deans. An undergraduate department also needed the approval of the entire Faculty of Arts and Sciences.[32] It was a pragmatic

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[27] Friedland, *The University of Toronto: A History*, 298–300.

[28] Ibid., 344-346. The William Lowell Putnam Mathematical Competition is an annual competition for small teams of Canadian and American mathematics undergraduates. It is administered by the Mathematical Association of America and has run since 1938.

[29] White, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000*, 180–181,198–199.

[30] Finerman, "Appendix: Computers in Higher Education", 215–229.

[31] Calvin C. Gotlieb, interview by Michael R. Williams, 5 May 1992, Transcript provided by Michael R. Williams.

[32] Hendriks, "An Institutional History of The Department of Computer Science at the University of

decision, but to push it through the university Senate, the departments that had sheltered computing for so long would need convincing. From their point of view, the Computation Centre was an independent and self-sustaining laboratory of the university, answerable only to the Joint Committee in Ottawa. Thus, for many years it was not perceived as a threat. Most mathematicians, engineers, and physicists took little interest in computing throughout most of the 1950s, let alone the Computation Centre. Yet quite often their students took great interest in the new machines, and by the 1960s a new generation of scientists came to depend on computers for their research. But if Watson and Gotlieb hoped to move the Centre into the academic realm, they could not expect to march in unopposed. Renaming the Computation Centre the Institute of Computer Science was a piecemeal tactic that created academic cachet without any cost. Students found it easier to conduct computing related research, but no department could complain about the arrangement because it didn't interfere with their budgets or enrolment.

Multidisciplinary and interdisciplinary approaches were common at Toronto in the 1960s, which might have paved the way for others to recognize computer science as much as any other factor. Academia was expanding while older, rigid disciplinary boundaries were falling, "but owing to jealousy on the part of the traditional academic departments, their removal initially took place in the graduate school."[33] Even there, a new department was not easy. Though Watson was gone, he had secured the support of Mathematics many years earlier through Chair D.B. DeLury who co-signed the initial proposal for a new computing department. Surprisingly, it was the new chair of physics, H.L. Welsh, who was most hesitant about the idea, but he was eventually swayed by the majority who wished to see the new department. It should be pointed out that a bachelor degree in computer science was not available at Toronto until 1971,

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Toronto: 1948-1971", 14.

[33] Friedland, *The University of Toronto: A History*, 479.

well after many other Canadian schools.[34]

Yet what happened to Watson's plan of the late 1950s tying a computing research and a new department to the ILLIAC II? How instrumental was the IBM 7090, less powerful but just as prestigious, in the negotiations to establish the diploma, the Institute, and Department of Computer Science? It was, after all, the million dollar machine that impressed the president so much.[35] It is hard not to imagine that the great price of the computer would have been in the mind – for good or ill – of any professor, dean, or member of the university governing structures asked to accommodate this new department. It is probable that the 7090 played a small role, but the arrival of computer science was not nearly as significant to the rest of the campus as that of the computer. Watson was right that such a computer was necessary for research, but was wrong about what kind of research.

The University of Toronto could have justified the 7090 simply by pointing to the breadth and depth of users who depended on the computer to go about their research. In 1962, around the time the 7090 replaced the 650, there were twenty different departments at the University of Toronto making use of the facilities.[36] The sheer volume of work had overwhelmed the older drum based computer, and until the Institute of Computer Science had their 7090 running some problems had to be run on an IBM 704 at IBM's Toronto data centre and a 7090 in New York.[37] Three years later the university use had nearly tripled.[38] In these years, there was no other university or organization in Canada that could summon a similar argument based on usage; not

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[34] University of Toronto, *Faculty of Arts and Sciences Calendar 1971–1972* (University of Toronto, 1971), 36–37. In 1968 computer science was recognized as an option for undergraduates in the Department of Mathematics.

[35] See page 281.

[36] Institute of Computer Science, *Computer Usage Report – July 1 to December 31, 1962* (University of Toronto, 1962), 25.

[37] The Acting Director of the Computation Centre, University of Toronto, *President's Report* (University of Toronto, 1962), 106.

[38] Institute of Computer Science, *Annual Report – July 1, 1964 - June 30, 1965* (University of Toronto, 1965), 84–85.

until at least 1965 was another computer as powerful as the 7090 installed in Canada.[39] By the mid 1960s the Institute of Computer Science was running the 7090 almost to capacity, at 148 of 168 hours per week.[40] Elsewhere in Canada, most other universities with serious computing programs operated the less powerful and less expensive IBM 7040 (or 7044). The list includes McGill, McMaster, the University of B.C., Alberta, Saskatchewan, Western Ontario, and Waterloo. Some had excess machine time to sell to local businesses. Other universities with smaller budgets or ambitions were able to get by with an IBM 1620. University user groups for both machines were organized in the mid 1960s.[41] In contrast, Toronto was alone with the 7090, but the Department of Electrical Engineering was additionally able to justify renting a 1620 for itself as early as 1960.[42]

Only a small fraction of the 7090's time used each year could be categorized as computer science, rather than scientific computing. Machine time summaries from this period indicate that computer science research generally used about a tenth of the computer resources, and at times much less. From 1962 to 1965, the Institute of Computer Science used about double that of other universities units, but this included academic and operational uses. When the Institute and Department of Computer Science were divided, the Department of Computer Science used less time than many others. During one twelve month period from 1965 to 1966, astronomy, chemistry, electrical engineering, physics, and the Institute for Aerospace Studies all had higher computer

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[39] Even IBM didn't operate a 7090 in its Canadian data centres, choosing instead to distribute and decentralize its computing power via twenty 1401s across the country and a 7044 in Toronto and Calgary. The first IBM System/360s – IBM's next generation computer – were more powerful than the 7090 but not installed in Canada until the mid 1960s. "Census of Computers in Canada", *The Computer Society of Canada Quarterly Bulletin* 5, no. 4 (June 1965), 15–16.

[40] Institute of Computer Science, *Annual Report – July 1, 1965 - June 30, 1966* (University of Toronto, 1966), 5.

[41] S.D. Baxter, Report on IBM 1620 Atlantic University Users Meeting, 10–11 July 1965, LAC RG77, Volume 393, File 6090–3, Notes on the Assembly of the University Users of IBM 7040/44 Equipment, Held at McGill University, 17–18 June 1965, LAC RG77, Volume 393, File 6090–3.

[42] V.G. Smith to H.G. Conn, 28 January 1960, UTARMS B1999–0025, Box 1, Folder C. It was paired with an IBM 1711 analog-digital conversion unit for use in "establishing techniques for analyzing actual industrial processes in terms of their input and output." Worsley, "News from Southern Ontario", 8.

usage.[43] Chemistry and physics regularly exceeded Computer Science machine time by extremely wide margins. Looking backwards to when the Ferut and IBM 650 were in use, the type of research undertaken then was not much different: scientific computing was always more prevalent than what might be identified as computer science.

At the same time, the IBM 7090 was a catalyst. It was a unifying device for the university, a launching pad for Watson's last manoeuvres before resigning, and its arrival symbolized Toronto joining the growing computer science community more than the 650 ever had. At the inauguration of the new machine President Bissell explicitly pointed out how rare it was for a single, though phenomenally expensive, piece of equipment to bring together so many disciplines.[44] In contrast, Bissell was at that time witnessing the academic decentralization of the University of Toronto as plans were put into action that year to establish satellite campuses at Scarborough and Mississauga, to the east and west of the main St. George campus. Computing was no longer a mere service centre to be treated with indifference, but a vital cog in the academic machine. It was through this interdisciplinary doorway that computer science could enter the university. Both Watson and Gotlieb had argued that a new department was needed to better supervise graduate students conducting computer science research who were otherwise stuck in less welcoming divisions. This reason was used to justify both the Institute of Computer Science and the Department of Computer Science. Yet it was not until 1963 that Gotlieb was finally able to furnish a reasonable depiction of computer science as an independent field of research, worthy of study in and of itself. Anything more specific, however, would have to wait.

The Department of Computer Science did benefit from the 7090 in other ways. It could participate actively in SHARE, and in fact hosted a SHARE conference shortly after the 7090 arrived. The prestige of the most powerful computer in the country was

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[43] That year, other Canadian universities used the 7090 more than the Department of Computer Science. Institute of Computer Science, *Annual Report – July 1, 1965 - June 30, 1966*, 102–103.

[44] President's Notes for Inauguration of the IBM 7090 Computer, 3 October 1962, UTARMS A1971–0011, Box 60, Folder 11.

also valuable to the new department, though to some degree the same could be said of any department at Toronto that used the computer, or the university as a whole. In 1963, IBM reduced its educational discount, prompting the Institute of Computer Science to seek an upgrade to an IBM 7094 Model II before the discount expired. The new equipment would increase the machine's speed by about two and half times, add new machine instructions, and cost roughly $600,000 with the existing discount. It would help the Institute cope with the rising demands, but these technical considerations gave way to another concern when Gotlieb justified it to his superiors. "A first-rate computing facility is of the utmost importance to the University of Toronto ... The arrival of the 7090 has placed us in the very top class of universities with regard to teaching and research in Computer Science. The proposed additions are expensive, but they are necessary to keep us in that class."[45] A brochure that advertised the computer science program specifically highlighted the 7090 as "an excellent facility for research," which "proved most useful in attracting applications from graduate students, and in discussions with prospective faculty members."[46] W.H. Kahan, a founding member of the Department of Computer Science, offered a more specific explanation as to why such an advanced machine was necessary for computer scientists. "I want to work on problems whose solutions, when I find them, will be intensely in demand. This means that I need access to machines the likes of which will be in widespread use only after three to five years have elapsed."[47]

His justification highlights one of the reasons it was important to sever computer science from the computing centre. The two have antagonistic objectives: while the first should be actively pushing the boundaries of the latest hardware and programming systems, the latter must be conservative to maintain the most reliable computing environment. After all, a university computing centre had many demands: faculty

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[45] C.C. Gotlieb to F.R. Stone, 18 July 1963, UTARMS A1971–0011, Box 77, Folder ICS.

[46] Computer Science, 1962, UTARMS A1970–0013, Box 2, Folder 3; and Institute of Computer Science, *Annual Report – July 1, 1965 - June 30, 1966*, 5–6.

[47] W. Kahan to G. de B. Robinson, 1968, UTARMS B2002–0003, Box 2, Folder 2.

and graduate students conducting research, inexperienced undergraduate students learning how to program, an administration increasingly interested in shifting payroll and scheduling from paper to computerized ledgers, and external programmers from other universities, businesses, and government laboratories purchasing machine time.[48] Once divided the two university units would be better able to pursue their own objectives in an independent and autonomous manner. A computer science department could focus on research and teaching and be unconcerned with the daily grind of maintenance and upkeep. These were the proper duties of an computing centre staff equally unconcerned with the academic responsibilities of research and teaching.

Of course, this is an idealized presentation, and even when departments of computer science were created in the 1960s, the separation was rarely clean. The director of a computing centre was often a faculty member, and programmers were often graduate or undergraduate students. At Toronto, Gotlieb chaired both the Institute of Computer Science and the Department of Computer Science until 1967, and several of the Institute staff members were hired from the ranks of the student body.[49] In 1963, twelve of the fifteen Canadian universities that responded to an international survey of university computing facilities had a director who was also at least an assistant professor of engineering, physics or mathematics.[50] Of course, a university computing environment was different from a corporate data processing department or a scientific laboratory.[51] A director of an academic computing centre should be intimately

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[48] Calvin C. Gotlieb, "How Many Computers per University?", in Finerman, *University Education in Computing Science*, 93–104.

[49] One example is Joe Csima, who worked intermittently on his doctoral dissertation under three different supervisors and worked in the Computation Centre (and Institute of Computer Science) between 1959 and 1965. C.C. Gotlieb to J.E. Gordon, 21 February 1964, UTARMS A1970–0013, Box 2, Folder 3.

[50] Keenan, "Sixth Survey of University Computing Facilities".

[51] In the 1960s there were a number of papers and workshops devoted to the analyzing a universities' unique computing needs and characteristics. See Robert F. Rosin, "Determining a Computing Center Environment", *Communications of the ACM* 8, no. 6 (July 1965), 463–468; Jack B. Dennis, "A Multiuser Computing Facility for Education and Research", *Communications of the ACM* 7, no. 9 (September 1964), 521–529; and much of Finerman, *University Education in Computing Science*, 215–229.

familiar with the needs of their campus. Detailed knowledge of the computer related curriculum and research was necessary to provide a conducive environment for inexperienced and experienced programmers alike. In the early 1960s, there were too few qualified individuals that such dual-roles were not only common but commonsense.

Yet in his 1959 article, Fein made clear that this separation was necessary. One result of many American universities' mad rush to acquire computers in the late 1950s – sparked in part by manufacturers' educational discounts – was that their computing centres were often forced to sell machine time to break even on their operations rather than focus on research or teaching. Until universities could reorient and wean themselves from the service income to encourage more traditional scholarly pursuits in computing, a distinct computer science department would be impossible. Only when the two roles of operations and academics were parted could both thrive.

In the second half of the 1960s there were signs at Toronto that Fein's premise was correct. If there was a disadvantage of having the biggest and busiest academic computing program it was the danger of over-extension and exhaustion. One of the problems was that Gotlieb was still the head of both the Institute and Department of Computer Science.[52] It was not until half way through 1967 that he resigned as head of the department, so that a new administrator could give their "undivided attention to such important tasks as faculty recruitment, selection of students, and development of new courses."[53] He would hold his position as Director of the Institute, where he faced several battles that needed his undivided attention.

One of the battlegrounds was the ambitious Dispatcher Project, launched in 1965. The plan was to expand the University of Toronto computing facilities with an IBM 360 Model 50 that would connect the main 7094 II to various remote terminals scat-

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[52] Gotlieb was busy with extra-curricular duties as well. In particular, he continued his editorial duties for the ACM until 1968. Around this time he was also heavily involved with the Government of Ontario and its attempt to establish regional academic computing centres, rather than have grant each university the funds to purchase their own system. Unsurprisingly, few universities supported this plan and Gotlieb recommended to the government that the plan be scrapped, which it was.

[53] C.C. Gotlieb to E. Sirluck, 22 June 1967, UTARMS B2002–0003, Box 1, Folder 3.

tered strategically across the St. George campus, Scarborough College, Erindale College, and York University.[54] Despite the potential for a time-sharing arrangement, it remained a batch oriented system, with jobs flowing from the terminals to the 7094 for processing and back. Some terminals would be a keyboard connected directly to the main computer, but the plans included half a dozen IBM 360 Model 20 computers as well.[55] It is not the place of this dissertation to evaluate the Dispatcher Project, but it would suffice to say that it was not immediately successful. The causes were many but above all the use of the campus computing facilities had been doubling roughly every two years, and the equipment could not keep up with the demand. By 1968, a petition was circulating among University of Toronto faculty and staff, seeking signatures from "fellow sufferers from the appalling service provided by the Institute of Computer Science."[56] Rationing of departmental computer time was implemented, and at one point Toronto was forced to turn to the University of Waterloo for extra computer time on their IBM 360, and for help with a more efficient and appropriate FORTRAN compiler.[57] By this time, the Dispatcher Project was an out-of-date solution that had "already been overtaken by other schemes." A centralized computing scheme was no longer viable for the largest university in Canada. An interesting consequence of Toronto's size was that as the only Canadian school with an IBM 7090, it could not make use of WATFOR, unlike virtually every other major Canadian university with an IBM 7040. In other words, it was lonely at the top.

Thomas Hull took the reins as chair of the Department of Computer Science from Gotlieb, and unhindered by the operational concerns that faced his predecessor he was able to expand the department with a strong faculty, particularly along theo-

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[54] Institute of Computer Science, Facilities for Remote Computing, Dispatcher System, March 1966, UTARMS A1977–0020, Box 41, Folder CS.

[55] Institute of Computer Science, Proposed Terminals of Dispatcher System, 1966, UTARMS A1977–0020, Box 41, Folder CS.

[56] W. Kahan to G. de B. Robinson, 1968, UTARMS B2002–0003, Box 2, Folder 2.

[57] C.C. Gotlieb to Chairmen of All Departments, 10 March 1967, UTARMS A1970–0013, Box 3, Folder 5, and C.C. Gotlieb to J.W. Graham, 2 October 1967, UTARMS A1970–0013, Box 3, Folder 5.

retical lines.[58] A numerical analyst who had spent two summers at Stanford, Hull was well connected with the computer research community, instead of the computer management side, to which Gotlieb was closer. Perhaps Hull's most famous recruit was Stephen A. Cook, who left the University of California, Berkeley in 1970 for Toronto. Cook wrote the famous 1971 paper "The Complexity of Theorem Proving Procedures", which introduced the theory of NP completeness.[59] For this work, Cook received the highest recognition of computer science, the A.M. Turing Award, in 1982.[60]

6.3 The Promise of Computer Science

Hull was also able to shepherd the new undergraduate program into place in 1971, roughly one quarter of a century after the Committee on Computing Machines first investigated modern computing devices. Roughly one quarter century after that, the Department of Computer Science was one of the largest at the University of Toronto; at the end of the millennium, there were over 3000 undergraduate students, 300 graduate students, and 60 faculty members.

The same year the Department of Computer Science was created, the Computing and Data Processing Society of Canada held its Fourth National Conference at the University of Ottawa. The keynote speaker was J.N.P. Hume, who began by characterizing the theme of the CDPSC conferences.[61] The first in 1958 was "We must get a

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[58] Unfortunately, this was at the same time that Kahan would leave for University of California, Berkeley. Ironically, Hull would steal one of Berkeley's rising stars back to Toronto a few years later.

[59] Stephen A. Cook, "The Complexity of Theorem-Proving Procedures", in *Proceedings Third Annual ACM Symposium on Theory of Computing* (May 1971), 151–158.

[60] The award citation reads: " For his advancement of our understanding of the complexity of computation in a significant and profound way. His seminal paper, 'The Complexity of Theorem Proving Procedures,' presented at the 1971 ACM SIGACT Symposium on the Theory of Computing, laid the foundations for the theory of NP-Completeness. The ensuing exploration of the boundaries and nature of NP-complete class of problems has been one of the most active and important research activities in computer science for the last decade."

[61] Hume, "The Promise of Computer Science", 3–8.

computer", the second in 1960 was "Must we get a computer?", and the third in 1962 was "Well, the payroll is working, now what?" The excitement surrounding relatively cheap and reliable computers of the late 1950s had given way to caution that could only come with experience, and followed by a mixed sense of relief, satisfaction and anticipation. The fourth and current conference had an official theme, "Computers: Challenge of the Future"; Hume interpreted this as "We have only begun to fight". His talk, from which the title of this chapter has been borrowed, "The Promise of Computer Science", was a defence of computer science. The original title had been "The Premise of Computer Science", which the program committee correctly altered to be "more appropriate to the theme of the Conference." To them, there was yet no premise, nothing that could be taken for granted when it came to computer science. It was new and undefinable. Hume agreed, noting that Canadian universities were only just beginning to recognize computer science with new departments or special divisions, so computer science could only be discussed in the future tense.

Hume was plainly optimistic about that future. His talk contained many visions, some useful and others fanciful. He concluded with a anecdote about his personal interactions with students as he anticipated a day when a computer could interact with a person the same way. Through the admitted jumble of thoughts and words, Hume shed light on the state of computer science and two things relevant to this dissertation. First, that the new discipline should be just that, new. Only unencumbered by the demands of other disciplines could it succeed. Second, even in his imaginative and far fetched examples, Hume was throwing down a gauntlet for those who would be computer scientists. He claimed that the discipline could only be distinguishable from others and worthy of regard if computer scientists could bring computers closer to the ordinary man. He believed they had to demonstrate that computers were neutral tools that could be used for bad or good. Just as physicists had unlocked the power of the atom to negative and positive consequences, the value of computers lay in their use, not their existence. It was the primary responsibility of a computer scientist to master the use of their tool so that it could be available to mankind.

To repeat Hume's words that opened this chapter: "Computers are an essential tool in much fundamental research in other fields. All students of science should be at home with them. But there must be a group of students who see in computer science an exciting new field of intellectual stimulation. For in them will rest the promise of computer science."[62]

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[62] Hume, "The Promise of Computer Science", 7.

Appendix A

A Short Primer on Using UTEC

This appendix serves two purposes. The first is to provide a more thorough explanation of the design and operation of the UTEC Mark I prototype than was presented in chapter 2. The second purpose is to explore the only UTEC code known to exist, and provide a transcription of selected examples. As the only surviving code written in Canada by Canadians for the first Canadian electronic digital computer it deserves preservation, and in doing so bestows light on how UTEC could have been used for practical computation, limited as it was.

A.1 Design and Operation of UTEC

After the UTEC project ended and the final demonstration was held at the ACM meeting in September 1952, the remnants of the machine were eventually dismantled and it is believed that any valuable parts were cannibalized or sold for scrap. No physical component of the UTEC project larger than a vacuum tube is known to have survived. Extant documentation is also limited. Few formal design documents or blueprints were preserved by University of Toronto staff, and many of those held by private individuals were lost to the normal ravages of over-exuberant housecleaning. The situation is not helped by the fact that there has been no contact by historians or archivists with Ratz since he left the project and academia in 1952. Within the University of Toronto Archives, there exists a single relevant box of material collected primarily by Gotlieb. The box contains progress reports, the occasional diagram and plans, but no blueprints.[1]

That said, there are several publications with comprehensive descriptions of UTEC. The first can be found in the proceedings of the 1952 ACM meeting. The meeting delegates were given a demonstration of UTEC, and R.F. Johnston, who was primarily responsible for the input and output design and implementation, wrote an article summarizing the purpose, operation, circuitry, and use of UTEC.[2] The other important text to depict UTEC is Gotlieb and Hume's 1958 *High-Speed Data Processing*. Following several chapters that explain the functional units of a modern computer, the authors select UTEC as an example of an"extremely primitive machine" that can be examined as a whole, a discussion that occupies only five pages.[3] While these two sources provide details concerning the design and operation of UTEC, a third offers an intriguing look into what it was like to write programs for UTEC. B.H. Worsley, a staff member of the Computation Centre throughout its entire existence, wrote the bulk of her doctoral dissertation at Cambridge, but completed writing in 1952 in Toronto.[4] It included a comparison of the EDSAC, the Manchester Mark I, and UTEC, though she was less concerned with the hardware than the preparation of programs for each machine. Her program examples will be presented in a later section. Unfortunately, although it is known that several UTEC reports describing multiword arithmetic subroutines were written, they cannot be located. The reports were not published but had limited circulation internally among the UTEC team members. Fortunately, the two people most responsible for the design and construction of UTEC, J. Kates and A.G. Ratz, also wrote doctoral dissertations related to the computer research under-

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[1] UTARMS B1988-0069, Box 01.

[2] Johnston, "The University of Toronto Electronic Computer", 154–160.

[3] Gotlieb and Hume, *High-Speed Data Processing*, 67.

[4] Worsley, "Serial Programming for Real and Idealized Digital Calculating Machines".

taken during the project. Kates' subject matter – his own theory of the operation of Williams tubes – is only peripherally related to the operation of UTEC as the particular tubes were not used on the prototype, but Ratz's dissertation provides an important glimpse into his thinking regarding the design of UTEC, and the arithmetic unit in particular.[5]

Unfortunately, recreating a complete understanding of UTEC is impaired by the prototype nature of the machine. Some specifications were relatively inflexible, but others changed frequently as various ideas and hardware components were tested. For example, the design of the parallel primary store implied that 12 bit word size was more or less invariant, but there were difficulties with the actual implementation of the Williams tubes. Although the plans called for a 512 word store, only 256 words (the even numbered storage locations) were available most of the time. More important, the instruction set was changed several times to accommodate lessons learned in the testing phase. Other modifications and improvements, less critical to the overall logical design but important nonetheless were frequent and common, as befitting an experimental prototype. Power supplies were changed, different vacuum tubes and storage tubes were used at different times, and an attempt was made in mid-1952 to add a magnetic tape system for auxiliary storage. Thus there is no singular and definitive description of UTEC, but by combining the various sources it is possible to arrive at an approximation.

UTEC was a parallel, binary, one-address digital computer.[6] Physically, it had about 800 vacuum tubes, and stood approximately six feet high, eight feet wide, and one foot deep. Twelve Williams tubes operated in parallel to provide 512 words of storage. UTEC used a 12 bit word, of which 3 bits specified one of eight instructions

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[5] Kates, "Space Charge Effects in Cathode-Ray Storage Tubes" and Ratz, "The Design of the Arithmetic Unit of an Electronic Digital Computer".

[6] For an introduction to the principles of computer architecture, the reader is encouraged to consult the early chapters of Gotlieb and Hume, *High-Speed Data Processing*, or for a more historically nuanced approach, Ceruzzi, *A history of modern computing*, 58–64.

and 9 bits pointed to the address – when the store was not working properly and only 256 bits were available, 8 bits were used to indicate the storage location. Otherwise, the 12 bit word referred to a signed 11 bit number, or about 3 decimal digits.

Input and output on the completed prototype was handled with modified six-hole Flexowriter paper tape equipment. In general, only four of the six holes held significant data. Both octal and binary coded decimal (BCD) numbers could be used to represent a word. In the former case, four rows of octal were used – one row for the instruction and three for the location – while in the latter case, three rows of BCD represented a single three digit number. Special symbols such as Stop Input or Decimal Input did use all six holes.[7] A switch on the control panel toggled between octal and decimal output.

The basic operation of UTEC depended on a handful of registers and counters: the 12 bit accumulator and 12 bit arithmetic register for arithmetic, the 9 bit control counter – similar to a program counter in today's terminology – which pointed to the storage location of the next instruction, the control register which held the instruction as it was decoded, and the 12 bit storage register for temporary storage during transfers to and from the accumulator, store, and input-output. The basic machine cycle was split into four periods, named A, B, C, and D. Each period required 30 microseconds and so a full clock cycle was 120 microseconds long. During A time, the control counter is read to determine the location of the next instruction. In period B, the instruction itself is read from the store into the control register and the control counter is incremented to point to the next instruction. In the C time, the instruction in the control register is decoded and in D time the instruction is carried out. To provide program branching, some instructions modified the control counter to point to a specific storage location and instruction rather than one sequential to the last.

As work on UTEC progressed, several different instruction sets were used. Table

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[7] Johnston, "The University of Toronto Electronic Computer", Figure 9.

A.1 contains a full set of the twelve different instructions proposed or implemented; as a maximum of eight could be used at any one time, the last five columns indicate approximately when each instruction was in use. The initial set was described in a September 1951 progress report (column 1951).[8] The set was not considered complete or optimal in anyway, but intended instead for testing purposes. In particular, it was expected that instructions T and U (transfer accumulator contents and unconditional transfer of control) would be replaced at a later time by more useful ones. By way of comparison, the Manchester SSEM initially had only seven instructions in June of 1948.[9] Though it and the 1951 UTEC set were similar in purpose, there were a few significant differences. The most obvious is that SSEM lacked input and output instructions, in all likelihood because at that point the Manchester prototype lacked input and output devices accessible to a programmer. Instead, this activity was accomplished by hand and visually. Difficulties getting the UTEC input and output tape system working may help explain why this practice was also adopted in Toronto and why both instructions were subsequently dropped until the end of 1952.

Worsley's dissertation includes a snapshot of the instruction set (column 1952a).[10] Though she finished writing around May 1952, her version of the instruction set and account of UTEC's features indicate that her familiarity with the machine began sometime prior to March 1952. At that time, "several relatively minor modifications were undertaken . . . to make the Model a more satisfactory computing instrument" including "a more useful set of orders" (column 1952b).[11] The changes to the UTEC instruction set since September 1951, including those described by Worsley in March 1952, are directly related to increased experience using the machine and writing programs.

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[8] Computation Centre Progress Report, October 1, 1950 to September 30, 1951, UTARMS B1988–0069, Box 1, Folder 2.

[9] Napper, "The Manchester Mark 1 Computers", 367.

[10] Worsley, "Serial Programming for Real and Idealized Digital Calculating Machines", 44.

[11] Computation Centre Progress Report, 1 January 1952 to 31 March 1952, UTARMS A1968–0007, Box 110, Folder 4. Worth noting is that these modifications took place after the decision was made to acquire the Ferranti Mark I and cancel the full-scale UTEC plans.

The input and output instructions were removed temporarily as these could be performed manually at the console until the tape reader and writer were operating more consistently. Until then, an output instruction was reserved and a halt instruction was added. More important was the introduction of the K instruction, which transferred the contents of the accumulator to storage without the sign bit, which was instead put in the least significant position of the accumulator. Though it was not functioning for Worsley, it was in effect, a carry mechanism to facilitate multiple word arithmetic. With UTEC's 12 bit word and small store, this was essential for non-trivial computations as it "materially shortens most routines."[12] Worsley's notes make clear that multiple word arithmetic subroutines had been written by this time, though the details and code do not seem to have survived. By September 1952 (column 1952c) and the ACM meeting, the input and output instructions were operating.

Gotlieb and Hume provide the final UTEC instruction set in their book (column 1958), though they warn that "different combinations of instructions were tried to see how the programming was affected, but for the purposes of this description the instruction code [below] will be assumed."[13] There is one large difference between this set and all 1952 sets: the removal of the K instruction and the gain of the R instruction, which shifted the contents of the accumulator to the right one bit. In any number notation, a right shift is the same as dividing by the base; in this case it divided the accumulator by 2. As UTEC lacked a multiplication or division instruction, the R instruction would have dramatically improved the speed of those programs that could take advantage of it. However, it is not clear if the instruction was implemented for UTEC, or if it is merely an example intended for the book. A block diagram included by Gotlieb and Hume shows clearly how it could have been supplied, but unless changes were made to the adder hardware, the K instruction would have been substantially more useful.

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[12] Johnston, "The University of Toronto Electronic Computer", 154.
[13] Gotlieb and Hume, *High-Speed Data Processing*, 68.

Table A.1: UTEC Instruction Sets

Instr.		Description	1951	1952a	1952b	1952c	1958
A	s	Add the contents of s into the accumulator	⋆	⋆	⋆	⋆	⋆
S	s	Subtract the contents of s from the accumulator	⋆	⋆	⋆	⋆	⋆
T	s	Transfer the contents of the accumulator to s	⋆	⋆			
t	s	Transfer the contents of the accumulator to s and clear the accumulator to zero	⋆	⋆	⋆	⋆	⋆
R		Shift the contents of the accumulator right one bit					⋆
K	s	Transfer $0a_1a_2\ldots\ldots a_{11}$ to s and clear accumulator to $00\ldots\ldots 00a_0$		(⋆)	⋆	⋆	
C+	s	Conditionally transfer control to s if the contents of the accumulator ≥ 0		(⋆)	⋆	⋆	⋆
C-	s	Conditionally transfer control to s if the contents of the accumulator < 0	⋆	⋆			
U	s	Unconditionally transfer control to s	⋆	⋆	⋆	⋆	
I	s	Input one word from the paper tape to s	⋆			⋆	⋆
O	s	Output the contents of s onto paper tape	⋆		⋆	⋆	⋆
H		Halt			⋆		⋆

Notes: – s is a storage location
– the 12 bits of the accumulator are $a_0a_1a_2\ldots\ldots a_{11}$
– (⋆) indicates an instruction that was not working at the time.

A.2 Programming UTEC

In various UTEC reports, references were made to routines that computed e^{-x}, $\sqrt{x}$, and even the elliptic integral defined by:

$$K = \int_0^{\Pi/2} \frac{d\Phi}{\sqrt{1 - msin^2\Phi}}$$

but code for these examples cannot be located. Furthermore, it is known that subroutines to handle multiple word arithmetic were conceived of at least as early as 1950, and eventually implemented during the testing phase of the machine. Although the routines did not survive (or cannot be located), a timing table for mathematical operations employing one to four words has been reproduced as table A.2.[14] Thus UTEC could compute with accuracy as high as 13 decimal digits, which was comparable to

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[14] Johnston, "The University of Toronto Electronic Computer", 160.

Ferut, but under those conditions was considerably slower than the British computer. Yet on a more level playing field, if a program did not resort to multiple word subroutines, UTEC was faster thanks to its parallel architecture.

Table A.2: UTEC Multiple word mathematical operations

	Word Extent							
	1		2		3		4	
Operation	n	Time	n	Time	n	Time	n	Time
Addition	2	240 μsec.	6	720 μsec.	9	1.1 msec.	12	1.4 msec.
Subtraction	2	240 μsec.	8	950 μsec.	15	1.6 msec.	18	2.2 msec.
Multiplication	2	18 msec.	42	70 msec.	56	120 msec.	70	260 msec.
Division	34	36 msec.	58	120 msec.	80	300 msec.	100	500 msec.
Complement	1	120 μsec.	6	720 μsec.	10	1.2 msec.	14	1.7 msec.
Modulus	4	480 μsec.	10	1.2 msec.	14	1.7 msec.	18	2.2 msec.
Square Root	36	200 msec.	57	2 sec.	80	5 sec.	100	14 sec.
Zero Test	6	720 μsec.	10	1.2 msec.	14	1.7 msec.	18	2.2 msec.
Input Decimal		400 msec.		800 msec.		1.2 sec.		1.6 sec.
Input Conversion	120	100 msec.	150	140 msec.	170	200 msec.	215	250 msec.
Output Decimal		400 msec.		800 msec.		1.2 sec.		1.5 sec.
Output Conversion	75	16 msec.	100	45 msec.	125	120 msec.	150	250 msec.

n refers to the number of instructions.

A.3 B.H. Worsley's UTEC Code

B.H. Worsley was one of the first two employees of the Computation Centre (the other was J.P. Stanley), hired in January 1948 by B.A. Griffith to operate the IBM 602A he had recently rented. Both attended training sessions organized by IBM on the operation of the 602A and were involved in the use of the punched card calculator at Toronto. In the fall of that year, Worsley travelled to the University of Cambridge to study the ongoing EDSAC project as work began on UTEC. Stanley followed her to Cambridge shortly later. Neither the NRC or DRB had approved of these junkets, but both were permitted to stay until EDSAC was operational the following spring. Not long after, Stanley returned with a table he had computed on EDSAC, but Worsley remained, now registered as a Ph.D. student at Newnham College of the University of Cambridge, supervised by D.R. Hartree.[15]

Her dissertation, "Serial Programming for Real and Idealized Calculating Machines", presented several numerical solutions to scientific problems (which she had solved with EDSAC) but was preoccupied by the notion of an "optimum basic universal digital machine."[16] That is, she hoped to discover a general set of computer instructions that could be implemented universally and optimally. As part of her study, she compared the three physical computers with which she was most familiar: the EDSAC, the Manchester Mark I, and UTEC. A description of each machine was provided, including physical characteristics, the preparation of programs, and noteworthy idiosyncrasies. This was followed in the first appendix by several programs written for all three machines, some trivial in nature but others significantly more complex.

A selection of her UTEC programs will now be presented, using instruction set 1952a. First, a short review of her notation:

a	the octal number 'a'
(a)	the storage location 'a'
C(a)	the contents of storage location 'a'
Acc.	the accumulator

At the time she wrote these programs, the odd numbered storage locations were not available, nor were the K and C+ instructions. Instead, the C- instruction was used, being nearly equivalent to the latter, and the K instruction is irrelevant to her examples.

A standard convention using four columns was used to transcribe the programs to paper. The first column from the left indicates the storage location; a number on the extreme far left is the entry point of a control transfer. The instruction code, or data, is

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[15] The conflicts sparked by these incidents are described beginning on page 122.

[16] Worsley, "Serial Programming for Real and Idealized Digital Calculating Machines", 133.

in the third column between the vertical lines. If enclosed in brackets, this value will be modified by the program as it runs. The fourth column contains comments.

A.3.1 Short Example

This short, nearly trivial, four line program puts |C(004)| in (004), computing the absolute value.

```
        100 | S    004 | -C(004) to Acc.
        102 | C-   106 | test sign
        104 | t    004 | -C(004) to (004) if C(004) < 0
102 →   106 | t    002 | clear Acc.
```

In line 100, the contents of location 004 are subtracted to the accumulator (it is assumed in advance that the accumulator is clear). If the contents of the accumulator are negative – C(004) was a positive number – line 102 causes program control to transfer to line 106 and end the program. If the accumulator is positive – C(004) was negative – then transfer the positive (and absolute) value in the accumulator to location 004, and end the program.

Unsurprisingly for such a straightforward operation, the EDSAC and Mark I programs are similar. All three are four lines long and the EDSAC code is functionally identical to the UTEC.

A.3.2 Extended Arithmetic Example

This longer example computes x^{1024}; x is assumed to be stored in location 004, and the result is also placed in location 004. Notably, this code uses a subroutine to handle the multiplication, which will be explained shortly.

```
        100 | S   202 |  } Set counter
126 →   102 | t   002 |  }
        104 | A   004 |  }                       }
        106 | T   160 |  } Replace C(004)        }
        110 | t   162 |  } by C(004)², using     }
        112 | A   112 |  } multiplication        }
        114 | U   156 |  } subroutine            }  Cycle
        116 | A   164 |  }                       }  ten
        120 | t   004 |  }                       }  times
        122 | A   002 |  }                       }
        124 | A   200 |  } Count                 }
        126 | C-  102 |  } and test              }

        200 | A   001 |  } Assume
        202 | A   012 |  }
```

Simply put, this routine computes x^2 10 times, producing x^{1024}. In greater detail, lines 100 and 102 prepare a counter so that the main body, lines 104–120, will cycle 10 (012 in octal) times, a number set in line 202. The cycle is controlled in lines 122–124: the first two of those lines decrements the counter by 1 and line 124 re-enters the cycle unless the counter equals 0. To compute x^2 in each cycle, the main body places x in storage location 160 and 162. These are two special locations, hard coded into the multiplication subroutine to contain the multiplier and multiplicand. The subroutine is stored from location 156 to 306, and is entered using what appears to be a Wheeler jump on lines 112 and 114, though no actual subroutine code exists making verification impossible. The Wheeler jump was well known by the 1950s as one of the most efficient means of enter and return from a subroutine. According to Worsley, the subroutines that existed for UTEC were all of the 'closed' type, a term derived from EDSAC usage. A closed subroutine was input into storage only once, generally at the end of the main program, and called by the main program whenever needed by a special calling sequence, in this case a Wheeler jump.[17] The subroutine used in this case put the product of the multiplication into location 164, which was transferred

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[17] A closed subroutine would have been placed within the main body of the program. For more on EDSAC subroutines, see Campbell-Kelly, "Programming the EDSAC: Early Programming Activity at the University of Cambridge", 17–18.

back to location 004 on line 120 so that the next cycle could begin, if necessary.

As both EDSAC and the Mark I had a multiplication operation implemented in hardware, Worsley's versions of the program for those machines was slightly shorter, not having to use a subroutine, although the flow of all three was similar. The EDSAC code is again functionally identical to that of UTEC, while the Mark I code makes appropriate use of one of the B-lines to count the cycles.

Appendix B

TRANSCODE and the TPK Algorithm

In the late 1970s Donald E. Knuth and Luis Trabb Pardo surveyed about twenty of the world's first "high-level" programming languages.[1] Their study begins with Zuse's 1945 Plankalkül, and continues though the evolution of symbolic and algebraic programming languages from Europe and North America, stopping short of the explosive growth in the field in the late 1950s. Though their survey includes the first FORTRAN, and several of its direct ancestors, other languages such as ALGOL and COBOL are left out, best considered derivatives of this initial period.

Studying and comparing some twenty languages in a single article is an unwieldy task, to say the least. Working from the assumption that "the best way to grasp the spirit of a programming languages is to read example programs," they conceived a fixed algorithm that could be expressed in each language they discussed. Known as the TPK algorithm, after their initials, it did nothing of particular computational value but was an attempt to capture the essence of a language, if not all of its capabilities.[2] Armed with such a template, they could quickly demonstrate some of the most common programming structures such as loops, conditionals, and arithmetic.

In figure B.1 we can see the algorithm expressed in a dialect of ALGOL 60. This

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[1] Knuth and Pardo, "The Early Development of Programming Languages", 197–274.

[2] Aside from their initials, TPK also implied 'typical'.

```
1 TPK:  begin integer i;  real y;  real array a[0 : 10];
2          real procedure f(t);  real t;  value t;
3            f  := sqrt(abs(t)) + 5 × t ↑ 3;
4          for i := 0  step 1  until 10  do read(a[i]);
5          for i := 10  step -1  until 0  do
6            begin y  :=  f(a[i]);
7            if y  >  400  then write(i, ''TOO LARGE'')
8                              else write(i,y);
9            end
10      end.
```

Figure B.1: The TPK algorithm in ALGOL 60.

language was chosen as an international standard that would be familiar to all readers, a Rosetta Stone of a sort. Its arbitrary purpose is to compute the function $f(t) = \sqrt{|t|} + 5t^3$. This is a useless function, but reasonably demonstrates a few arithmetic features. In line 4, eleven constant values are read in, and line 5 starts looping through lines 6, 7, and 8. The values are computed in the reverse order (10,9,8,...,0), and through each iteration of the loop, the algorithm prints out the current iteration and the result of computing the function for the values read in. If the result is greater than 400, it prints the words "TOO LARGE" instead. See figure B.2 for a suggested table of data and suitable results. Because many of the languages of the period could not handle alphabetic output, "TOO LARGE" could be replaced by the number 999.

Knuth and Trabb Pardo's article includes a lengthy examination of Glennie's first automatic programming system for the Ferranti Mark I, AUTOCODE, and a 32 line implementation of the TPK algorithm in AUTOCODE. However, it is believed that computer historian Martin Campbell-Kelly has written a more historically accurate implementation. For example, if a language lacked floating-point capabilities, Knuth and Trabb Pardo used integers, and did so with their example. Campbell-Kelly includes a scaling routine that was available to handle the real arithmetic, which is a more reasonable assumption for language intended to handle scientific computation.

Input	Output	
1.5	10	0.04472
8.0	9	0.03162
-6.0	8	999
9.5	7	-44.85586
2.3	6	47.75414
9.9	5	999
2.1	4	62.35158
-2.1	3	999
6.0	2	-1077.55051
0.001	1	999
-0.002	0	18.09974

Figure B.2: TPK test data and expected results.

Because AUTOCODE was not particularly influential and never found outside of Manchester, a TPK routine is not included here. However, Brooker's Autocode was influential and the TPK algorithm in B.3 as written by Campbell-Kelly is more appropriate.[3] Though there is no connection between Autocode and TRANSCODE in terms of influence, comparing the two is a valuable experience as the two successful automatic programming systems for the Ferranti Mark I.

As the reader will note, Autocode was an algebraic language, and easy to follow, even for a beginner. Floating point variables are called $v1, v2, v3, \ldots$, and integer variables – or index variables – are $n1, n2, n3, \ldots$. The entire program was read into the computer, and started when it reached the final instruction ($j1$), which jumped to line 1. The similar $j3, 11$ is a looping instruction to handle eleven iterations. The arithmetic is handled on lines 7–12, demonstrating the use of F to external functions, in this case absolute value and square root. As Autocode could not print alphabetic output, 999 is output if the result of each calculation is greater than 400. The output of this program, as indicated by Campbell-Kelly, can be seen in figure B.5.

Finally, an implementation of the TPK algorithm in TRANSCODE is listed in figure

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[3] Campbell-Kelly, "Programming the Mark I: Early Programming Activity at the University of Manchester", 162.

	Program			Notes	
1	$n1$	$=$	1		cycle 11 times
3	$vn1$	$=$	I	inputs a_i	
	$n1$	$=$	$n1 + 1$		
	$j3, 11$	$\geq$	$n1$	tests for last cycle	
	$n1$	$=$	11		
2	$*n2$	$=$	$n1 - 1$	print i	cycle 11 times
	$v12$	$=$	F6($vn1$)	$v12 = \sqrt{\|a_i\|}$	
	$v12$	$=$	F1($v12$)		
	$v13$	$=$	$5 \otimes vn1$	$v13 = 5a_i^3$	
	$v13$	$=$	$vn1 \otimes v13$		
	$v13$	$=$	$vn1 \otimes v13$		
	$v12$	$=$	$v12 + v13$	$y = \sqrt{\|a_i\|} + 5a_i^3$	
	$j4, v13$	$>$	400		
	$*v12$	$=$	$v12$	prints y	
	$j5$				
4	$*v12$	$=$	999	prints 999	
5	$n1$	$=$	$n1 - 1$		
	$j2, n1$	$>$	0	tests for last cycle	
	H			halts	
	($j1$)			starts programme	

Figure B.3: The TPK algorithm in Brooker's Autocode.

	Program				Notes
	NUMB	input ″			Input values
	DRUM	001			Copy NUMB to track 001
	CNST	5++			
		4+2+			
		999++			
		″			
	INST	017			
001	READ	001.0	000.0	X00.0	Read track 001 to X01 page
002	LOOP	011.0	000.6	000.0	Set B6 to count down from 11
003	ZERO	Z01.0	000.0	000.0	$0 \rightarrow Z01$
004	KOMP	X11.6	Z01.0	Y01.0	$\lvert(X11.6)\rvert - (Z01) \rightarrow Y01$
005	$\frac{1}{2}$QRT	Y01.0	000.0	Y01.0	$\sqrt{\lvert(X11.6)\rvert} \rightarrow Y01$
006	MULT	X11.6	X11.6	Z01.0	$(X11.6)^2 \rightarrow Z01$
007	MULT	X11.6	Z01.0	Z01.0	$(X11.6)^3 \rightarrow Z01$
008	MULT	C01	Z01.0	Z01.0	$5 \times (Z01) \rightarrow Z01$
009	ADDN	Y01.0	Z01.0	Z01.0	$(Y01) + (Z01) \rightarrow Z01$
010	PRNT	001.1	002.0	Z26.0	Print B6
011	SUBT	Z01.0	C02	Z02.0	$(Z01) - 400 \rightarrow Z02$
012	TRNS	014	000.0	Z02.0	Jump to 014 if $Z02 \geq 400$
013	TRNS	015	000.0	000.0	$X01.6 < 400$, jump to 015
014	OVER	C03.0	000.0	Z01.0	$999 \rightarrow Z01$
015	PRNT	001.1	006.0	Z01.0	Print result or 999
016	TRNS	003.0	000.6	000.0	Jump to 003 if $B6 \geq 0$
017	QUIT	000.0	000.0	000.0	End of code
	ENTR				

Figure B.4: The TPK algorithm in TRANSCODE.

B.4, written by this author, with reference to the TRANSCODE manual.[4] The line numbers and decimal points were omitted when a program was punched to tape. Variables enclosed in parentheses, such as (X01), refer to the contents of address X01. The first instruction, NUMB, is followed by the eleven input values terminated by a " (double quote) character as in figure B.2 that the main loop will iterate through; they are transferred to magnetic drum position 001 by the DRUM instruction. The three CNST lines that follow are the constants C01, C02, and C03 (equal to 5, 400, and 999) necessary for the coefficient of $5t^3$, to test if the result exceeds 400, and the 999 that replaces "TOO LARGE" during output; as with NUMB instruction, the " terminates the list of constants. The next line, INST 017, indicates that 17 instructions follow; the last must be QUIT 000.0 000.0 000.0. Line 001 reads the input values from drum position 001 to the X page positions X01 to X21. In this case, only X01 to X11 are relevant.

The main loop of the program beings on line 002, with the eponymous instruction LOOP, which selects B6, the sixth B-line, as a counter to track the eleven iterations. The matching instruction TRNS on line 016 will automatically decrement B6 and send control back to line 003 until B6 is negative. These two lines cause the program to loop through the inner instructions eleven times. It also gives the programmer the power to index the X, Y, or Z pages on each pass through the loop. For example, X11.6 on the first pass refers to X01, on the second pass X02, and so on until the final pass, when it refers to X11.

The inner instructions perform two tasks. The first is to compute the function $f(t) = \sqrt{|t|} + 5t^3$ for the input values – on each pass through the loop, t is contained in the indexed variable X11.6. First, the Z01 address is set to zero, necessary for the next line. The instruction KOMP X01 Z01 Y01 places |(X01)| - (Z01) into address Y01; thus line 004 computes $|t|$. The square root of (Y01) is placed into address Y01 in line 005.

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[4] Computation Centre, "TRANSCODE Manual".

Lines 006 and 007 compute the cube of *t* and place that result in address Z01; line 008 multiplies the (Z01) by 5, putting the product back into address Z01. Finally the sum of (Y01) and (Z01) is placed back into address Z01.

The second task of the inner instructions is to test and print the final result. Line 010 prints the contents of B6; for output purposes only Z22 to Z26 could be used to refer to the contents of B2 to B6. On the first pass through the main loop B6 holds the value 10. The output of PRNT is a very precise floating-point number: the mantissa (one digit, decimal point, rest of mantissa rounded-off), the mantissa's sign, a space, the two digit exponent, and the exponent's sign. Thus the digit 10 emerges as 1.0+ 01+. If the earlier result is greater than 400, then 999 must be printed instead of the result itself. This logic is handled in lines 011 to 015. First, (C02) is subtracted from (Z01) and places the remainder in Z02. If the remainder is greater than 0, program control is transferred to line 015 where 999 replaces the final result in address Z01 and is printed on line 016; if the remainder is less than 0, transfer control to line 016 and print the earlier result. The output can be seen in the second column of figure B.5.

To the casual observer of these two TPK implementations, Autocode holds several distinct advantages over TRANSCODE. First, with some very straightforward guidance regarding floating-point and integer variables, a programming novice would find a simple Autocode program such as this is much easier to read. The algebraic operations are plain, whereas the three-address notation employed by TRANSCODE would be more familiar to an experienced programmer accustomed to reading and writing programs using machine instructions. Speedcoding, one of the direct inspirations for TRANSCODE also used a three-address notation.[5] Second, the Autocode output is also easier to read, not employing the mantissa and exponent notation. That said, TRANSCODE's PRNT instruction was more flexible than this example demonstrates. It could print multiple columns of consecutive variables; indeed, to most ac-

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[5] Backus, "The IBM 701 Speedcoding System", 4–6.

Autocode	TRANSCODE
+10.	1.0+ 01+
+0.04472	4.47200+ 02-
+9.	9.0+ 00+
+.03162	3.16200+ 02-
+8.	8.0+ 00+
+999.	9.99000+ 02+
+7.	7.0+ 00+
-44.85586	4.48559- 01+
+6.	6.0+ 00+
+47.75413	4.77541+ 01+
+5.	5.0+ 00+
+999.	9.99000+ 02+
+4.	4.0+ 00+
+62.35157	6.23516+ 01+
+3.	3.0+ 00+
+999.	9.99000+ 02+
+2.	2.0+ 00+
-1077.55051	1.077501- 03+
+1.	1.0+ 00+
+999.	9.99000+ 02+
+.	0.0+ 00+
+18.09974	1.80997+ 01+

Figure B.5: Autocode and TRANSCODE TPK output.

curately reproduce the TPK algorithm, the index and result could both have been printed on the same line, but the program would be needlessly complex. The length of the printed mantissa was also flexible.

Autocode makes no reference to the architecture of the Mark I, but TRANSCODE specifically makes use of the B-lines, and to good effect. The automatic looping and indexing features offered by TRANSCODE are relatively sophisticated when compared to Autocode, where the programmer was responsible for implementing these features manually as desired.

Appendix C

Glossary

C.1 Directory of Persons and Committees

Advisory Committee on Scientific Research Established by the University of Toronto President and Board of Governors in 1945 to ensure a continued relationship with the NRC following the war

Andrews, E.G. Built Bell Laboratories relay calculators designed by George R. Stibitz

Ballard, B.G. Head of NRC Radio and Electrical Engineering Division, later NRC Vice-President

Barnes, Colin Physicist and member of Committee on Computing Machines

Baxter, Stuart D. Doctoral student of B.A. Griffith

Beatty, Samuel Dean of the Faculty of Arts & Sciences (1936–1952) and chair of the Department of Mathematics (1934–1952)

Bissell, Claude T. President of the University of Toronto (1958–1971)

Brooker, R.A. Ferranti Mark I programmer at Manchester University, and author of programming guide for the Mark I and Autocode automatic programming system

Buchholz, Werner Former student of V.G. Smith, and as member of IBM's Project Stretch coined the term byte

Bullard, Edward C. Geophysicist, chair of the Department of Physics, chair of the Committee on Computing Machines (1948–1949)

Casciato, Len UTEC technician working under Josef Kates, and co-founder of KCS Data Control

Committee on Computing Machines Established in 1945 by S. Beatty to visit computing centres in the US, and recommend a course of action for Toronto regarding modern computing machines; when the first federal grants arrived to establish the Computation Centre, it became an oversight committee

Computation Centre Advisory Committee Two Computation Centre Advisory Committees replaced the Computation Centre Committee in 1962: (Administrative) was to oversee policy and budgets, while (Programming) was more concerned with daily operations

Computation Centre Committee Under K.F. Tupper, the Committee on Computing Machines was reformed (with minimal membership changes) into the Computation Centre Committee in 1950, to better provide oversight regarding the activities of the Computation Centre

Computation Centre Joint Committee Ottawa-based committee whose members were top-ranking NRC, DRB, and Toronto administrators; its primary responsibility was the federal capital and annual grants that allowed the Computation Centre to purchase Ferut and the IBM 7090 and to operate year to year

Court, G.L. Comptroller, University of Toronto

Davies, E.L. Vice-chairman of the DRB

DeLury, D.B. Chair of the Department of Mathematics (1958–1968)

Doeringer, E. Summer student and early UTEC contributor

Field, G.E. Chief Scientist, DRB

Fraser, W. DRB representative and Ferut programmer in the Computation Centre

Gellman, Harvey S. Doctoral student of E.C. Bullard, Computation Centre mathematician, and founder of H.S. Gellman and Co., one of Canada's first computing consulting companies

Gillies, Donald B. Computation Centre summer student of 1949 helped write multiple word mathematical routines for UTEC

Glennie, A.E. Ferranti Mark I programmer at Manchester University, and author of AUTOCODE automatic programming system (precedes Brooker's Autocode)

Gordon, Andrew R. Head of the Department of Chemistry and Dean of the School of Graduate Studies

Gotlieb, Calvin C. Physicist, Acting Director and Chief Computer of the Computation Centre, Director of the Institute of Computer Science, and Chair of the Department of Computer Science

Griffith, Byron A. Statistician, most active early member of Committee on Computing Machines, and instigator of statistics laboratory that became Computation Centre

Hart, J.F. NRC representative and Ferut programmer in the Computation Centre, and founder of the Department of Computer Science at UWO

Hartree, Douglas R. Applied Mathematician, Manchester and Cambridge Universities, designer of Meccano (and other) Differential Analyzer, and promoter of digital computing

Hull, Thomas E. Founding member and second Chair of the Department of Computer Science

Hume, J.N.P. Co-author of TRANSCODE and founding member of Department of Computer Science

Johnston, Robert F. Co-designer of UTEC, especially input-output component

Kahan, William H. Doctoral student of B.A. Griffith and founding member of Department of Computer Science

Kates, Josef Co-designer of UTEC, especially storage component, and co-founder of KCS Data Control

Kilburn, Thomas Co-designer of SSEM and Manchester Mark I, and designer of Ferranti Atlas

Lewis, Wilfrid B. Director of the Chalk River Atomic Energy Project

Mackenzie, C.J. President of the NRC

Mayberry, John P. Computation Centre summer student of 1949 helped write multiple word mathematical routines for UTEC

McKay, R.W. Physicist, assisted with the memory design of ILLIAC II

Neumann, John von Mathematician, co-inventor of stored-program concept, and leader of a project to build a electronic computer at the Institute for Advanced Study and Princeton University

Okashimo, K. Doctoral student of B.A. Griffith

Popplewell, Cecily M. Spent several months in Toronto assisting with St. Lawrence Seaway backwater calculations

Prinz, D.G. Employee of Ferranti and author of programming guide for Ferranti Mark I

Ratz, Alfred G. Co-designer of UTEC, especially arithmetic unit

Rubinoff, Morris Engineering graduate of the University of Toronto, spent time at Harvard University Computation Laboratory, Princeton University, before settling at University of Pennsylvania

Smillie, Keith W. Doctoral student of B.A. Griffith

Smith, Kenneth C. Electrical engineering doctoral student and assisted with the design of ILLIAC II

Smith, Sidney E. President of the University of Toronto

Smith, Victor G. Electrical Engineer and member of the Committee on Computing Machines

Solandt, Omond M. Chairman of the DRB

Stanley, James P. Together with B.H. Worsley, first employee of the Computation Centre

Steacie, E.W.R. President of the NRC

Stein, H.H. UTEC technician, working under Alfred Ratz

Stibitz, George R. Designer of Bell Laboratories relay calculators

Stone, F.R. Vice-president of the University of Toronto

Strachey, Christopher Seconded to the Computation Centre by the NRDC to assist with St. Lawrence Seaway calculations on Ferut

Tupper, K.F. Dean of the Faculty of Applied Science and Engineering, and second Director of the Computation Centre

Turing, Alan M. Mathematician, Ferranti Mark I programmer at Manchester University, and author of first programming guide for the Mark I

Watson, William H. Director of the Computation Centre and chair of the Department of Physics

Williams, F.C. Inventor of Williams Tube, a CRT used for computer storage and co-designer of SSEM and Manchester Mark I

Worsley, Beatrice H. Computation Centre Mathematician, co-writer of TRANSCODE, and founding member of Department of Computer Science

Zimmerman, H.H. Chairman of the DRB

C.2 Acronyms and Significant Computers

ACM Association for Computing Machinery

AECL Atomic Energy of Canada Limited

ALGOL Algorithmic Language

ASCC See IBM ASCC

BINAC Binary Automatic Computer, built by the Eckert Mauchly Computer Corporation for the Northrop Aircraft Company in 1949

BMEWS Ballistic Missile Early Warning System

BRL Ballistic Research Laboratory, U.S.

CACM Communications of the ACM

CARDE Canadian Armament and Development Establishment

CDC Control Data Corporation

CDPSC Computing and Data Processing Society of Canada (later known as CIPS)

CIPS Canadian Information Processing Society (formerly known as CDPSC)

CNC Complex Number Calculator, the first Bell Telephone Laboratories relay calculator

COBOL Common Business Oriented Language

CPC IBM Card Programmable Calculator

CRC Computer Research Corporation

CRT Cathode Ray Tube

DRB Defence Research Board, Canada

DRTE Defence Research Telecommunications Establishment, Canada

EDSAC Electronic Delay Storage Automatic Calculator of Cambridge University

EDVAC Electronic Discrete Variable Automatic Computer of the University of Pennsylvania and BRL

ENIAC Electronic Numerical Integrator and Computer of the University of Pennsylvania and BRL

ERA Engineering Research Associates

Ferut Ferranti Mark I at the University of Toronto

FORTRAN Formula Translation

FORTRANSIT FORTRAN IT, a dialect of FORTRAN for the IBM 650

IAS Institute for Advanced Study, of Princeton University

IBM International Business Machines

IBM 1401 Very successful inexpensive solidstate magnetic-core business computer of 1960s

IBM 1620 Inexpensive solidstate magnetic-core scientific computer of the 1960s

IBM 602/602A Calculating Punch Electromechanical plug-board programmable calculator of late 1940s/early 1950s

IBM 650 Very successful magnetic drum computer of the 1950s

IBM 701 Defense Calculator Williams tube based electronic computer; the first commercial computer from IBM

IBM 704 Magnetic core improvement over IBM 701; notably offered floating point arithmetic hardware

IBM 709 Tube-based scientific computer introduced in late 1950s; improved version of IBM 704

IBM 7040/44 Scaled-down less expensive version of IBM 7090

IBM 7090/94 Expensive solidstate magnetic core scientific computer of the 1960s derived directly from the IBM 709

IBM ASCC IBM Automatic Sequence Controlled Calculator, otherwise known as the Harvard Mark I

IBM PSRC IBM Pluggable Sequence Relay Calculators

IBM Stretch Otherwise known as the IBM 7030, a solidstate magnetic-core supercomputer designed in the mid 1950s

ICS Institute of Computer Science, of the University of Toronto

IT Internal Translator, a programming language for IBM 650

ILLIAC Illinois Automatic Computer, of the University of Illinois

JACM Journal of the ACM

KCS J. Kates, L. Casciato and J. Shapiro, of KCS Data Control Limited

LGP-30 Librascope/General Precision 30, inexpensive drum based computer of 1950s

MANIAC Mathematical Analyzer Numerical Integrator And Computer, of Los Alamos Scientific Laboratory, U.S.

MIT Massachusetts Institute of Technology

MTAC Mathematical Tables and other Aids to Computation

MUSE Microsecond Engine, referring to high-speed computer with a microsecond cycle time; MUSE was developed by Kilburn at Manchester and later known as Atlas when Ferranti joined the project

NBS National Bureau of Standards, U.S.

NCR 102A/D National Cash Register 102A/D, inexpensive drum-based computer of the 1950s (D indicated a decimal model)

NPL National Physical Laboratories, U.K.

NRC National Research Council, Canada

NRDC National Research Development Corporation, U.K.

ORDVAC Ordnance Variable Automatic Computer, of BRL

PERM Permanent storage convention of Ferranti Mark I

IBM PSRC See IBM PSRC

RCAF Royal Canadian Air Force

RCN Royal Canadian Navy

RCS Routine Changing Sequence

RDA Rockefeller Differential Analyzer

SEAC Standards Eastern Automatic Computer, of the NBS

SGS School of Graduate Studies of the University of Toronto

SILLIAC Sydney ILLIAC, of University of Sydney, Australia

SOAP Symbolic Optimal Assembly Program, a programming system for IBM 650

SSEC IBM Selective Sequence Electronic Calculator

SSEM Manchester University Small Scale Experimental Machine (predecessor of Manchester Mark I)

TRE Telecommunications Research Establishment, U.K.

UBC University of British Columbia, Canada

UNIVAC Universal Automatic Computer

UTEC University of Toronto Electronic Computer

UWO University of Western Ontario, Canada

WATFOR Waterloo FORTRAN IV, from the University of Waterloo

Appendix D

Chronology of Events

An ordered chronology of major events, with page references.

1933 Hartree and Porter construct a differential analyzer from Meccano, 18

1943 Bell Labs Model II relay calculator designed by Stibitz; the Committee on Computing Machines will look to copy the nearly identical Model IV in the fall of 1948, 21

August 1944 Harvard Mark I, otherwise known as the IBM ASCC, unveiled to public, 19

June 1945 Annual meeting of the Canadian Mathematical Congress, a possible inspiration for the establishment of modern computing at the University of Toronto, 14

June 1945 "First Draft of a Report on the EDVAC" written by von Neumann, 24

November 1945 Beatty applies for and receives $1000 travel grant for newly established Committee on Computing Machines, 12

February 1946 ENIAC dedicated publicly, 23

June 1946 Committee on Computing Machines tours computing centres and electronic computer projects in the United States, 16

July–August 1946 The Moore School Lectures are held at the University of Pennsylvania, 23

August 1946 Committee on Computing Machines drafts "Preliminary Report on Modern Computing Machines", summarizing their tour, concluding that the purchase or construction of a large-scale computer is inadvisable, 25

December 1946 Committee on Computing Machines produces the ambitious "Preliminary Plans for a Proposed Computing Centre at the University of Toronto", advocating the establishment of a large computing centre (with an electronic computer, punched card calculators, and small differential analyzer) to serve the entire nation, 30

January 1947 First Chalk River atomic energy problem arrives at Computation Centre, though work delayed until following year, 48

March 1947 University of Toronto President Smith, apprehensive about the level of investment needed for the latest proposal, approaches NRC President Mackenzie for federal financial support; Mackenzie agrees that proposal has merit and offers tentative support, 32

September 1947 Committee on Computing Machines awarded $6,500 by NRC to initiate Computation Centre, 35

September 1947 V.G. Smith awarded $2,000 grant by University of Toronto to start electronics research eventually leading to UTEC; with funds he hires Ratz, though little happens until May 1948, 91

October 1947 Committee on Computing Machines approaches DRB for additional financial support, 37

January 1948 Griffith hires Worsley and Stanley to operate the IBM 602, 59

January & April 1948 Joint NRC and DRB meetings are held in Ottawa to discuss long-term funding for Computation Centre; instead of a large capital grant, smaller, renewable annual operational grants are approved to expand Centre more slowly, 38

Spring 1948 Griffith hires Gellman, to assist with the IBM 602, 62

May 1948 Smith, Ratz, Doeringer and Kates begin electronics research, 92

June 1948 Manchester SSEM operating, the world's first working stored-program computer, 142

July 1948 Gotlieb joins Computation Centre to oversee relay computer project; visits Stibitz and Bell Labs to discuss constructing a copy of Model IV, 67

July–August 1948 Worsley builds a differential analyzer from Meccano, 82

September 1948 Worsley and Stanley leave for Cambridge, without permission of DRB and NRC, to study EDSAC and modern computing methods, 64

September 1948 Bullard new chair of the Department of Physics and Committee on Computing Machines, 53

September 1948 Gotlieb selected as Acting Director of Computation Centre, 55

October 1948 Decision made to mimic von Neumann's IAS computer design, so that UTEC will be a parallel binary computer with Williams tubes for primary storage, 95

March 1949 DRB and NRC cancel relay computer project after licensing costs escalate overall cost of project too high; though there is some confusion, the Computation Centre is to push ahead exclusively with electronic computer project, UTEC, 69

June 1949 Bullard resigns from Toronto; Watson eventually named new chair of physics; Tupper reluctantly becomes chair of Committee on Computing Machines, 115

July–October 1949 Concrete specifications for UTEC are established, 101

Autumn 1949 Modified SSEM operating; Ferranti will build production version known as Ferranti Mark I, 143

September 1949 Gotlieb offers the first two graduate courses related to modern computing, 211

January 1950 Earnest construction of UTEC begins, 103

April 1950 Committee on Computing Machines reformed as Computation Centre Committee, 117

1951 Computation Centre replaces IBM 602A with considerably faster electronic IBM 604, 65

May 1951 UTEC prototype nearly complete, though demonstration not expected until the fall; planning for full-scale UTEC begins, 106

October 1951 Less than two weeks after Ratz submits full-scale UTEC plans, suggestion arrives from Ottawa to acquire Ferranti Mark I instead of proceeding with UTEC, 108

December 1951–February 1952 Decision made, against the wishes of many in Toronto, to purchase Ferranti Mark I and end UTEC program, 109

April 1952 Ferut arrives at the University of Toronto, 135

April–May 1952 Gotlieb travels to Manchester for six weeks to learn how to program Ferut and hire assistants; he returns with Mark I program library, 147

May 1952 St. Lawrence Seaway Backwater Calculation project officially begins on Ferut; trial calculations were done the previous year with the desktop calculators, 163

June 1952 Three new committees replace the Computation Centre Committee: the Ottawa-based Computation Centre Joint Committee, consisting of high-level NRC, DRB, and Toronto administrators; and the two University of Toronto Computation Centre Advisory Committees. The Administration committee was chaired by Watson, who was also the director of the Computation Centre not long after; the Programming committee was led by Gotlieb, who was also promoted to 'Chief Computer', 139

Summer 1952 At Manchester, Glennie writes AUTOCODE for Ferranti Mark I, 181

September 1952 Ferut nearly operational as ACM holds first international meeting at the University of Toronto, 144

November–December 1952 The first programming course is offered at the University of Toronto; it is followed by a second course was offered the following spring, and a more intensive third course in June 1953, 212

1953 Mark I input routines rewritten in Toronto to simplify programming; Hume is the primary author, 156

June 1953 DRB sends Fraser to work in the Computation Centre as its representative programmer; the NRC sends Hart in September, 175

Summer 1953 On Lake Ontario, Ferranti-Canada and the Royal Canadian Navy demonstrate DATAR, a real-time anti-submarine tracking and display computer system, 274

September 1953 Speedcoding system for the IBM 701 described at ACM meeting, 178

October 1953 Hume and Worsley begin writing TRANSCODE; it is usable the following summer, 185

1954 A.V. Roe and the RCAF acquire the second and third modern computers in Canada, both an NCR-102A, 217

1954 At Manchester, Brooker writes Autocode for Ferranti Mark I; it is usable toward the end of the year, 183

March 1954 Watson first rebukes the University in a memo for failing to see the potential of the Computation Centre as an academic home; Tupper disagrees with many of his claims and the issue is dropped, 246

June 1954 Wayne University hosts the "First Conference on Training Personnel for the Computing Machine Field", 209

October 1954 TRANSCODE manual published; articles describing TRANSCODE followed not long after in the JACM, *Physics in Canada*, and *Computers and Automation*, 189

October 1954 Watson writes a second memo to the University, looking to establish the Computation Centre as the source for computing experts in Canada; again, the memo is largely ignored, 247

1955 IBM launches Project Stretch, an ambitious attempt to build the world's fastest computer using leading edge technologies, 255

August 1955 The University of Wisconsin hosts the Computing Laboratory in the University conference, 201

December 1955 A teletype link is successfully tested between the universities of Toronto and Saskatchewan, enabling remote TRANSCODE programming; the experiment is repeated in 1957 with the University of Alberta, 194

December 1955 At a Computation Centre Joint Committee meeting held in Ottawa, a replacement for Ferut is first discussed, 234

December 1955 The Computation Centre Joint Committee rebukes the university for failing to properly acknowledge the Computation Centre, 249

1956 At Manchester, a high-speed transistorized computer project known as MUSE (for microsecond engine) is launched; in 1959 Ferranti agrees to support the project and it is renamed Atlas, 261

1956 Ferranti-Canada completes a prototype transistorized mail sorting computer for the Canadian post office, 275

July 1956 The ILLIAC II project is officially launched at the University of Illinois; MacKay spends a one year's leave-of-absence on the project at Illinois, joined in January 1957 by K.C. Smith, 235

1957–1962 DRTE designs, constructs, and uses its own solid state computer, 273

1957 Thanks to the increased availability of inexpensive computers, external use of the Computation Centre drops and the University of Toronto becomes its primary user, 226

March 1957 Watson writes to President Smith with a proposal to create an academic department dedicated to computing; as Smith resigned around this time, his response is unknown, 250

Summer 1957 Replacement for Ferut sought, as ILLIAC II will not be ready in time; Burroughs and IBM submit proposals, 237

November 1957 The University selects the IBM 650 to replace Ferut; it is a marginally better machine, and it is possible the decision was swayed by a $10,000 annual fellowship grant offered by IBM, 238

1958 Gotlieb and Hume publish *High-Speed Data Processing*, 219

1958 Philco releases the first commercial transistorized computer, the S-2000, and the US Air Force mandates that all computers purchased in the future for BMEWS will be transistorized, 273

April 1958 Ferut ceases operation in the Computation Centre; the IBM 650 arrives to replace it in May, 239

June 1958 The Computing and Data Processing Society of Canada holds its first conference at the University of Toronto, 221

November 1958 Watson forwards his original proposal regarding the creation of a new academic department of computing to the newly installed President Bissell; Watson is now tying the ILLIAC II to a new department and Bissell's response is noncommittal, 254

November 1958 In advance of a December 1958 Joint Committee meeting, Watson prepares a report to justify constructing a copy of the ILLIAC II in Toronto, 257

December 1958 At a meeting in Ottawa, the Joint Committee holds off on a major decision regarding the ILLIAC II, not entirely free from doubt about the cost or time projections and leadership, 259

September 1959 Fein, a consultant to Stanford University, publishes an article in the CACM calling for universities to create academic departments of computer science, 310

December 1959 IBM just meets a deadline to deliver a new transistorized IBM 7090 to the US Air Force, 277

January 1960 The final 40-page ILLIAC II proposal is completed by the Computation Centre; the costs and timeline are more firm, despite delays at Illinois, 261

February 1960 The Joint Committee approves the ILLIAC II project, with the majority of the financing coming from the NRC, the Banting Fund, and the University of Toronto, 266

September 1960 Gotlieb and McKay visit Illinois, and report back that both the cost and timeline estimations were far too low; the two remain optimistic, but Watson quickly realizes that the project is no longer feasible and a new computer must be selected, 267

March 1961 Watson and Gotlieb decide that an IBM 7090 would be the best choice to replace the IBM 650, given that they can no longer afford to build the ILLIAC II, 278

June 1961 Watson and DeLury propose an Institute of Computer Science, 283

June 1961 Watson proposes a post-graduate Diploma Course in Computing and Data Processing, 285

Summer 1961 Watson begins a sabbatical year that would become a resignation, 282

1962 Watson's departure becomes official and Gotlieb is promoted to Director of the Computation Centre, 292

January 1962 The University agrees to establish the Institute of Computer Science, replacing the Computation Centre, 285

January 1962 The University approves of the new diploma program, 286

June 1962 An IBM 7090 is installed at the University of Toronto, 281

September 1962 The Institute of Computer Science hosts SHARE XIX, the first SHARE meeting outside of the US, 280

October 1962 A special ceremony is held in Toronto to inaugurate the IBM 7090, the most expensive computer in the country, 281

1963 Ferranti-Canada finishes ReserVec, an airline seat reservation system for Trans-Canada Air Lines, 275

1963 Ferranti-Canada briefly enters the general-purpose commercial computer business with the FP-6000, but the product-line is sold off by the parent company, Ferranti UK, to ICT, 275

January 1963 Gotlieb proposes to establish a new Department of Computer Science, splitting the Institute into academic and operational functions, 293

July 1963 Gotlieb begins process to upgrade IBM 7090 to IBM 7094 Model II, a $600,000 upgrade, 318

July 1963 Gotlieb produces a more comprehensive six page proposal regarding the establishment of a Department of Computer Science, 294

July 1963 UWO announces an undergraduate Department of Computer Science, although new students do not enrol until September 1964, 297

1964 After SGS approves Gotlieb's more comprehensive proposal, the University Senate approves the establishment of a new graduate Department of Computer Science in time for the 1964-65 academic year, 296

April 1964 The University of Alberta creates a Department of Computing Science; at first it offers a master's degree only, but by 1967 both an undergraduate and doctoral degree are available, 297

April 1964 The University of Waterloo announces that a Division of Computer Science has been created, leading to a Bachelor of Arts, 298

Summer 1965 Four undergraduate students at the University of Waterloo write WATFOR, a student oriented FORTRAN compiler for the IBM 7040, 298

June 1967 Gotlieb resigns as chair of the Department of Computer Science to focus on his work in the Institute of Computer Science; Hull is selected as the new chair, 320

1971 Under Hull, a new undergraduate Department of Computer Science is created, 322

Bibliography

Primary Sources (Archives)

Associate Committee on Computers - Agenda meetings minutes and proceedings, Library and Archives Canada, RG77, Volume 134, File 17–15–1–20.

Programming of problems sub-committee by Physics Division to Computation Centre, Library and Archives Canada, RG 77, Volume 211, File 15–17–13–C–4.

Associate Committee on Computers - Agenda meetings minutes and proceedings, Library and Archives Canada, RG 77, Volume 52, File 6090–3.

Consolidated grant for research to University of Toronto under the direction of K.F. Tupper re: computation centre, Library and Archives Canada, RG77, Volume 52, File 17–28B–1.

University of Toronto, Office of the President, 1908–1957, University of Toronto Archives and Records Management Services, Accession A1968–0007.

University of Toronto, Office of the President, 1941–1967, University of Toronto Archives and Records Management Services, Accession A1971–0011.

University of Toronto, Institute of Computer Science, 1956–1969, University of Toronto Archives and Records Management Services, Accession A1970–0013.

University of Toronto, Board of Governors, 1919–1971, University of Toronto Archives and Records Management Services, Accession A1973–0025.

University of Toronto, Department of Graduate Records, 1827–1970, University of Toronto Archives and Records Management Services, Accession A1973-0026.

University of Toronto, Office of the Executive Vice-President (Academic) and Provost, 1946–1971, University of Toronto Archives and Records Management Services, Accession A1977–0020.

Gotlieb, Calvin Carl. Papers, University of Toronto Archives and Records Management Services, Accession B1988–0069.

Gotlieb, Calvin Carl. Papers, University of Toronto Archives and Records Management Services, Accession B2002–0003.

Smith, Victor George. Papers, University of Toronto Archives and Records Management Services, Accession B1999–0025.

Strachey, Christopher. Papers, National Cataloguing Unit for the Archives of Contemporary Scientists, Oxford University, Bodleian Library, Special Collections and Western Manuscripts, Accession 71–1–80.

Worsley, Beatrice H. Papers, Queen's University Archive, Accession 1053.

Primary Sources (Oral Histories)

Len Casciato, interview by Michael R. Williams, 6 July 1992, Transcript provided by Michael R. Williams.

Harvey S. Gellman, interview by Michael R. Williams, 9 June 1992, Transcript provided by Michael R. Williams.

Calvin C. Gotlieb, interview by Henry S. Tropp, Computer Oral History Collection, edited transcript of tape recording, 29 June 1971, UTARMS B2002–0003, Box 8, Folder 1.

Calvin C. Gotlieb, interview by Henry S. Tropp, Computer Oral History Collection, transcript of tape recording, 29 July 1971, UTARMS B2002–0003, Box 8, Folder 1.

Calvin C. Gotlieb, "Early Computer Developments in Canada", interview by Ted Paull and John N. Vardalas, National Museum of Science and Technology, transcript of tape recording, 14 August 1984, UTARMS B2002–0003, Box 1, Folder 17.

Calvin C. Gotlieb, interview by Michael R. Williams, 29 April 1992, Transcript provided by Michael R. Williams.

Calvin C. Gotlieb, interview by Michael R. Williams, 30 April 1992, Transcript provided by Michael R. Williams.

Calvin C. Gotlieb, interview by Michael R. Williams, 5 May 1992, Transcript provided by Michael R. Williams.

Calvin C. Gotlieb, interview by Michael R. Williams, 6 May 1992, Transcript provided by Michael R. Williams.

Thomas E. Hull, interview by Michael R. Williams, 12 June 1992, Transcript provided by Michael R. Williams.

J.N.P. Hume, interview by Michael R. Williams, 11 June 1992, Transcript provided by Michael R. Williams.

Josef Kates, interview by Henry S. Tropp, Computer Oral History Collection, edited transcript of tape recording, 29 June 1971, Archives Center, National Museum of American History.

Josef Kates, interview by Michael R. Williams, 9 June 1992, Transcript provided by Michael R. Williams.

Primary Sources (Theses)

Baxter, Stuart D., "Numerical Methods for the Solution of Hyperbolic Differential Equations with the Aid of an Electronic Computer", Ph.D. thesis, Mathematics, University of Toronto (1958).

Bruce, W. Robert, "Monte Carlo Calculations of the Scattering of X-rays in Low Atomic Number Materials.", Ph. D thesis, University of Saskatchewan (1956).

Gotlieb, Calvin C., "Problems connected with the trajectory of a yawing shell", Ph.D. thesis, Physics, University of Toronto (1947).

Ham, J.M., "The solution of a class of linear operational equations by methods of successive approximations", Ph.D. thesis, Electrical Engineering, MIT (1952).

Kahan, William M., "Gauss-Seidel Methods of Solving Large Systems of Linear Equations", Ph.D. thesis, Mathematics, University of Toronto (1958).

Kates, Josef, "Space Charge Effects in Cathode-Ray Storage Tubes", Ph.D. thesis, Physics, University of Toronto (1951).

Kumar, S., "Semantic Clustering of Index Terms", Ph.D. thesis, Computer Science, University of Toronto (1968).

Okashimo, K., "The Numerical Integration of Integro-Differential Equations of Convolution Type", Ph.D. thesis, Mathematics, University of Toronto (1955).

Pashler, P.E., "The determination of the forces on a shell in flight by a radio method", Ph.D. thesis, Physics, University of Toronto (1947).

Perrier, J.F., "An Electronic Analogue Computer for the Solution of Tenth-Degree Polynomials", Ph.D. thesis, Electrical Engineering, University of Toronto (1953).

Ratz, Alfred G., "The Design of the Arithmetic Unit of an Electronic Digital Computer", Ph.D. thesis, Electrical Engineering, University of Toronto (1951).

Rubinoff, Morris, "A new method of measuring the angular motion of a spinning projectile in flight", Ph.D. thesis, Physics, University of Toronto (1946).

Smillie, Keith W., "A Mathematical Treatment Of Certain Movement Of Fish – An Application of the Theory of Markov Processes", Ph.D. thesis, Mathematics, University of Toronto (1952).

Smith, Kenneth C., "Flux Reversal in Ferrites", Ph.D. thesis, Physics, University of Toronto (1960).

Worsley, Beatrice H., "A Mathematical Survey of Computing Devices With an Appendix on Error Analysis of Differential Analyzers", Master's thesis, MIT (1947).

Worsley, Beatrice H., "Serial Programming for Real and Idealized Digital Calculating Machines", Ph. D thesis, University of Cambridge (May 1952).

Primary Sources (Books and Articles, including reprints)

"Techniques Department", *Communications of the ACM* 1, no. 4 (1958), 7,8.

"Census of Computers in Canada", *The Computer Society of Canada Quarterly Bulletin* 5, no. 4 (June 1965).

Alt, Franz L., "The Computing Laboratory in the University", *Journal of the American Statistical Association* 53, no. 282 (Jun 1958), 624–625.

Alt, Franz L., "A Bell Telephone Laboratories' computing machine", in Brian Randell ed., *The Origins of Digital Computers*, 3rd edition (Berlin: Springer-Verlag, 1982).

Andrews, E.G., "Telephone Switching and the Early Bell Laboratories Computers", *Annals of the History of Computing* 4, no. 1 (1982), 13–16.

Andrews, E.G. and H.W. Bode, "Use of the Relay Digital Computer", *Annals of the History of Computing* 4, no. 1 (1982), 5–13.

Atchison, William F. et al., "Curriculum 68: Recommendations for academic programs in computer science: A report of the ACM curriculum committee on computer science", *Communications of the ACM* 11, no. 3 (1968), 151–197.

Backus, John W., "The IBM 701 Speedcoding System", *Journal of the ACM* 1, no. 1 (1954), 4–6.

Backus, John W. and H. Herrick, "Speedcoding and Other Automatic Programming Systems", in *Proceedings of a Symposium on Automatic Programming for Digital Computers* (Washington DC: The Office of Naval Research, May 1954), 106–113.

Baehne, George Walter ed., *Practical Applications of the Punched Card Method in Colleges and Universities* (Morningside Heights, New York: Columbia University Press, 1935).

Bemer, Robert W., "Automatic programming systems", *Communications of the ACM* 2, no. 5 (1959), 16.

Bennett, J.M., D.G. Prinz and M.L. Woods, "Interpretative sub-routines", in *ACM '52: Proceedings of the 1952 ACM national meeting (Toronto)* (ACM Press, 1952), 81–87.

Borden, B.C., "FORTRANSIT: A Universal Automatic Coding System for the IBM 650", in "Canadian Conference for Computing and Data Processing, Proceedings", 349–359.

Brooker, R.A., "An attempt to simplify coding for the Manchester electronic computer", *British Journal of Applied Physics* 6 (September 1955), 307–311.

Brooker, R.A., "The Programming strategy used with the Manchester University mark I Computer", *Proceedings, Institution of Electrical Engineers, Part B, Supplement* 103 (1956), 151–157.

Brooker, R.A., "The autocode programs developed for the Manchester University computers", *The Computer Journal* 1, no. 1 (April 1958), 15–21.

Bruce, W. Robert and H.E. Johns, "The Spectra of X Rays Scattered in Low Atomic Number Materials", *British Journal of Radiology* Supplement No. 9 (1960).

Burnett-Hall, D.G, L.A.G. Dresel and P.A. Samet, *Computer Programming and Autocodes* (Princeton, NJ: D.Van Nostrand Company, Inc., 1964).

Campaigne, H., "Review: High-Speed Data Processing", *Mathematical Tables and Other Aids to Computation* 12, no. 64 (1958), 315–317.

Chase, George C., "History of mechanical computing machinery", in *Proceedings of the 1952 ACM national meeting (Pittsburgh)* (ACM Press, 1952), 1–28.

Chung, J.H. and Calvin C. Gotlieb, "Test of an Inventory Control System on FERUT", *Journal of the ACM* 4, no. 2 (1957), 121–130.

Conte, S. D. et al., "An undergraduate program in computer science – preliminary recommendations", *Communications of the ACM* 8, no. 9 (1965), 543–552.

Cook, Stephen A., "The Complexity of Theorem-Proving Procedures", in *Proceedings Third Annual ACM Symposium on Theory of Computing* (May 1971), 151–158.

Cowan, D.D. and J.W. Graham, "Waterloo microcomputer systems for the 1980's", in *ACM '82: Proceedings of the ACM '82 conference* (ACM Press, 1982), 13–17.

Curtiss, J.H., "A Symposium of Large Scale Digital Calculating Machinery", *Mathematical Tables and Other Aids to Computation* 2, no. 18 (April 1947), 229–238.

Curtiss, J.H., "The New Significance of Computation in Higher Education", in Hammer, *The Computing Laboratory in the University*, 11–14.

Dennis, Jack B., "A Multiuser Computing Facility for Education and Research", *Communications of the ACM* 7, no. 9 (September 1964), 521–529.

Dwyer, Paul S., "The Use of Desk Calculators", in Hammer, *The Computing Laboratory in the University*, 79–84.

Fein, Louis, "The role of the University in computers, data processing, and related fields", *Communications of the ACM* 2, no. 9 (September 1959), 7–14.

"Appendix: Computers in Higher Education", in Finerman, *University Education in Computing Science*, 215–229.

Forsythe, George E., "The Generation and Use of Orthogonal Polynomials for Data Fitting with a Digital Computer", *Society for Industrial and Applied Mathematics* 5, no. 2 (June 1957).

Fraser, W., "Experience of the Defence Research Board in Mail Order Computer Service", in "Canadian Conference for Computing and Data Processing, Proceedings", 370–376.

Gellman, Harvey, "The Calculation of Complex Hypergeometric Functions with the IBM Type 602 - a Calculation Punch", in *Proceedings of the International Business Machines Seminar* (IBM, December 1949), 161–168.

Gellman, Harvey, Byron A. Griffith and James P. Stanley, "Internal Conversion in the L1-Shell", *Physical Review* 80, no. 5 (1950), 866–874.

Glinski, George S., "Computer Education in Canadian Universities", in "Canadian Conference for Computing and Data Processing, Proceedings", 23–28.

Goldstine, Herman H. and Adele Goldstine, "The Electronic Numerical Integrator and Computer", *Mathematical Tables and other Aids to Computation* 2, no. 15 (1946), 97–110.

Gotlieb, Calvin C., "Machines for Thought", *Physics in Canada* (1951), 3–7.

Gotlieb, Calvin C., "The Cost of Programming and Coding", *Computers and Automation* 25 (September 1954), 14–15,25.

Gotlieb, Calvin C., "Running a Computer Efficiently", *Journal of the ACM (JACM)* 1, no. 3 (1954), 124–127.

Gotlieb, Calvin C., "Free Use of the Toronto Computer, and the Remote Programming of it", *Computers and Automation* (May 1956), 20–45.

Gotlieb, Calvin C., "Equipping a University Computing Laboratory", in Hammer, *The Computing Laboratory in the University*, 171–174.

Gotlieb, Calvin C., "Backwater Computations for the St. Lawrence Power Project, Part B: Backwater Calculations on the Ferranti Digital Computer", *The Engineering Journal* (February 1960), 61–66.

Gotlieb, Calvin C., "Review: A guide to FORTRAN programming", *Computing Reviews* (Jan-Feb 1962).

Gotlieb, Calvin C., "Software Problems", in "Proceedings of the Third Conference of the Computing and Data Processing Society of Canada, McGill University, 2-3 June 1962", 198–204.

Gotlieb, Calvin C., "How Many Computers per University?", in Finerman, *University Education in Computing Science*, 93–104.

Gotlieb, Calvin C. and J.N.P Hume, *High-Speed Data Processing* (New York: McGraw-Hill Book Company, Inc., 1958).

Graham, J.W., "A Co-operative Course in Honours Mathematics with Actuarial and Computer Science Options", *CDPSC Quarterly Bulletin* 4, no. 3 (April 1964), 15–16.

Griffith, Byron A. and James P. Stanley, "On the Numerical Calculation of the Internal Conversion in the K-Shell; the Electric Dipole Case", *Physical Review* 75, no. 3 (Feb. 1949), 534–535.

Hart, J. F. and Beatrice H. Worsley, "Self-Consistent Field Calculations at the University of Toronto", in "Canadian Conference for Computing and Data Processing, Proceedings", 298–305.

Hartree, Douglas R., "The ENIAC, an Electronic Calculating Engine", *Nature* 158 (1946), 500–506.

Hartree, Douglas R., "The Use of the Differential Analyzer to the Evaluation of Solutions of Partial Differential Equations", in "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945", 327–337.

Hartree, Douglas R., "A Historical Survey of Digital Computing Machines", *Proceedings of the Royal Society of London A* 195 (1948), 265–271.

Hartree, Douglas R., *Calculating Instruments and Machines* (University of Illinois Press, 1949).

Hartree, Douglas R., *The Calculation of Atomic Structures* (New York: J. Wiley, 1957).

Hartree, Douglas R. and Arthur Porter, "The Construction and operation of a Model Differential Analyzer", *Manchester Literary & Philosophical Society Memoirs and Proceedings* 79 (1935), 51–73.

Hohn, Franz, "The First Conference on Training Personnel for the Computing Machine Field", *The American Mathematical Monthly* 62, no. 1 (Jan. 1955), 8–15.

Howland, J.L. and Keith W. Smillie, "Some Mathematical and Programming Techniques Employed in the Operation of a Scientific Computing Facility", in "Canadian Conference for Computing and Data Processing, Proceedings", 78–87.

Hume, J. N. P. and Beatrice H. Worsley, "Transcode: A System of Automatic Coding for Ferut", *Journal of the ACM* 2, no. 4 (1955), 243–252.

Hume, J.N.P., "Technical Developments: Input and Organization of Sub-Routines for Ferut", *Mathematical Tables and Other Aids to Computation* 8, no. 45 (1954), 30–36.

Hume, J.N.P., "The Promise of Computer Science", in *Proceedings of the Fourth National Conference, University of Ottawa, 1964* (Toronto: University of Toronto Press, 1964), 3–8.

Institute of Computer Science, *Computer Usage Report – July 1 to December 31, 1962* (University of Toronto, 1962).

Institute of Computer Science, *Annual Report – July 1, 1964 - June 30, 1965* (University of Toronto, 1965).

Institute of Computer Science, *Annual Report – July 1, 1965 - June 30, 1966* (University of Toronto, 1966).

Johnston, Robert F., "The University of Toronto Electronic Computer", in *ACM '52: Proceedings of the 1952 ACM nation meeting (Toronto)* (ACM Press, 1952), 154–160.

Keenan, T.A., "Sixth Survey of University Computing Facilities", Technical report (Rochester, N.Y.: Computing Centre, University of Rochester, 1963).

Kumar, S. and Calvin C. Gotlieb, "Semantic Clustering of Index Terms", *Journal of the ACM* 15, no. 4 (1968), 493–513.

Lewis, Wilfrid B., "A "Scale of Two" High-Speed Counter using Hard Vacuum Triodes", *Proceedings of the Cambridge Philosophical Society* 33 (1937), 549–558.

Lewis, Wilfrid B., *Electrical Counting: With special reference to alpha and beta particles* (Cambridge: Cambridge University Press, 1942).

McCracken, Daniel, *A Guide to FORTRAN Programming* (New York: Wiley, 1961).

McFarlane, H.M, "Backwater Computations for the St. Lawrence Power Project, Part A: Hydraulic Engineering Aspects of Computations", *The Engineering Journal* (February 1960), 55–60, 66.

Meagher, Ralph E., "Equipping a University Computing Laboratory", in Hammer, *The Computing Laboratory in the University*, 181–185.

Mendelsohn, Nathan S., "Some Elementary Properties of Ill Conditioned Matrices and Linear Equations", *The American Mathematical Monthly* 63, no. 5 (May 1956), 285–295.

Mezei, L., "News of Southern Ontario", *CDPSC Quarterly Bulletin* 3, no. 4 (July 1963), 11–12.

Morgan, J.H., "Scientific Computation Within the Defence Research Board", in "Proceedings of the Third Conference of the Computing and Data Processing Society of Canada, McGill University, 2-3 June 1962", 59–67.

Morse, P.M., "On the Use of Digital Computers", *Physics Today* (Oct 1956), 21.

Neumann, John von, "First Draft of a Report on the EDVAC", Technical report (Philadelphia, Pa.: Moore School of Engineering, University of Pennsylvania, 30 June 1945).

Neumann, John von, "High-speed Computing Devices and Mathematical Analysis", in "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945".

Newell, Allen, Alan J. Perlis and Herbert A. Simon, "Letters: Computer Science", *Science* 157, no. 3795 (September 22 1967), 1373–1374.

Petherick, E.J., "Advance Notes on RASCAL", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 255–264.

Ratz, Alfred G. and Victor G. Smith, "A Method of Gating for Parallel Computers", *Transactions of the American Institute of Electrical Engineers* 70 (1951), 510–516.

Robinson, A., "The testing of cathode ray tubes for use in the Williams type storage system", in *ACM '52: Proceedings of the 1952 ACM national meeting (Toronto)* (New York, NY, USA: ACM Press, 1952), 42–45.

Robinson, A.A., "The Reliability of High-Speed Digital Computing Machines", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 199–201.

Rosin, Robert F., "Determining a Computing Center Environment", *Communications of the ACM* 8, no. 6 (July 1965), 463–468.

Rowlands, H.W., "The Canadian Scene in Computing and Data Processing", in "Canadian Conference for Computing and Data Processing, Proceedings", 287–297.

Sammet, Jean E., "Programming Languages: History and Future", *Communications of the ACM* 15, no. 7 (1972), 601–610.

Smith, Victor G., "Engineering Mathematics", in "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945", 43–50.

Stanley, James P., "On the Numerical Calculation of the Internal Conversion in the K-Shell – The Electric Dipole Case", *Canadian Journal of Research, Section A* 27 (1949), 17–25.

Stanley, James P. and Maurice V. Wilkes, *Table of the Reciprocal of the Gamma Function for Complex Argument* (Toronto: Computation Centre, University of Toronto, 1950).

Stibitz, George R., "Introduction to the Course on Electronic Digital Computers", in Campbell-Kelly and Williams, *The Moore School lectures: Theory and Techniques for Design of Electronic Digital Computers*.

Strachey, Christopher, "Logical or Non-mathematical Programmes", in *ACM '52: Proceedings of the 1952 ACM national meeting (Toronto)* (ACM Press, 1952), 46–49.

Viavant, William, "The Computing Laboratory in the University", *American Mathematical Monthly* 65, no. 5 (May 1958), 376.

Watson, William H., "A National Policy for Applied Mathematics", in "Proceedings of the First Canadian Mathematical Congress, Montreal, 1945", 111–113.

Watson, William H., "Report of the Director of the Computation Centre", in University of Toronto, *President's Report*, 113–114.

Watson, William H., "Report of the Director of the Computation Centre", in *President's Report* (University of Toronto, 1956), 103–104.

Watson, William H., "On Learning to do Better", in "Canadian Conference for Computing and Data Processing, Proceedings", 1–5.

Watson, William H. and Calvin C. Gotlieb, "Submission to the Royal Commission on Canada's Economic Prospects", Technical report (Toronto: The Computation Centre, University of Toronto, October 1955).

Weik, M.H. ed., *A Survey of Domestic Electronic Digital Computing Systems*, BRL report no. 971 (Aberdeen Proving Ground, Md.: Ballistic Research Laboratories, 1955).

Wheeler, David J., "Checking Facilities", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 106.

Wilkes, Maurice V., "The Best Way to Design an Automatic Calculating Machine", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 182–184.

Wilkes, Maurice V., David J. Wheeler and Stanley Gill, *The Preparation of Programs for an Electronic Digital Computer*, 2nd edition (Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1957).

Williams, F.C., "The University of Manchester Computing Machine", in Campbell-Kelly and Williams, *The Early British Computer Conferences*, 171–177.

Worsley, Beatrice H., "The EDSAC Demonstration: Report on a Conference on High Speed Automatic Calculating Machines", Technical report (Cambridge University Mathematical Laboratory, January 1950).

Worsley, Beatrice H., "Computer Training at Toronto", in Jacobson, "Proceedings of the First Conference on Training Personnel for the Computing Machine Field", 71–72.

Worsley, Beatrice H., "News of Toronto and the Toronto section", *CDPSC Quarterly Bulletin* 3, no. 2 (January 1963), 12.

Worsley, Beatrice H., "News from Southern Ontario", *CDPSC Quarterly Bulletin* 4, no. 2 (January 1964), 7–10.

Worsley, Beatrice H. and J. N. P. Hume, "A New Tool for Physicists", *Physics in Canada* 10, no. 4 (Summer 1955), 11–20.

Primary Sources (Conference Proceedings)

Canadian Conference for Computing and Data Processing, Proceedings (Toronto: University of Toronto Press, 1958).

Proceedings of the First Canadian Mathematical Congress, Montreal, 1945 (Toronto: The University of Toronto Press, 1946).

Proceedings of the Third Conference of the Computing and Data Processing Society of Canada, McGill University, 2-3 June 1962 (Toronto: University of Toronto Press, 1963).

Finerman, A. ed., *University Education in Computing Science,* ACM Monograph Series, 215–229 (New York: Academic Press, 1968).

Hammer, Preston C. ed., *The Computing Laboratory in the University* (Madison, WI: The University of Wisconsin Press, 1957).

Jacobson, Arvid W. ed., *Proceedings of the First Conference on Training Personnel for the Computing Machine Field,* Wayne University Computation Laboratory (Detroit: Wayne University Press, June 22 and 23 1955).

Primary Sources (University Calendars and related)

University of Alberta, *Calendar 1964–1965* (University of Alberta, 1964).

University of Toronto, *President's Report* (University of Toronto, 1948).

University of Toronto, *President's Report* (University of Toronto, 1949).

University of Toronto, *President's Report* (University of Toronto, 1951).

University of Toronto, *President's Report* (University of Toronto, 1955).

University of Toronto, *President's Report* (University of Toronto, 1962).

University of Toronto, *President's Report* (University of Toronto, 1963).

University of Toronto, *School of Graduate Studies Calendar 1964–1965* (University of Toronto, 1964).

University of Toronto, *Faculty of Arts and Sciences Calendar 1971–1972* (University of Toronto, 1971).

University of Western Ontario, *Report of the President* (University of Western Ontario, 1964).

Primary Sources (Newspapers)

"Announcements", *University of Toronto Bulletin* (January 1962), 4.

"Huge Pushbutton Brain to be Built at U. of T.", *Globe and Mail* (May 18 1949), 5.

"Machines Short-Circuit Complex Calculations", *Globe and Mail* (December 15 1951), 4.

"Ship's Maiden Trip Starts Toronto-Manchester Service", *The Globe and Mail* (April 29 1952), 3.

"Electronic Computer Mathematics Genius, Poor Checker Player", *The Globe and Mail* (September 6 1952), 19.

"Electronic Computer Intended for Defense Gets Peaceful Tryout", *The Globe and Mail* (December 24 1955), 4.

"University Tests Teletype, Computer System to Speed Up Research", *Saskatoon Star Phoenix* (December 1955).

Primary Sources (Manuals)

Brooker, R.A., "Programmers' Handbook for the Manchester Electronic Computer Mark II" (Manchester University Computing Machine Laboratory, 1952).

Computation Centre, "TRANSCODE Manual" (University of Toronto, October 1955).

Computation Centre, *Library Programs for the IBM TAPE 650 Electronic Data Processing Machine*, Revised January 1960 edition (Toronto, January 1960).

Hart, J.F., "The Transcode Automatic Programme", Technical report (National Research Council of Canada, Division of Physics, 1955).

International Business Machines Corporation, "Principles of Operation, Type 701 and Associated Equipment, Form 24-6042-1" (New York: International Business Machines Corporation, 1953).

Turing, Alan M., "Programmers' Handbook for Manchester Electronic Computer" (Manchester University, 1951).

TRANSCODE, A System of Coding for the Ferranti Mark I Computer, By J.N.P. Hume and B.H. Worsley, 1 October 1954, UTARMS A2005–0021.

D.G. Prinz, An Introduction to Programming on the Manchester Electronic Digital Computer, made by Ferranti Ltd, Moston, Manchester 10, UTARMS A2005–0021.

Secondary Sources (Theses)

Akera, Atsushi, "Calculating a Natural World: Scientists, Engineers, and Computers in the United States, 1937-1968", Ph. D thesis, University of Pennsylvania (1998).

Vardalas, John N., "Moving up the Learning Curve: The Digital Electronic Revolution in Canada, 1945-1970", Ph.D. thesis, History, University of Ottawa (1998).

Secondary Sources (Published)

"Universities: Editor's Note", *Annals of the History of Computing* 8, no. 01 (1986), 35.

"Deaths: Dr. Rubinoff, CIS Pioneer", *University of Pennsylvania Almanac* 50, no. 17 (13 January 2004), 3.

Akera, Atsushi, "Voluntarism and the Fruits of Collaboration: The IBM User Group SHARE", *Technology and Culture* 42, no. 4 (October 2001), 710–736.

Aspray, William ed., *Computing Before Computers*, 1st edition (Ames, Iowa: Iowa State University Press, 1990).

Aspray, William, *John von Neumann and the Origins of Modern Computing* (Cambridge, Mass.: MIT Press, 1990).

Aspray, William, "The Institute for Advanced Study Computer: A Case Study in the Application of Concepts from the History of Technology", in Rojas and Hashagen, *The First Computers: History and Architectures*, 179–193.

Aspray, William, "Was Early Entry a Competitive Advantage? U.S. Universities That Entered Computing in the 1940s", *IEEE Annals of the History of Computing* 22, no. 3 (July 2000), 42–87.

Backus, John W., "The History of FORTRAN I, II and III", *Annals of the History of Computing* 1, no. 01 (1979), 21–37.

Backus, John W., "Programming in America in the 1950s", in Howlett et al., *A History of Computing in the Twentieth Century: A Collection of Essays*, 125–136.

Baldwin, R.B., *The Deadly Fuze* (San Rafael, Ca.: Presidio Press, 1980).

Ball, Norman R. and John N. Vardalas, *Ferranti-Packard: Pioneers in Canadian Electrical Manufacturing* (Montreal: McGill-Queen's University Press, 1994).

Ball, William E., "Programming Languages and Systems", in Pollack, *Studies in Computer Science*, 52–94.

Bemer, Robert W., "Nearly 650 Memories of the 650", *Annals of the History of Computing* 8, no. 01 (1986), 66–69.

Bennett, J.M. ed., *Computing in Australia: The Development of a Profession* (Sydney, NSW: Hale & Iremonger in association with the Australian Computer Society, 1994).

Bigelow, Julian, "Computer Development at the Institute for Advanced Study", in Howlett et al., *A History of Computing in the Twentieth Century: A Collection of Essays*, 291–310.

Bleackley, Beverly J. and Jean La Prairie, *Entering the Computer Age: The Computer Industry in Canada: The First Thirty Years* (Agincourt, Canada: The Book Society of Canada Limited, 1982).

Bowles, Mark D., "U.S. Technological Enthusiasm and British Technological Skepticism in the Age of the Analog Brain", *IEEE Annals of the History of Computing* 18, no. 4 (October 1996), 5–15.

Bregzis, Ritvars, Calvin C. Gotlieb and Carole Moore, "The Beginning of Automation in the University of Toronto Library, 1963–1972", *IEEE Annals of the History of Computing* 24, no. 2 (Apr–Jun 2002), 50–70.

Brennan, Jean Ford, *The IBM Watson Laboratory at Columbia University: A History* (IBM, 1971).

Bromley, Allan G., "Analog Computing Devices", in Aspray, *Computing Before Computers*, 156–199.

Bruemmer, Bruce H., "Early Computer User Groups", *Annals of the History of Computing* 12, no. 01 (1990), 55–61.

Buchholz, Werner, "Anecdotes: Origin of the Word Byte", *Annals of the History of Computing* 3, no. 1 (January–March 1981), 72–72.

Campagna, Palmiro, *Requiem for a Giant: A.V. Roe Canada and the Avro Arrow* (Toronto: Dundurn Group, 2003).

Campbell, Scott M., "Beatrice Helen Worsley: Canada's Female Computer Pioneer", *IEEE Annals of the History of Computing* 25, no. 3 (Oct-Dec 2003), 51–62.

Campbell, Scott M., "Review: The Computer Revolution in Canada", *Scientia Canadensis* 27 (2003), 126–129.

Campbell-Kelly, Martin, "Programming the EDSAC: Early Programming Activity at the University of Cambridge", *Annals of the History of Computing* 2, no. 01 (1980), 7–36.

Campbell-Kelly, Martin, "Programming the Mark I: Early Programming Activity at the University of Manchester", *IEEE Annals of the History of Computing* 2, no. 2 (April-June 1980), 130–168.

Campbell-Kelly, Martin, "The Development of Computer Programming in Britain (1945 to 1955)", *Annals of the History of Computing* 4, no. 02 (1982), 121–139.

Campbell-Kelly, Martin, "Christopher Strachey, 1916-1975: A Biographical Note", *Annals of the History of Computing* 7, no. 01 (1985), 19–42.

Campbell-Kelly, Martin, *ICL: A Business and Technical History* (Oxford, New York: Clarendon Press, Oxford University Press, 1989).

Campbell-Kelly, Martin, "Punched Card Machinery", in Aspray, *Computing Before Computers*, 122–155.

Campbell-Kelly, Martin ed., *The history of mathematical tables: from Sumer to spreadsheets* (Oxford, New York: Oxford University Press, 2003).

Campbell-Kelly, Martin and William Aspray, *Computer: A History of the Information Machine*, 1st edition (New York: BasicBooks, 1996).

Campbell-Kelly, Martin and Michael R. Williams eds., *The Moore School lectures: Theory and Techniques for Design of Electronic Digital Computers* (Cambridge, Mass., Los Angeles: MIT Press, Tomash Publishers, 1985).

Campbell-Kelly, Martin and Michael R. Williams eds., *The Early British Computer Conferences* (Cambridge, Mass., Los Angeles: MIT Press, Tomash Publishers, 1989).

Ceruzzi, Paul E., *Reckoners: The Prehistory of the Digital Computer* (Westport, Conn.: Greenwood Press, 1983).

Ceruzzi, Paul E., "Electronics Technology and Computer Science, 1940-1975: A Coevolution", *Annals of the History of Computing* 10, no. 04 (1988), 257–275.

Ceruzzi, Paul E., "Relay Calculators", in Aspray, *Computing Before Computers*, 200–222.

Ceruzzi, Paul E., *A history of modern computing* (Cambridge, Mass.: MIT Press, 1998).

Cohen, I. Bernard, *Howard Aiken: Portrait of a computer pioneer* (Cambridge, MA: MIT Press, 1999).

Cortada, James W., *Before the computer: IBM, NCR, Burroughs, and Remington Rand and the industry they created, 1865-1956* (Princeton, N.J.: Princeton University Press, 1993).

Croarken, Mary, *Early Scientific Computing in Britain* (Oxford (England), New York: Clarendon Press, Oxford University Press, 1990).

Dornian, Alan, "ReserVec: Trans-Canada Air Lines' Computerized Reservation System", *Annals of the History of Computing* 16, no. 02 (1994), 31–42.

Edwards, Paul N., "Think Piece: Making History – New Directions in Computer Historiography", *IEEE Annals of the History of Computing* 23 (January 2001), 86–88.

Eggleston, Wilfrid, *National Research in Canada: The NRC, 1916-1966* (Toronto: Irwin Clarke, 1978).

Ensmenger, Nathan and William Aspray, "Software as Labor Process", in Hashagen et al., *History of Computing: Software Issues. International Conference on the History of Computing, ICHC 2000, April 5-7, 2000, Heinz Nixdorf MuseumsForum, Paderborn, Germany*, 139–165.

Ensmenger, Nathan L., "The 'Question of Professionalism' in the Computer Fields", *IEEE Annals of the History of Computing* 24, no. 4 (October-December 2001), 56–74.

Estrin, Gerald, "The WEIZAC Years (1954-1963)", *Annals of the History of Computing* 13, no. 04 (1991), 317–339.

Friedland, Martin L., *The University of Toronto: A History* (Toronto: University of Toronto Press, 2002).

Froese Fischer, Charlotte, *Douglas Rayner Hartree: his life in science and computing* (Singapore, London: World Scientific, 2003).

Galler, Bernard A., "The IBM 650 and the Universities", *Annals of the History of Computing* 8, no. 01 (1986), 36–38.

Grier, David Alan, "From the Editor's Desk", *IEEE Annals of the History of Computing* 26, no. 3 (July-September 2004), 2–3.

Grier, David Alan, *When computers were human* (Princeton: Princeton University Press, 2005).

Griffith, Byron A., "My Early Days in Toronto", *IEEE Annals of the History of Computing* 16, no. 2 (1994), 55–64.

Haigh, Thomas, "The Chromium-Plated Tabulator: Institutionalizing an Electronic Revolution, 1954-1958", *IEEE Annals of the History of Computing* 24, no. 4 (October-December 2001), 75–104.

Hashagen, Ulf, Reinhard Keil-Slawik and Arthur L. Norberg eds., *History of Computing: Software Issues. International Conference on the History of Computing, ICHC 2000, April 5-7, 2000, Heinz Nixdorf MuseumsForum, Paderborn, Germany* (Berlin: Springer, 2002).

Heising, William P., "The Emergence of FORTRAN IV from FORTRAN II", *Annals of the History of Computing* 6, no. 1 (1984), 31–32.

Hemmes, David, "FORTRANSIT Recollections", *Annals of the History of Computing* 8, no. 01 (1986), 70–73.

Hord, R. Michael, *The Illiac IV, the first supercomputer* (Rockville, Md.: Computer Science Press, 1982).

Howlett, Jack, Nicholas C. Metropolis and Gian-Carlo Rota eds., *A History of Computing in the Twentieth Century: A Collection of Essays* (New York: Academic Press, 1980).

Hume, J.N.P., "Development of Systems Software for the Ferut Computer at the University of Toronto, 1952 to 1955", *IEEE Annals of the History of Computing* 16, no. 2 (1994), 13–19.

Johnson, D. L., "Generating and Testing Pseudo Random Numbers on the IBM Type 701", *Mathematical Tables and Other Aids to Computation* 10, no. 53 (Feb 1965), 8–13.

Kates, Josef and Victor G. Smith, "The Scotch Plaid Raster", *Transactions of the American Institute of Electrical Engineers* 70 (1951).

Kempner, A.J., "On the separation and computation of complex roots of algebraic equations", *University of Colorado Studies* 16 (1928), 75–87.

Knuth, Donald E., "George Forsythe and the Development of Computer Science", *Communications of the ACM* 15, no. 8 (August 1972), 721–726.

Knuth, Donald E. and Luis Trabb Pardo, "The Early Development of Programming Languages", in Howlett et al., *A History of Computing in the Twentieth Century: A Collection of Essays*, 197–274.

Lavington, Simon H., *A History of Manchester Computers* (National Computing Centre, Manchester, England: NCC Publications, 1975).

Lavington, Simon H., "The Manchester Mark I and Atlas: A Historical Perspective", *Communications of the ACM* 21, no. 1 (1978), 4–12.

Lavington, Simon H., *Early British Computers* (Manchester: Manchester University Press, 1980).

Mahoney, Michael S., "Computer Science: The Search for a Mathematical Theory", in John Krige and Dominique Pestre eds., *Science in the 20th Century* (Harwood Academic Publishers, 1997), 617–634.

Mahoney, Michael S., "Software as Science – Science as Software", in Hashagen et al., *History of Computing: Software Issues. International Conference on the History of Computing, ICHC 2000, April 5-7, 2000, Heinz Nixdorf MuseumsForum, Paderborn, Germany*, 25–48.

McGregor, J., "Professor paved the way for blind students", *London Free Press* (August 11 2002).

McKenzie, D.P., "Edward Crisp Bullard. 21 September 1907-3 April 1980", *Biographical Memoirs of Fellows of the Royal Society* 33 (December 1987), 66–98.

McLaughlin, Kenneth, *Waterloo: The Unconventional Founding of an Unconventional University*, 1st edition (Waterloo, Ont.: University of Waterloo, 1997).

Napper, R.B.E., "The Manchester Mark 1 Computers", in Rojas and Hashagen, *The First Computers: History and Architectures*, 365–377.

Nash, Stephen ed., *A History of Scientific Computing* (New York: ACM Press, 1990).

Owens, Larry, "Vannevar Bush and the Differential Analyzer: The Text and Context of an Early Computer", *Technology and Culture* 27, no. 1 (January 1986), 63–96.

Owens, Larry, "Where Are We Going, Phil Morse? Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957", *IEEE Annals of the History of Computing* 18, no. 4 (October 1996), 34–41.

Perlis, Alan J., "Two Thousand Words and Two Thousand Ideas-The 650 at Carnegie", *Annals of the History of Computing* 8, no. 01 (1986), 42–46.

Petiot, Linda, "Dirty Gertie: The DRTE Computer", *Annals of the History of Computing* 16, no. 02 (1994), 43–52.

Pinch, Trevor J. and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts: Or How Sociology of Science and the Sociology of Technology Might Benefit Each Other", in Wiebe E. Bijker, Thomas Parke Hughes and Trevor J. Pinch eds., *The Social Construction of Technological Systems* (Cambridge, Mass.: MIT Press, 1987), 17–47.

Pollack, Seymour V., "The Development of Computer Science", in Pollack, *Studies in Computer Science*, 1–51.

Pollack, Seymour V. ed., *Studies in Computer Science* (Washington, D.C.: Mathematical Association of America, 1982).

Porter, Arthur, "Building the Manchester differential analyzers: A personal reflection", *IEEE Annals of the History of Computing* 25, no. 2 (April–June 2003), 86–92.

Porter, M.E., *Competitive Advantage: Creating and Sustaining Superior Performance* (New York: The Free Press, 1985).

Pounder, E.R., "William Heriot Watson 1899-1987", *Transactions of the Royal Society of Canada, Series VI* 1 (1990), 595–598.

Pugh, Emerson W., *Building IBM: Shaping an Industry and Its Technology* (Cambridge, Mass.: The MIT Press, 1995).

Randell, Brian ed., *The Origins of Digital Computers*, 2nd edition (Berlin: Springer-Verlag, 1975).

Raymond, Eric S. ed., *The new hacker's dictionary*, 3rd edition (Cambridge, Mass.: MIT Press, 1996).

Robinson, Gilbert de Beauregard, *The Mathematics Department in the University of Toronto, 1827-1978* (Toronto: University of Toronto Press, 1979).

Rogers, Everett M., *Diffusion of Innovations*, 5th edition (New York: The Free Press, 2003).

Rojas, Raúl and Ulf Hashagen eds., *The First Computers: History and Architectures* (Cambridge, Mass.: MIT Press, 2000).

Schlombs, Corinna, "Towards International Computing History", *IEEE Annals of the History of Computing* 28, no. 1 (Jan-Mar 2006), 108,107.

Scott, James, *Of Mud and Dreams: University of Waterloo, 1957–1967* (Toronto: Ryerson Press, 1967).

Smillie, Keith W., "Velvet Gloves and Latin Squares: Memories of Some Early Computing in Canada", in L. Gotlieb ed., *Canadian Information Processing Society Session 84 Proceedings* (1984), 323–326.

Smillie, Keith W., "People, Languagaes, and Computers: A Memoir", *IEEE Annals of the History of Computing* 26, no. 02 (2004), 62–74.

Stachniak, Zbigniew, "The Making of the MCM/70 Microcomputer", *IEEE Annals of the History of Computing* 25, no. 3 (April–June 2003), 62–75.

Stern, Nancy, "The Eckert-Mauchly Computers: Conceptual Triumphs, Commercial Tribulations", *Technology & Culture* 23, no. 4 (October 1982), 569–582.

Strauss, Marina, "Harvey Gellman: 1924-2003", *The Globe and Mail* (10 May 2003), F11.

Thomas, David, *Knights of the New Technology: The Inside Story of Canada's Computer Elite* (Toronto: Key Porter Books, 1983).

Trimble, George R., "The IBM 650 Magnetic Drum Calculator", *Annals of the History of Computing* 8, no. 01 (1986), 20–29.

Vardalas, John N., "From DATAR to the FP-6000: Technological Change in a Canadian Context", *Annals of the History of Computing* 16, no. 2 (Summer 1994), 20–30.

Vardalas, John N., *The Computer Revolution in Canada: Building National Technological Competence* (Cambridge, Mass.: MIT Press, 2001).

Welch, Gregory W., Robert V. D. Campbell and I. Bernard Cohen eds., *Makin' Numbers: Howard Aiken and the Computer* (Cambridge, Mass.: MIT Press, 1999).

White, Richard, *The Skule Story: The University of Toronto Faculty of Applied Science and Engineering, 1873-2000* (Toronto: Faculty of Applied Science and Engineering, University of Toronto, 2000).

Wilkes, Maurice V., *Memoirs of a Computer Pioneer* (Cambridge, Mass.: MIT Press, 1985).

Williams, Michael R., "UTEC and Ferut: The University of Toronto's Computation Centre", *IEEE Annals of the History of Computing* 16, no. 2 (1994), 4–12.

Williams, Michael R., *A History of Computing Technology*, 2nd edition (Los Alamitos, Calif.: IEEE Computer Society Press, 1997).

Williams, Michael R., "A Preview of Things to Come: Some Remarks on the First Generation of Computers", in Rojas and Hashagen, *The First Computers: History and Architectures*, 1–13.

Secondary Sources (Unpublished, URLs)

"Los Alamos National Laboratory: History: Staff Biographies: J. Carson Mark" ⟨URL: `http://www.lanl.gov/history/people/J_Mark.shtml`⟩ – visited on 10 April 2006.

Campbell, Scott M., "'WAT' For Ever: Student-Oriented Compilers and Computing at the University of Waterloo, 1957-1967", Institute for the History and Philosophy of Science and Technology, University of Toronto (2001).

Hendriks, Martha, "An Institutional History of The Department of Computer Science at the University of Toronto: 1948-1971" (1992).

Information Services, "St. Lawrence Seaway History", Technical report (The St. Lawrence Seaway Management Corporation, March 2003).

Shaw, G.C. and V. Kaczkowski, "St. Lawrence Seaway", *Canadian Encyclopedia* (21 March 2006 2006), ⟨URL: `http://www.thecanadianencyclopedia.com`⟩.

Smillie, Keith W., "The Computer and Me: Desk Calculators" ⟨URL: `http://www.cs.ualberta.ca/~smillie/ComputerAndMe/Part08.html`⟩ – visited on 3 March 2004.

Smillie, Keith W., "The Department of Computing Science: The First Twenty-Five Years", Technical report TR91-01 (Department of Computer Science, University of Alberta, February 1991).