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Elected FRS 1965

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Early life and war service

Tom Kilburn was one of the early pioneers of the stored-program computer. He was born on 11 August 1921 in Earlseaton near Dewsbury in the West Riding of Yorkshire. His father was John William Kilburn, who was initially a statistical clerk and then a company secretary.

Kilburn attended Wheelwright Grammar School, Dewsbury, which was a school of high academic standards and regularly sent boys to Cambridge and Oxford. Kilburn was there from September 1932 to July 1940. He was obviously a high flyer. When it came to specializing, he felt drawn towards chemistry, but his headmaster persuaded him to do mathematics instead. He was interested in sport and athletics, and was a keen footballer. He took the Higher School Certificate Examination (in four subjects) and on the results he was awarded a State Scholarship and a County Major Scholarship. He had the further success of being awarded a Minor Open Scholarship to Sidney Sussex College, Cambridge.

Kilburn went up to Sidney Sussex in 1940, when the war was in progress. He elected to take the course for the Mathematical Tripos, or rather a two-year version of it, because two years at the university were all that students were allowed under wartime regulations. Although it is not obvious from its name, the Mathematical Tripos stressed mathematical physics just as strongly as pure mathematics, and it had long been one of the traditional routes to a career in physical science. It would have provided Kilburn with a strong exposure to electromagnetic theory.

Kilburn duly obtained first-class honours both in Part I of the Tripos and in the Preliminary Examination for Part II. His academic record clearly marked him out for a research appointment, and he was offered and accepted an appointment at the Telecommunications Research Establishment (TRE), Malvern, the establishment responsible for research and development of radar for the Royal Air Force (RAF). After a crash course in electronics at the City and Guilds College, he joined TRE on 10 September 1942 and was put to work in Group 19, led by F.C. (later Sir Frederic) Williams (FRS 1950), a virtuoso of electronic circuit design with a flair for practical applications. Williams had contributed on the circuit side to IFF (Identification Friend and Foe), GCI (Ground Controlled Interception), Rebecca-Eureka, and Oboe. Given his ultimate role in life, there could not have been a better environment for Kilburn to serve his apprenticeship. In 1943 he married Irene Marsden.

The cathode ray tube memory

Williams visited the USA in June 1946. While there, he heard talk about the possibility of storing information in the form of a charge distribution on the back of the screen of an ordinary cathode ray tube (CRT). Initially, Williams's interest was aroused because of possible applications in radar. The challenge in developing an effective system lay in the fact that the charge distribution would rapidly leak away and the information would be lost. This would be prevented if means could be found for continually reading the information and rewriting it at sufficiently short intervals for no serious degeneration to occur.

On his return to TRE, Williams started a series of experiments and by mid-October 1946 he was able to demonstrate the storage of a single bit. By that time it had become apparent that CRT storage might have a crucial role in the development of digital computers. Kilburn, who had been working under Williams on other projects for about four years, was assigned to work on the memory. E.H. Cooke-Yarborough has told us that he heard a lecture that Williams gave on the subject of CRT memories, and noted that Kilburn had become an important member of the group. In December 1946 Williams moved from TRE to the University of Manchester, where he became Professor of Electro-Technics and Head of the Department. The work on the CRT memory was still at a very early stage and Williams made plans to continue it at the university. In this he had the support of the Government and, as part of the support, Kilburn was seconded to work under Williams at the university, while remaining on the TRE strength. The secondment took effect on 14 January 1947.

Kilburn had been moving up through the grades of the Scientific Civil Service. He had joined as an Assistant Grade 3 and went up to Junior Scientific Officer on 1 April 1943; he became an Acting Scientific Officer on 1 April 1945. On 2 October 1946, when it was known that he would be seconded to the University of Manchester, his appointment as a Scientific Officer was confirmed; promotion to Senior Scientific Officer was mooted, but he was considered too young. On 1 December 1947 he completed a progress report for TRE covering his year's work on secondment at the University and summarizing the work done so far on the CRT memory (1)*. This report received wide circulation, both in Britain and in the USA.

The first author of this memoir met Kilburn when he and Williams were settled in at Manchester and beginning to think about the design of a computer that would use the CRT memory. Kilburn took a full part in the discussion and, at the end of the day, the first author asked Williams about him and his background. 'What you must always remember', said

* Numbers in this form refer to the bibliography at the end of the text.

Williams, 'is that Tom is a Yorkshireman'. It was a good summing up; a Yorkshireman Kilburn was, and a Yorkshireman he remained, even after a long residence west of the Pennines.

Contribution to development of the CRT memory

Late in his life Kilburn gave a talk to the Computer Conservation Society in London on his early work. A transcript of the talk is printed in *Computer Resurrection,* the Bulletin of the Computer Conservation Society (7). Kilburn began by describing the work he had done during his first three months at Manchester; this included exploring the design space with a view to arriving at the best possible design. In the 1947 report mentioned above, Kilburn had described various alternatives to the system used for the original demonstration in which zeros were represented by a dot written on the tube and ones by a dash. All these had to be investigated and evaluated. In the end, Kilburn fixed on a system in which a focused spot and a defocused spot were used, a system that he found to be markedly superior.

There was also a problem that had worried Williams from the beginning. The CRT memory was highly susceptible to interference; with the early version it only needed someone to ride down the road on a motorcycle to fill the whole tube with random zeros and ones. A cathode ray tube is an awkward object to screen, but eventually an adequate solution to the problem was arrived at. Kilburn goes on (7):

> We had a cathode ray tube which would store patterns on the CRT store over long periods but it wasn't really proof that the cathode ray tube system would work in a computer, because if at very high speed you write noughts over ones, or ones over noughts, which is what you are doing in the computer constantly, the signals you get from the screen are not balanced and the base line starts heaving up and down. We'd never seen this heaving up and down because we'd never fed it quickly enough but we surmised that it would be there and indeed it was.
>
> So I decided to design some gear which would test this, but after a few weeks (actually I was travelling into Yorkshire at the time in that awful winter of 1947 and I did a lot of design on the train) one of the conclusions I came to was that the only way to test whether the cathode ray tube system would work in a computer was, in fact, to build a computer. So I designed the smallest computer which was a true computer (that is a stored program computer) which I could devise, and we ended up with a one-tube, 32-lines, 8-digit machine. The signals did in fact heave up and down and the design of the amplifier and the clamping system to deal with that was quite an interesting exercise.

This was the origin of the famous 'baby'. Not only did it serve its primary purpose of being the vehicle whereby confidence in the CRT memory was established, but it was also the first example of a computer working on the stored-program principle to be demonstrated. The original program that was run on the 'baby' on 21 June 1948 was one to determine the highest factor of a given integer.

Besides giving some feeling for the period, the above quotation shows that Kilburn fully recognized that there was a dimension to computer design that went beyond the kind of circuit engineering that he had learned in Williams's group. This can be summarized by saying that the circuits must be capable of handling completely arbitrary waveforms without any bits being lost or spurious bits being introduced. A failure that, in a radar or television set, would merely lead to a harmless flash on the screen would, in a computer, most probably lead to a permanent error.

Testing computer circuits for freedom from errors arising in the above way is full of pitfalls and Kilburn showed remarkable insight by realizing, at that early period, that the only really reliable way to test a computer component is to run it on a computer.

Kilburn had taken advantage of his secondment to the university by registering for a PhD. He wrote a thesis based on his work on CRT storage and took his degree in 1948. Although Kilburn was not yet leading the computer developments and was registered for a PhD himself, he began to help Williams to guide and supervise the work of new research students who joined the group. Williams continued to keep a very close eye on the work being done and played a full part in all the discussions that took place.

Having successfully completed the 'baby' and used it to establish the viability of the CRT memory as an effective storage mechanism for an electronic computer, Kilburn now felt that the job for which he had been on loan from TRE was finished. He had been promoted to Acting Senior Scientific Officer on 1 November 1948, and he now looked forward to taking some holiday and returning to TRE.

This was not to be. Discussions between Williams and Sir Ben Lockspeiser (FRS 1949), Chief Scientist at the Ministry of Supply, led to a contract to design and build a full-scale computer to Williams's specification being placed by the Ministry with Ferranti Ltd. This computer was intended to be the first example of a commercial design which was to be marketed in due course by Ferranti. To provide Ferranti with design information, it would be necessary for Williams's group to build an engineering prototype. Kilburn was clearly a key man as far as this project was concerned, and Williams arranged for him to be offered a post as university lecturer to work on it. Kilburn accepted this offer and sent in his resignation from government service, to take effect on 31 December 1948.

Ferranti Mark I

Williams and Kilburn decided not to design and build a prototype *ab initio.* Instead, they proceeded by way of a series of enhancements of the 'baby', which, in consequence, evolved through a series of working computers, each larger and more powerful than the one before. One of the first enhancements was the introduction of index registers, long referred to at Manchester as B-lines. The index register was an early Manchester invention that became universally adopted. It was the brainchild of a small group of which Kilburn was a member, the other members being Williams, M.H.A. Newman FRS and G.C. Tootill.* The team working on the enhancements was expanded to include A.A. Robinson, who worked on multiplier design, G.E. Thomas, who concentrated on the magnetic drum storage, and D.B.G. Edwards, who improved the CRT memory, expanded the order code and provided for programmable transfers of data between the drum and CRT memory.

The final computer in the series, which included a drum acting as a second-level back-up memory, became usable in the summer of 1949 and fully operational by October. It was a machine of some power and enabled the mathematicians to gain valuable experience. It was closed down in the summer of 1950, when delivery of the Ferranti machine was in sight. By that time it had done much useful work on Mersenne numbers and other applications.

The Ferranti machine was delivered in February 1951 and underwent a period of running in. It was demonstrated at a very successful inaugural conference held in July 1951, and it

* Tootill joined the Manchester team on secondment from TRE some months after Kilburn, and worked closely under Kilburn's direction during the design and building of the 'baby'. His notebook of that period is still extant and it is in there, in Kilburn's hand, that the record of the running of the first program is recorded.

quickly got into its stride. The large-capacity magnetic drum was a valuable feature and made the machine useful for problems involving large quantities of data, as well as providing a highly reliable back-up for the CRT memory.

It is evident that Kilburn, now a senior lecturer, had by this time taken over direction of the work on the computer developments from Williams, who was much occupied by the management of his department. Williams's research interests had also shifted to other aspects of electrical engineering. Henceforward, Williams's name is not to be found on the list of authors of published papers on computer topics, with the exception of one published in 1953—on recent advances in CRT storage—that had evidently been drafted earlier (3).

The CRT storage pioneered by Williams and Kilburn received significant take-up internationally. For example, both the IBM 701 and IBM 702 incorporated the CRT storage under licence. Williams and Kilburn worked closely with the National Research Development Corporation (NRDC) on the handling of patents. All existing patents taken out by Williams and Kilburn were transferred to the NRDC, and they arranged that all future patents on inventions by members of the university computer team would be taken out by the NRDC.* It was agreed that any resulting revenue would be shared equally between the NRDC and the university. This revenue from patents provided funding for further research at the university for many years.

The provision of a computing service as a departmental activity became recognized at this time, although it was not until 1951 when R.A. Brooker, then a member of the Cambridge team, was appointed to be leader of the software activity, that the department acquired a strong focus on user requirements.

In return for financial support, the Government made it clear that it expected that computer time would be made available to users outside the University of Manchester. The available time in 1955—about 100 hours a month—was shared out as follows: Computing Machine Laboratory, 12 hours; the rest of the university, 30 hours; other universities, 13 hours; governmental and industrial organizations, 45 hours. As a result of these arrangements, the computer made possible many important contributions to science at Manchester and elsewhere.

Meg and Mercury

Kilburn's interest lay in the continued enhancement of technology and in processor architecture rather than in computer applications. It was therefore natural that as soon as the Ferranti Mark I machine was operational he should turn his attention to the design of a successor machine. He was supported in this by Williams, who continued to contribute to aspects of circuit design. This new machine was known in the laboratory as Meg (megacycle machine). It was intended to be an upgraded version of the Mark I.

There was no problem in upgrading the serial computing circuit to work at 1 megahertz instead of at 0.1 megahertz, but the serial CRT memory was already working close to its ultimate speed. Core memory was known to be under development but had not yet been demonstrated. Accordingly, Kilburn decided to design a parallel CRT memory, 10 bits wide, which was capable of the required data rate, but to do so in such a way that it would be a simple matter to change over to a core memory when that became possible.

* Tom Kilburn was named as inventor or co-inventor on over 75 patents.

Four separate accesses of the 10-bit memory were required for a 40-bit word. The outputs were concatenated and serialized by means of a delay line. The machine had hardware provision for floating-point arithmetic, using a 10-bit exponent and a 30-bit numerical part. A floating point addition took 180 microseconds and a multiplication 360 microseconds. In this form, Meg ran its first program in May 1954. Later, various enhancements were made.

In due course Ferranti produced a commercial version of the Meg and marketed it under the name of Mercury. By then core memory was available and was used in place of the CRT memory. The first shipment was to the Norwegian Defence Research Establishment in August 1957. The second shipment was to the University of Manchester in late 1957, the acceptance tests being passed on 5 February 1958. Mercury was regarded as good value for money and was, in British terms, a commercial success. Nineteen in all were sold and at least four of them were still working in 1970.

Transistor computer

The development of a transistorized computer went on in parallel with that of the Meg and was regarded as primarily a research activity. Originally the intention was to build the smallest possible economic computer, but it was later realized that, if the implementation could be in terms of transistors, much valuable experience of their use would be obtained. The first version was commissioned in November 1953. For main memory it had a magnetic drum, rescued from the final version of the original experimental machine, which had been closed down in the summer of 1950. One track was used for the program counter and another for the accumulator. A 1 + 1 address instruction set, in which the second address specified the location of the next instruction that would be executed, was used in order to make optimum coding possible. Altogether there were 200 transistors and 1300 diodes.

It was a very remarkable achievement to build a working computer at all with such a small amount of equipment, let alone to build it with transistors. The only transistors available were of the point-contact variety. Not only were they difficult to use, but they also presented manufacturing problems that were never properly brought under control. Moreover, they were very unreliable. Nevertheless, the computer worked and much experience was obtained with it. A second extended version, with a hardware multiplier, was commissioned in April 1955.

One would hardly have expected this work to lead to any industrial interest. However, the coming of junction transistors changed the picture, and Metropolitan–Vickers Ltd, a major Manchester-based firm of electrical engineers, was able to redesign the circuits to use them. The resulting computer was running in 1956. Junction transistors were much easier to manufacture. They were also much easier to use in the design of switching circuits because, like vacuum tubes, they presented a high input impedance. Metropolitan–Vickers made six computers in all and used them mainly for internal purposes. They ran for five years and are said to have had an impressive reliability record.

From this point onwards, transistors were to become the regular basis for the design of computers, and the early experience with them that Kilburn and his team had obtained put the team in a strong position to proceed with their next project.

Muse and Atlas

Kilburn initiated the Muse (later Atlas) project in late 1956 with the object of designing a machine that would exploit to the full both existing and emerging technology, and would approach an operating speed of one instruction per microsecond. It would use the fast junction transistors that were then coming available. The Atlas project is to be compared with the IBM STRETCH and the UNIVAC LARC projects, which proceeded in similar time frames.

The Atlas has an important place in the history of the development of computer hardware, because it introduced—and demonstrated the viability of—the one-level memory system. This led the way to the modern virtual memory, a system that is now in universal use even in laptops. Kilburn was also the first designer of a major computer to make multi-programming—that is, the minimization of processor idle time by the rapid switching of the processor from one task to another—an integral part of his design. The Atlas design also included a variety of other speeding-up devices of less seminal importance, for example the use of a fast read-only memory containing code for the implementation of instructions designed to complement the basic instruction set (extracodes). Kilburn also contributed personally to the circuit design of the Atlas, in particular to the design of an adder with a fast carry-path (4, 6).

From the beginning it was clear that the efficient pursuit of the above aims would need more capital than the university could provide. During 1957 and 1958, long-drawn-out discussions between the university, the Government and industry proceeded with the aim of securing the necessary support, but to no avail. Finally, Kilburn decided that he would go ahead on a limited scale using regular departmental resources, supplemented by the reserve that the university had built up from the sale of computer time. Eventually, the NRDC offered some support and, partly as a result, Ferranti saw their way to becoming involved; this was confirmed officially in January 1959.

Kilburn assembled a very able team to work on the Atlas. D.B.G. Edwards, who had been in the group since September 1948, was his second-in-command on the hardware side. D. Howarth from Ferranti, together with F.H. Sumner from the university, led the development of the operating system. Because the operating system was responsible for the management of the processor switching required to implement multi-programming, its development was a major development task. Work on high-level languages and compilers was led initially by R.A. Brooker and later by D. Morris. This included work on the 'Compiler-Compiler' (Brooker *et al.* 1963), a system for the automatic generation of compilers.

It follows from the foregoing that, in the Atlas project, Kilburn found himself concerned in a major way with the management of teams engaged in software development. Although he had written many short test programs to assist in hardware development and had taken an interest in the optimizing of inner loops of larger programs, Kilburn had had no personal experience of the writing and debugging of long programs. At the implementation level he therefore had to rely heavily on the experienced teams that he had established.

Altogether, three Atlas systems were built, including the one for the University of Manchester. The other two went to London University and the Rutherford Laboratory. These gave good service and contributed greatly to the computing power available to the British scientific community. A simplified version, without the paging mechanism and known as Atlas 2, was evolved at Cambridge in conjunction with ICT Ltd (into which the Ferranti computer department had become merged as a result of an industrial merger) and with Kilburn's approval. Two of these, in addition to the prototype, were sold.

At MIT, a group under the direction of F.J. Corbató was working on the operating system for the CTSS, a pioneering time-sharing system running on an IBM 7090 modified by the provision of a second memory bank. This system also depended very heavily on multi-programming. Although the Manchester group was working on a batch processing system, the two groups had much in common, particularly as regards memory protection and the buffering of input and output. This became clear during a panel discussion held at a conference organized by the International Federation for Information Processing in Munich, Germany, in 1962. The panel discussion was arranged by the first author of this memoir, and he invited both Sumner from Manchester and Corbató from MIT to take part (Popplewell 1962).

Department of Computer Science

When the Atlas was fully commissioned and running a computing service, Kilburn did not go on at once to another computer design project. Instead he turned his attention to departmental organization. Up to that time, the computer activity, although virtually autonomous, had been conducted within the Electrical Engineering Department under F.C. Williams. The time was now ripe for it to be transformed into an independent Department of Computer Science that would not only form a home for computer research but would also provide a full range of undergraduate courses leading to first degrees in computer science. Kilburn was to be head of the new department, with the title of Professor of Computer Science, having held the title Professor of Computer Engineering since 1960, when he first became a professor.

The organization and running-up of the new department made a major call on Kilburn's time for the next two or three years. He regarded this as a good investment, because it established a sound base for future projects. The establishment of the undergraduate courses alone was a major undertaking. As might be expected, it put a greater emphasis on hardware than those offered in the departments of computer science that were later to come into operation in other universities. The new department grew rapidly. It started with a faculty of 12 and within three or four years had grown to 16, including four professors.

As the head of what was now a major teaching department, Kilburn found himself drawn into university administration in the wider sense. From 1970 to 1972 he served as Dean of the Faculty of Science and later, from 1976 to 1979, as Pro Vice-Chancellor.

MU5

In about 1966 Kilburn and his team began to work on MU5, which was to be their final major computer project. The architecture of MU5 was specifically designed to provide support for operating systems and high-level languages. An approach was made to ICT for help with the building of the system. ICT were very cooperative and offered the use of their latest technology, including facilities for the manufacture of multi-layer platters for interconnect. On the strength of this, and on the understanding that ICT would also benefit, the Science Research Council (SRC) made the University a large grant, totalling £630 000 over a period of five years.

In late 1968, ICL Ltd—as ICT had become as a result of further mergers—was contemplating a new range of computers, and the MU5 was being thought of as a possible top-end machine for that range. ICL did in fact examine this proposal very seriously, but in the end they chose a composite option that, although owing much to the MU5, also drew on other sources.

When ICL announced the new range (the 2900 series) in April 1974, there was no mention in the announcement of any contribution made by Kilburn and his team. This caused consternation on the university side; Kilburn, in particular, felt strongly that he and his team had suffered a moral wrong. It also caused the SRC to enquire how it came about that the large grant they had made to the university had not benefited ICL.

The Managing Director of ICL endeavoured to make amends in a public speech. After referring to the sources of information that ICL had enjoyed he went on to say ‘perhaps most of all we learnt from the work of Professor Kilburn and his team at Manchester University’ (Lavington 1998, p. 49). This by no means satisfied Kilburn, who, with true Yorkshire bluntness, made it clear that he expected monetary compensation for the university.

This would not be the place to follow the course of the dispute. It was not settled until Kilburn had retired and his successor, D.B.G. Edwards, had taken over. By then major changes had also occurred in the higher management of ICL. ICL agreed to make the university a single payment of £500 000, along with a gift of six PERQ workstations. They also agreed that the university should, for a further period of five years, continue to enjoy a special discount on the purchase of equipment and should have continued access to certain of ICL’s factory facilities on a cost basis. At the same time ICL acknowledged its debt to the university for technical assistance in a form that fully satisfied the SRC. It was a condition of the settlement that this acknowledgement should not be made known except to the SRC until five years had elapsed.*

Once the settlement had been made, cordial relations between the university and ICL were rapidly re-established. This occurred in time for the university to play a full part, jointly with ICL, in certain new government initiatives, especially the Alvey initiative, that made it a requirement that there should be such collaboration.

Personal and professional qualities

In the following passage, the first author recalls how he first came to know Kilburn well:

> Although we met fairly frequently, it was not until 1957 that I got to know Kilburn well. In that year, we both joined a party of British computer scientists and engineers who attended a conference at the Weapons Research Establishment, Salisbury, South Australia, travelling by way of RAF Transport Command. It was a fascinating trip. We flew in a Hudson aircraft, which had four piston engines and cruised at 8000 feet. Jet aircraft were just about to come in, and we were all very conscious of the fact that never again were we likely to have the opportunity of inspecting a representative slice of the Earth’s surface from such a low altitude. The trip took eight days. We flew by day and slept comfortably by night at various staging points along the route. Kilburn entered into the spirit of this adventure and enjoyed it as much as the rest of us did. He was in a relaxed mood, and I date my friendship with him from that time.

Kilburn was among the earliest computer pioneers who established the subject of computer design. He went on to be responsible for a series of machines, all of which were in a true sense his personal creation. He knew how to pick and lead a team, and inspire its members to pull together. This ability was perhaps best illustrated during the design of Atlas, when his technical and managements skills were key factors in the success of the project.

* Our authority for these statements is to be found in a letter, of which a copy is preserved at the University of Manchester, signed by the Vice-Chancellor—Professor Mark (later Sir Mark) Richmond FRS—dated 19 November 1982, and addressed to Mr David Dace, Director Mainframe Systems, ICL, Manchester. Shortly afterwards, Professor Richmond signed an internal letter addressed to the university’s Bursar and others in which he stated that the cheque for £500 000 had been received.

Within his own laboratory, his was the dominating personality and his leadership went unchallenged. Members of his project teams were very loyal to him. In contrast, people who only met Kilburn away from his laboratory were apt to find him a very private person. This also applies, in varying degrees, to some of his more junior colleagues. He kept himself reined in and chose his words with care. In spite of this—perhaps because of it—he was highly effective as a committee member and was a good lecturer.

Kilburn's preferred model for research in computer engineering was to design a computer, to commission it, and only then to publish a detailed description and evaluation. His favourite medium for publication was the *Proceedings of the Institution of Electrical Engineers*. It was foreign to his way of proceeding to engage in discussion of particular features of architectural or engineering design in isolation; he saw them against the compromises and trade-offs that dominated his daily life as a design engineer. For example, he saw the virtual memory system—the most seminal of all his personal contributions to computer architecture—against the background of its application to the design of the Atlas and to that of other machines with which he was associated. He did not contribute in any major way to the large literature that grew up about paging and its problems.

Perhaps because of his preference for the particular rather than the general, Kilburn did not, in his mature years, make a practice of attending computer conferences. In contrast he had, in his earlier years, attended various conferences in addition to the one in Australia mentioned above. For example, in June 1949 he attended, with several colleagues also from Manchester, a conference held in Cambridge. Again, in December 1951 he went to the USA to participate in a working conference organized by the National Bureau of Standards in Washington DC on the specific subject of CRT memories. On his way there, he attended the first Joint Computer Conference held in Philadelphia, where he presented a paper by Williams and himself on `The University of Manchester Computing Machine' (2). When the conference in Washington was over, he accepted an invitation from the National Bureau of Standards to visit Los Angeles to examine the Standards Western Automatic Computer (SWAC), which had just then come into action and was going through its teething troubles. The SWAC was the first US computer to use the CRT storage.

Although in later life Kilburn would always express an extreme dislike of travel, this did not prevent him from undertaking a number of major trips, most of which were in response to invitations to deliver lectures or present invited papers. For example, he spoke on the Atlas at the UNESCO conference held in Paris in 1959 (5). He visited the Soviet Union on two occasions, namely in October 1961 and in September 1967. On both trips he had D.B.G. Edwards with him, and on the first trip he also took his wife.

Kilburn would always take the month of August as holiday, part of which would be devoted to a family holiday somewhere in the UK, preferably not far from Manchester. Part of the time he would spend reflecting on the department's research programme and in reassessing priorities. The first few weeks after his return formed a hectic period of readjustment for his colleagues.

Retirement

In 1981, when he was approaching the age of 60, Kilburn announced his intention to retire at the end of the academic year. Because, under the regulations then in force, he could have continued for a further seven years, this was in effect early retirement. His reason was that his wife was in a poor state of health, and he wished to be able to spend more time with her.

Kilburn had made all arrangements to retire with this in view, when tragically his wife died, only two weeks before the date fixed. Kilburn was pressed by his colleagues to continue full-time activity in the department, but he preferred to retire as planned. Unwilling to lose him altogether, they urged him to keep in touch by spending part of one day every month in the department, and to this he agreed. Otherwise, he enjoyed himself in the company of his family and in pursuing various private occupations such as gardening, playing his piano, listening to music, and following the fortunes of Manchester United Football Club, of which he had long been a fervent supporter. This, incidentally, was an enthusiasm that he shared with the second author of this memoir. One of the reasons why he always liked to spend his summer holiday near to Manchester was so that he could easily slip back for the first match of the season.

As the 50th anniversary of the demonstration of the historic `baby' came into view, the University of Manchester, together with the City of Manchester, planned a large-scale celebration. Simultaneously, the Computer Conservation Society initiated a project to build a working replica of the `baby' itself and sought Kilburn's help. The way in which Kilburn threw himself into this project made his old colleagues feel that he had taken on a new lease of life. The replica was installed in the Museum of Science and Industry in Manchester, and its formal switching on by Kilburn and Lady Williams, via a satellite video link, was the highlight of the anniversary celebrations. One of his last actions before his death was to stand in front of the replica and to record a talk for showing on 6 December 2000 at the Computer Museum History Center in California, of which he had been made a Fellow.

Tom Kilburn died in Manchester on 17 January 2001. His wife had died in 1981. He is survived by a son and a daughter.

Acknowledgments

We should like to acknowledge the great help we have received from many colleagues and friends. We should like to acknowledge especially the great help we received from Professor David B.G. Edwards, who succeeded Kilburn as head of the Department of Computer Science. Not only did be provide us with a lengthy manuscript, dealing among other matters with the computers built at Manchester during Kilburn's tenure, but he also read our draft and commented on it. We would also like to thank Dr R.B.E. Napper, who has read and commented on drafts of this manuscript and checked much of the detail. We are much indebted to Mr Peter Hall, a former Director of ICL, for replying to our queries about the controversy between the University and ICL. We also thank Mr Edward Cooke-Yarborough, Professor R.A. Brooker and Professor Simon Lavington, as well as other colleagues who have contributed useful inputs to this memoir. We are indebted, too, to Ms C.A. Minter of Qinetiq for supplying information from the TRE archives, and to Mrs S.J. Briscoe for help in preparing the bibliography. Finally, we should like to express our gratitude to Mr John Kilburn for supplying us with personal information about his father.

The frontispiece photograph was taken in about 1978 by F.I. Hoyle, Department of Computer Science, University of Manchester, and is reproduced with permission.

Honours and awards

1945	BA (Cantab.)
1947	MA (Cantab.)
1948	PhD (Manchester)

1953 DSc (Manchester)
1965 Elected a Fellow of the Royal Society
1968 Honorary DU (Essex)
1970 Fellow of the British Computer Society
1971 W. Wallace McDowell Award of IEEE
1973 Appointed CBE
1973 BCS John Player Award
1974 BCS Distinguished Fellow
1976 Elected FREng: Founder Fellow of the Royal Academy of Engineering
1977 Honorary DUniv (Brunel)
1978 Royal Medal of The Royal Society
1978–79 Member of Council of The Royal Society
1979 Honorary DSc (Bath)
1980 Elected Foreign Associate, US National Academy of Engineering
1981 Honorary DTech (CNAA)
1982 Computer Pioneer Award, IEEE Computer Society: Charter Recipient
1983 Eckert–Mauchly Award, awarded jointly by the ACM and the IEEE Computer Society
1996 Howarth Medal for Enterprise and Innovation in the North West, Royal Society for the Encouragement of the Arts, Manufactures and Commerce (RSA)
1997 Mountbatten Medal, National Electronics Council (jointly with M.V. Wilkes)
1998 Honorary Member, Manchester Literary and Philosophical Society
1998 Honorary DSc (University of Manchester)
2000 Fellow of the Computer Museum History Center, California

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(2) (11) 1951 (With F.C. Williams) The University of Manchester computing machine. In *Proc. Joint AIEE-IRE Computer Conference, Philadelphia*, pp. 3–7.

(3) (16) 1953 (With F.C. Williams, C.N.W. Litting, D.B.G. Edwards & G.R. Hoffman) Recent advances in cathode ray tube storage. *Proc. Instn Elect. Engrs* **100**, 523–539.

(4) (25) 1959 (With D.B.G. Edwards & D. Aspinall) Parallel addition in digital computers: a new fast 'carry' circuit *Proc. Instn Elect. Engrs* **106B**, 464–466.

(5) (27) MUSE. *International Conference on Information Processing, UNESCO, Paris*, p. 433.

(6) (30) 1960 (With D.B.G. Edwards & D. Aspinall) A parallel arithmetic unit using a saturated-transistor fast-carry circuit. *Proc. Instn Elect. Engrs* **107B**, 573–584.

(7) (39) 1990 From cathode ray tube to Ferranti Mark 1 *Br. Comp. Soc. Computer Resurrection* **1** (2), 16–20.