A batch-processing operating system for the Whirlwind I computer

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ABSTRACT

The Whirlwind I computer was developed at M.I.T. in the late 1940s and early 1950s primarily for use in real-time applications, most notably in early development of the U. S. continental air defense system. It was the fastest first-generation machine and the first to use magnetic core memory. Under sponsorship of the Office of Naval Research, time on Whirlwind was made available for general-purpose use by M.I.T. students and researchers on a program-it-yourself basis, their use coordinated and supported by the small so-called Scientific and Engineering Computation Group. During 1951 through 1955, this group developed a variety of coding techniques and aids for using Whirlwind, including a batch-processing operating system incorporating many of the logical capabilities which appear in today's systems. The hardware available, the operational philosophy, and the accomplishments of the group are briefly described.

THE WHIRLWIND I COMPUTER

The development of operating systems for the Whirlwind I computer was an evolutionary process which extended over the entire decade from its early operation in 1950 until its retirement in 1959, with the greatest effort concentrated in the early half of the decade. It also extended over Whirlwind's two distinct areas of intended application as: (1) a real-time control system, and (2) a general-purpose computational tool. I can only report on the latter application area. Before I attempt to describe some of the operational thinking and accomplishments of the 1951–1955 period, let me outline the evolving hardware context which led up to and through that time period.

History

I joined Project Whirlwind in the Servomechanisms Laboratory at the Massachusetts Institute of Technology on a part-time basis in December 1947, while I was still an undergraduate. The project had been in existence for three years under the sponsorship of the Special Devices Section of the Navy's Bureau of Aeronautics before being transferred to the new Office of Naval Research (ONR).[1] Its original purpose had been to develop an aircraft flight simulator incorporating a real-time stability and control analyzer, for which its young project leader, Jay W. Forrester, had first thought in terms of analog computation. After visiting the University of Pennsylvania in the Fall of 1945, he decided instead to build a general-purpose digital computer which would be called Whirlwind I.

Logical Design

Whirlwind's intended real-time applications required high speed and high reliability but not particularly high precision. The logical design which Robert R. Everett completed in 1947 called for a 16-binary-digit parallel machine with instructions comprising a 5-bit operation code and a single 11-bit address capable of addressing an internal storage of 2048 words. In today's terms, this would be a 4K-byte RAM, although the use of pure binary numbers made each word capable of storing a sign and about 4.5 decimal digits.

Whirlwind's instruction code, like many other first-generation machines, bore considerable similarity to von Neumann's IAS computer (which was to store 1024 40-bit words with two instructions per word). Operating in parallel at a one megahertz cycle rate with eight cycles per instruction exclusive of memory access (specified at 8 microseconds, a speed achieved with magnetic cores in 1953 though not with the original electrostatic storage tubes) and built-in multiply and divide (at about 16 and 32 microseconds), Whirlwind performed some 17,000, and after 1953, some 40,000 operations per second, by far the fastest first-generation machine.

Early Programming

I completed my graduate work in the Mathematics Department (my thesis included a Whirlwind program which was never run) and joined Project Whirlwind in February 1949 as a full-time, about-to-be programmer. Programming was a relatively untrodden field at the time since no stored-program computer had yet gone into operation anywhere in the world. (Wilkes's serial, mercury-delay-line-storage EDSAC at Cambridge University became the first on May 5, 1949.) My job was to develop programs intended to aid future scientific and engineering users in making use of a portion of the time available on Whirlwind for research projects of their own. This allocation was to continue despite the high priority of the intended real-time control applications which, over the next three years, evolved from flight analysis through air traffic control to continental air defense (and, ultimately, the SAGE system). By 1951, hardware development was under Air Force sponsorship, though ONR retained an interest in the use of Whirlwind for general-purpose computation, and Project Whirlwind had become the M.I.T. Digital Computer Laboratory.

Initially, these user aids were envisioned as preprogrammed sub-routines to handle such things as decimal-to-binary and binary-to-decimal conversions for input and output, the computation of roots, trigonometric and other mathematical functions, the solution of algebraic and differential equations, and the processing of complex variables, matrices and the like. But practical experience, hard and slowly learned, suggested that these facilities, though important, were not the crux of the problem.

Test Storage

By 1950, the central processor was in operation, but due to difficulties with the specially-designed electrostatic storage tubes which were to provide the main memory, our only hands-on experience with Whirlwind for many months involved the use of a so-called test storage comprising 32 words of what is today called programmable read-only memory or PROM, with each bit represented by a toggle switch, and five words of flip-flops (vacuum-tube circuits storing one bit each) that could be substituted for any five of the PROM registers. Each flip-flop register could be preset to a value set in front-panel toggle switches and its contents were continuously indicated on the front panel. In addition to its extensive use to test hardware and to demonstrate the early Whirlwind, this test storage served permanently as Whirlwind's "bootstrap" loader.

Early Peripheral Devices

The early input equipment was limited to, besides the quite useful toggle switches mentioned above, a slow punched-paper tape reader. Output, in addition to the indicator lights on the flip-flop and internal registers, and the audio output mentioned below, comprised a ten-character-per-second printer and, more importantly, a device unique to Whirlwind among early machines and crucial to its air defense applications—a cathode-ray-tube (CRT), the beam of which could be deflected to arbitrary x and y coordinates by output instructions. Probably the most widely seen demonstration of Whirlwind, before electrostatic storage become operational, used the CRT to display the solution to the differential equation describing a ball bouncing on a horizontal axis, repeated at successively-increased horizontal speeds until it hit a hole in the floor and fell through.

After electrostatic storage made possible more elaborately scaled and calibrated graphics, and computer-generated dot-matrix decimal and alphanumeric displays of a thousand or more characters per frame at about 200 characters per second, an automatic camera was attached to a second CRT so that graphs and, more importantly, memory dumps and other aids to program debugging, could be recorded for future reference. Another off-beat but useful output, incorporated after we noted the sound of unintentional audio crosstalk on intercom wires strung around the 2500-square-foot computer area to permit maintenance engineers to talk to operators, consisted of intercom stations connected to selected flip-flops in the accumulator, program counter or elsewhere, so an operator could hear how things were progressing and know when a bug had put the program into an endless loop. This also led inevitably to programs to make the computer play recognizable tunes.

Full-scale Storage

When reasonably reliable operation of the early 16×16 bit electrostatic storage tubes began late in 1950, the availability of 256 additional words of storage opened whole new vistas after months of cramming things into 32 words. Reasonably reliable operation was unfortunately preceded by some months of reasonably unreliable operation—I can still feel the pain of watching on a monitor while a small black cloud would slowly overspread the pattern of bits in a defective tube and my program would sputter and die, with an audio accompaniment not unlike the sound of an encephalogram of a patient dying on TV today. By late 1951, a second bank of tubes, each capable of storing a 32×32 array, expanded the memory to 1280 words, not counting test storage and the 100 or so unconsecutively numbered locations we sometimes used, that lay inside the circumference but outside the 16×16 square array in the first bank of tubes. Almost 3K bytes; this was heaven indeed.

By that time, work on a coincident-current magnetic core memory conceived by Forrester in the Spring of 1949 had progressed to the point at which it appeared more promising than the electrostatic tubes, both in speed and in reliability, but the electrostatic memory continued in use until it could be replaced in August and September 1953 by 2048 words of 8 microsecond-access cores in two 16-high stacks of 32×32 core arrays. This form of memory quickly became the standard of the computer industry and remained so for roughly the next 15 years.

Later Peripheral Devices

The 1951 to 1953 period also saw the addition of: a magnetic drum system with a 64K-byte capacity and 64K-byte-per-second transfer rate; four magnetic tape drives each with 250K-byte capacity and about 800-byte-per-second transfer rate in which the tapes were for all practical purposes not removable; a 200-character-per-second photoelectric paper tape recorder which to our great joy could stop and start between individual characters rather than requiring an inch or two of blank tape for stopping as an earlier, slower unit had; a real-time clock useful in logging; a 1200-digit-per-second character generator for the CRT; and a joystick and later a light gun for use with the CRT (facilities important for air defense applications and for demonstrations but not used in the general-purpose system). In a 1954 description of the system,[2] I described the core, drum, and tape capabilities as "a storage hierarchy of ample sizes, speeds, and versatility," something I would hardly say today.

THE GENERAL-PURPOSE OPERATING SYSTEM

As mentioned, the intent of Whirlwind's so-called Scientific and Engineering Computation (S&EC) Group which I headed under ONR sponsorship was to make the computer available to qualified users with the proviso that they do their own programming, and to provide support for training offered to graduate and undergraduate students, and (through special one and two week full-time summer session courses) to interested people from business and industry. Wearing a second hat as Assistant Professor of Digital Computation in the Electrical Engineering Department, I had the pleasure of preparing and teaching both the regular and the summer programs at M.I.T. during that period. During 1953 and 1954, Whirlwind was used by 10 staff members of the S&EC Group, by some 35 graduates and four undergraduates in connection with their theses, and by about 25 undergraduates, 40 graduates, and 100 summer students in connection with M.I.T. courses.

Batch Processing

With so many users sharing the 40 or so hours per week of Whirlwind time available to this activity, much of it scheduled in the middle of the night and on weekends, hands-off batch processing was the order of the day. Whirlwind's file storage capabilities may have been "ample" for one user at a time, but would have been grossly inadequate for online multi-task moment-by-moment time sharing developed a few years later by another group on another computer at M.I.T.

It is perhaps interesting to note that the luxury of time-shared access to supercomputers and of full-time access to powerful personal computers are enjoyed by today's users at monthly costs approximating their own salaries for a single day. In the early 1950s, the daily salary of a Whirlwind user, if indeed he had one, would not normally have covered the cost of half a minute of machine time.

Assemblers and Interpreters

Operating as it did on short fixed-point pure-binary words, Whirlwind clearly required input and output conversion routines and some way of extending the effective word length for computational purposes. It took only a little exposure to the problems of assigning absolute memory locations to variables and instructions to suggest that the task should be handled along with decimal-to-binary conversion by the computer itself, through the actual implementation of assembly programs with symbolic (we called them "floating") addresses extended over several years.

Double-precision arithmetic seemed best accomplished by an interpretive routine, a program which treated the instructions specified by a user as data to be interpreted and then executed one at a time. Given a double-precision interpreter, a floating-point capability could be included at little extra cost in machine time. Furthermore, an interpreter could greatly facilitate the debugging of a program by pre-checking for some kinds of mistakes and by storing a trail (a "trace") of the logical path followed and of intermediate results to the extent desired by the user.

There was also no great additional time required to interpret instructions written in a form unrelated to the single-address instruction logic built into Whirlwind. This led to the development of fairly powerful and more easily debugged (but still machine-like) languages such as the Summer Session and the TAC and SAC languages used in the 1953 and 1954 summer courses. An interpreter was also used to implement an Algebraic Language developed by two users of Whirlwind, J. H. Laning and N. Zierler, which was an early precursor to the FORTRAN language later implemented with a compiler.

The "Comprehensive System"

Most users, other than students in M.I.T. courses, used the so-called Comprehensive System. They wrote their own programs as machine-language instructions in assembly-language form with numerical computation to be executed by an interpreter in double-precision floating point (signed 24-bit numbers with signed 6-bit scale factors, roughly equivalent to 7-decimal-digit precision with magnitudes ranging from 10^{-10} to 10^{10}) while logical computation was executed in Whirlwind's internal format (signed integers from -32767 to 32767).

Operational Procedures

Whether written in the Comprehensive System, the Summer Session or other languages, programs were keyed and verified on six-hole paper tape by trained personnel in Whirlwind's tape preparation room, each tape identified by job, user, program and revision number. Listings were returned to the users and tapes filed in the room. When a user wished a test or production run, he or she filled out a brief performance request form specifying the paper tape or tapes to be run and any special instructions, though for the most part the entire specification was expected to be included in the tape(s) being run. Information needed for the analysis of program performance, beyond that generated by the program itself or routinely provided by the operator and the system, was specified on a "post-mortem request" tape to be run at the termination of failed program. By 1955, performance requests were often specified on a "director" tape which controlled the processing of a series of individual runs.

Thus, the files of user programs, data, and results were kept on paper tape and in printed or plotted form, produced by professional operators and filed manually by clerks. Assemblers, interpreters, utility programs, and post-mortems were kept on a single magnetic tape. They amounted to about 24K bytes for the entire Comprehensive System and 16K bytes for the Summer Session system. From tape, they were automatically copied to core or drum as required. Programs were assembled prior to each run using two other tapes for auxiliary storage in a two-pass system.

CONCLUSION

While the users of Whirlwind would certainly have been happy to have had today's facilities available to them, they would also surely recognize many of the logical capabilities of today's operating system in the system they used in 1955 and before.

ACKNOWLEDGEMENTS

The development of the Comprehensive System at M.I.T. paralleled that of other systems at the time and drew a considerable part of its inspiration from them, most notably from the Cambridge University group. Several of its leading lights, M. V. Wilkes, D. J. Wheeler, S. Gill and E. Mutch, participated in one or more Summer Sessions and shared many ideas with us. Those at Whirlwind who contributed ideas and working programs to the system included, in alphabetical order, D. N. Arden, S. Best, D. Combelic, M. S. Demurjian, H. H. Denman, J. T. Gilmore, J. M. Frankovich, I. Hazel, F. C. Helwig, E. S. Kopley and J. D. Porter (who took over direction of the group as I phased out of it).

REFERENCES

1. Redmond, Kent C., and Thomas M. Smith. *Project Whirlwind—The History of a Pioneer Computer* Bedford, Massachusetts: Digital Press, 1980.
2. Adams, Charles W. "Report R-233—The M.I.T. System of Automatic Coding: Comprehensive, Summer Session, and Algebraic—a Talk Delivered at the Symposium on Automatic Programming for Digital Computers, May 12, 1954," Cambridge, Massachusetts: Digital Computer Laboratory, M.I.T., 1954.