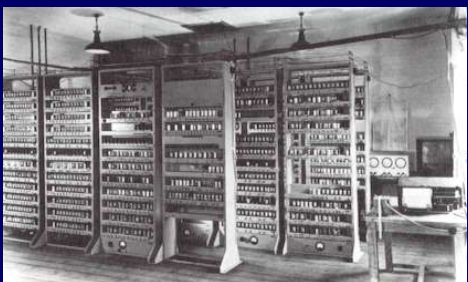# Computer Commemoration

At Grange Farm

THE COMPUTER – the 20th century's legacy to the next millennium.

This monument commemorates the early pioneers responsible for the development of machines that led to, or indeed were, the first electronic digital computers.

This spot was chosen because the COLOSSUS, the first effective, operational, automatic, electronic, digital computer, was constructed by the Post Office Research Station at Dollis Hill (now BT research), whose research and development later moved from that site to Martlesham, just east of here and the landowners thought this would be a suitable setting to commemorate this achievement.

The story of these machines has nothing to do with the names and companies that we associate with computers today. Indeed the originators of the computer are largely unknown, and their achievement little recorded.

All the more worth recording is that this first machine accomplished a task perhaps as important as that entrusted to any computer since.

The electronic digital computer is one of the greatest legacies the 20th century leaves to the 21st.

The History of Computing…

The shape of the monument is designed to reflect a fundamental concept in mathematics. This is explained in the frame entitled "The Monument".

You will notice that some of the Stations are blue and some are orange. Blue stations talk about concepts and ideas pertinent to the development of the computer, and orange ones talk about actual machines and the events surrounding them.

The monument was designed and funded by a grant making charity.

FUNDAMENTAL FEATURES OF COMPUTERS

The computer is now so sophisticated that attention is not normally drawn to its fundamental characteristics. But, of course, these were not all developed at once:

FORM	Digital – operating on <u>numbers</u> rather than measured physical quantities.
SPEED	Operates at <u>electronic</u> speeds, much faster than would be possible for humans or any mechanical device (the slowest electronic computers were about 1,000 times as fast as was possible from an electro-mechanical device).
CALCULATIONS	Performance of <u>arithmetic and/or logical operations</u>.
AUTOMATIC SEQUENCING	By means of some form of <u>program</u>, the machine automatically carries out a largely pre-determined sequence of operations.
CONDITIONAL BRANCHING	The results of intermediate calculations can be used to change the course of later ones. It is this which gives the computer its power of decision making.
STORED PROGRAM	The operations to be performed are governed by a program which is <u>stored internally</u> in the computer along with the data. Apart from making programming much easier, this also allows the program itself to be altered in the course of execution and therefore allows the computer to solve the widest range of problems,
SELF PROGRAMMING	The power and effectiveness of the computer is greatly enhanced if its computing power can be used to <u>assist in its own programming</u>. The computer can be used to convert easily understood code into binary, thus simplifying the programmer's job.
INPUT/ OUTPUT	The computer requires a means of <u>taking in information</u> (input) and of <u>presenting the results</u> of its work (output).

EARLY PIONEERS 1

Charles Babbage was a Cambridge mathematician who initially developed and attempted to build a mechanical "Difference Engine". This was a large and complex device for calculating and printing certain types of mathematical table. But in 1837 he had the idea for what he termed an "Analytical Engine" - a general-purpose mechanical computer controlled by sets of punch cards.

Though mechanical, the complexity and detail of Babbage's design was staggering. The 'Engine' had a store for 1,000 50-digit numbers in a volume 30 inches by 25 by 30-40 high.

In three short years he invented many of the fundamental concepts that are embodied in the logical design of the modern computer. His incomplete prototype machine and engineering drawings are now among the Science Museum's most prized exhibits. Babbage's design for a Difference Engine has since been successfully constructed - providing yet further evidence of the technical merits of his design.

Yet Babbage himself became very frustrated with his own designs.

His ideas, many of which were uncannily like those adopted for 20th century computers, were over a century ahead of their time and only became fully practical once electronic components were available. At the technological level of the time in which he lived and with no one to discuss his ideas with, his dreams of the general-purpose Analytical Engine could not be fully brought to fruition.

Yet more than anyone, Babbage was the first to realise that a machine could replace some of the work of the human mind. However, it seems his ideas did not influence those who constructed the first electronic computers simply because they were ignorant of his work.
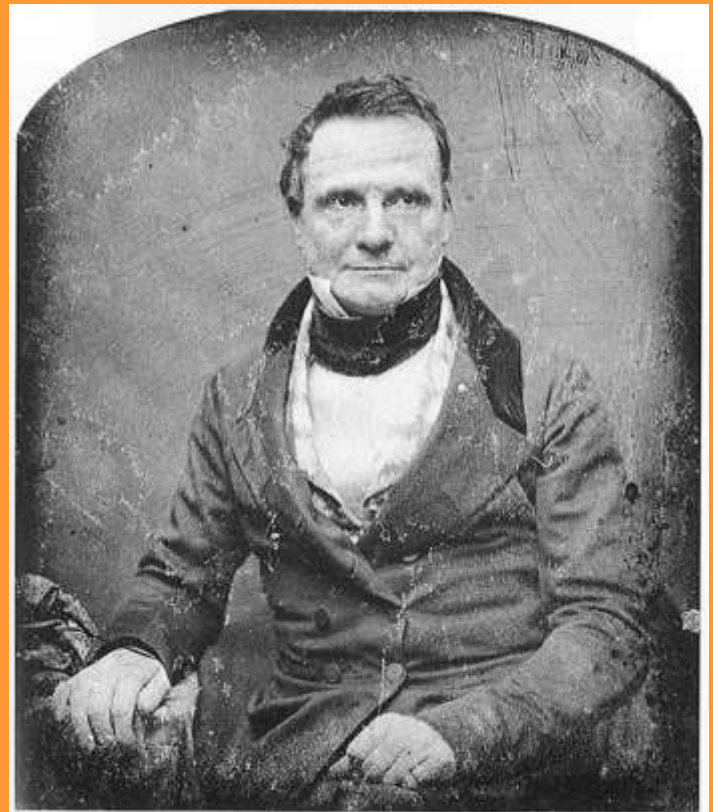
Charles Babbage

In the 20th Century, four pioneers contributed a great deal in the run up to the first working Electronic Digital Computers without actually ever producing electronic machines themselves.

EARLY PIONEERS 2

USA   **John Atanasoff**   **1940**

Designed and part-completed a special-purpose Electronic Digital Computer for solving sets of linear simultaneous equations. His work was known to several people in the USA and consequently his ideas may have had some influence over the design of the early American machines.

Germany   **Konrad Zuse**   **1941**

Built the first operational program-controlled computer - this was an electro-mechanical device, controlled by punched tape.

Helmut Schreyer, a colleague of Zuse's, designed an electronic version of Zuse's electro-mechanical unit. However, this work was not known outside Germany at the time and so Zuse did not influence the British or US machines.

USA   **Howard Aiken**   **1943**

Mark I program controlled electro-mechanical computer.

USA   **George Stibitz**   **1944**

Model III programmed electro-mechanical computer.

None of these machines worked at electronic speeds or had conditional branching, a stored program or any self-programming facility. However, the Mark I and Model III (and other machines produced by Aiken and Stibitz) certainly assisted later on in the development of ENIAC and the EDVAC concept (although initially the designers were ignorant of Aiken's work). Furthermore, some very advanced features were included (e.g. remote operation, floating point).

But mechanical and electro-mechanical machines were not fast enough. Only the speed offered by electronic calculation was enough to be significantly faster than manual calculation.

THE COMPUTER AS AN ABSTRACT CONCEPT

Quite often a branch of mathematics is discovered before it is appreciated that it is of use in the real world. This happened with the computer.

In August 1900, in Paris, at the start of a new century, David Hilbert, one of the world's leading mathematicians, listed 23 outstanding problems in mathematics. These included questions regarding the foundations of mathematics and whether specific problems were soluble. In 1928 he made one of his questions more specific: to determine whether there was some definite system that, in principle, could decide the truth of any mathematical assertion.

In April 1936, at Cambridge, a student named Alan Turing handed to his lecturer, Max Newman, a paper: *On Computable Numbers*. This answered Hilbert's question in the negative: no such all embracing system exists.

But in the process of this abstract mathematical proof, Turing analysed the concepts of computing and showed that what could be calculated by a human computer could also be calculated by a machine. His theoretical machine - the Turing Machine - turned out to be uncannily similar to the computer which evolved by 1949. In fact Turing was formalising many of the ideas put forward by Babbage and others in the previous century, though Turing himself seems to have been unaware of, and therefore not influenced by, Babbage's work.

David Hilbert

This moment may be considered to have launched the
AGE OF THE COMPUTER!

In 1943 World War II was at its height. At Bletchley Park the team working on breaking the German secret codes, in particular those based on the use of the Enigma Cipher machine, had achieved great success - partly due to the contributions of Alan Turing. However, German improvements to their coding system and the use of a new cipher machine, built by the Lorenz Company, meant that these hard won successes were in danger of being lost.

Max Newman (born Neumann), Alan Turing's old lecturer, was in charge of a section at Bletchley Park and Turing worked with him. Turing had contributed significantly to the ideas behind the decoding work. There had already been built some limited electro-mechanical and electronic/electro-mechanical devices (known as Heath-Robinsons) to help the deciphering, though the performance of these had been held back by unreliability and lack of speed.

Max Newman was an excellent mathematician, but he found that, much to his annoyance, he was not in fact very good at deciphering and breaking the codes. He was capable of it, he just didn't have an affinity for it. He believed however, that much of what he found so tedious and difficult could be automated. He envisioned a purpose-built machine that would be capable of mechanising some of the laborious code-breaking procedures that were currently being done by hand.

However, he had no idea how to build such a machine, or who would be up to the task of doing it. Tommy Flowers, an engineer from the Post Office Research Station (Dollis Hill), had already been working on special-purpose electro-mechanical devices for Bletchley Park. Flowers had a good deal of previous experience in electronic switches from his work at Dollis Hill and Alan Turing was aware of some of his work.

Tommy Flowers believed that what Max Newman wanted was possible. The machine, he reasoned, would have to be able to input the information very fast and use electronic valves to undertake the logical operations that were needed.

Max Newman

This was a very significant act of faith because nothing like the number of 1,500 valves that would be required had ever been made to operate reliably and continuously before. Despite this, Gordon Radley (in charge of Dollis Hill) gave his complete and financial support to Flowers and the project: a significant indication of the faith he had in his engineers and the importance of the work.

The machine Flowers and his team built was named COLOSSUS and began doing useful work within hours of its installation at Bletchley Park in November 1943. By March 1944 its track record in helping to break the German codes was impressive. In the amazingly short period of 11 months the COLOSSUS had been designed from scratch, constructed and brought into use.

Yet until it had been built, Bletchley Park showed no interest or faith in Flowers and his COLOSSUS design. They wouldn't even fund the construction, despite Newman having requested it. Indeed, Flowers recalls that it was not until they had been furnished with the first COLOSSUS that they realised what it could do: "They [Bletchley Park] couldn't believe it!".

As a result, ten more COLOSSI were commissioned in March 1944. With so much of the code-breaking automated, the whole process became a lot more effective and faster.

The new machines were of considerably enhanced specification, the first of these was built and operational by 8.30am on June 1st, in time to make a significant contribution to the D- Day landings on 6th June 1944.

The COLOSSUS II took in data at the rate of 25,000 bits per second. The reliability of COLOSSUS II was so great that it could typically perform a hundred thousand million bit comparisons between errors. A Pentium PC built around 1999 and programmed to do the same code breaking task would take approximately twice as long as COLOSSUS to achieve the result!

Whilst COLOSSUS was designed for a specific task and did not have stored program capability, it was still able to function beyond its design. For example, it was capable of simple whole number multiplications. It could also be programmed as necessary using its plug boards, though this took a long time.

In all some 10 COLOSSI were built, and used successfully to decipher large numbers of strategically vital messages to and from the German Military High Command.

Indeed, it is now known that their contribution helped significantly to shorten the war.

Tommy Flowers

In the USA, World War II brought the need for the calculation of Firing Tables for different types of gun. The complex calculation (a partial differential equation) for just one type of gun required 3 months' work by a team of 176 human calculators.

Lieutenant Herman Goldstine, a mathematician, was in charge of calculating work carried out on this at the Moore School of Engineering at the University of Pennsylvania.

John Mauchly

In a chance conversation he had heard of the interest of John Mauchly, a Professor at the Moore School, of using vacuum tubes (an American word for valves) for computation. Goldstine persuaded his superiors to commission a machine.

John Mauchly met on a number of occasions between 1940 and 1941 with Dr. John Atanasoff (the creator of the Atanasoff Berry Computer, or ABC) to discuss his ideas. Atanasoff gave Mauchly details of his own computer design, but how far Dr. Atanasoff's ideas influenced John Mauchly remains a matter of dispute.

Working with John Presper Eckert, a first class engineer, John Mauchly started work to build an Electronic Digital Automatic Computer in June 1943.

Presper Eckert

ENIAC (the Electronic Numeric Integrator And Computer) was ready for work at the very end of 1945. A huge machine; it contained 18,000 vacuum tubes and weighed 30 tons; a testament to Eckert's technical skill that it worked at all. Unusually it operated in decimal rather than the 'usual' binary.

The ENIAC was built to undertake arithmetic rather than the logical calculations for which the COLOSSUS was designed. ENIAC employed conditional branching, greatly adding to its functionality and allowing more complex programs to be run.

The basic work for which ENIAC was designed was the solution of partial differential equations, which occur in many areas of applied science, and many of which could not be solved prior to the advent of computers. In its first three months of operation it worked for some weeks on a preliminary design of the H-Bomb.

Like the COLOSSUS, ENIAC employed parallel processing. However, it was capable of much more complex and varied calculation than the COLOSSUS. The method of programming the ENIAC - which involved extensive cross-wiring between plug boards - was such that it might take a team of programmers a day or so to set up the program, that might then take only a few minutes to run. It was very reliable. Later, in 1947/48, the programmers found that the programs could be kept in the machine's store originally designed only for numerical data, and it was used in this mode in March/April 1948.

John Presper Eckert
- first from left

Herman Goldstine
- fourth from left

John Mauchly
- fifth from left

Paul Gillon
- first from right

Displayed courtesy of Hagley Museum and Library, Wilmington, Delaware, USA.

This essentially made ENIAC the first stored-program electronic computer. However, the store was read-only (thus not allowing the ENIAC to achieve its full potential), an important distinction to bear in mind when we look at the later Manchester 'Baby'. The performance was slower using a stored-program, but the increased functionality of programs more than made up for this fact.

THE CONCEPT OF OUR COMPUTERS

In the summer of 1944, long before ENIAC was operational, the eminent Hungarian/American mathematician John von Neumann, was introduced to the work being done on the ENIAC by Goldstine when they met by chance on a railway platform. Shortly afterwards, Von Neumann became a consultant on the project and the next summer he circulated a *First Draft Report on the EDVAC.* This set out the principles on which a fully effective general purpose computer, as the term is now understood, should be based. In particular it incorporated, for the first time, the concept of controlling the arithmetic and input/output operations via instructions that were stored in the memory, rather than held on punched tape or represented by cables and switches.

Such instructions could be fetched and decoded at a speed comparable with that of the arithmetic unit. Moreover, programs could be prepared away from the machine while it was busy on some other computation, and quickly loaded when required merely by being read into the machine's storage unit.

It was only later, in 1947, that it was appreciated that this would allow instructions themselves to be generated, and perhaps changed, during the course of a computation. Address calculations could be performed in order to select specific data items from storage - facilities that were the practical realisation of the sort of fundamental properties that gave the mathematical concept of the Turing Machine its tremendous logical power.

The very great majority of computers constructed for many years broadly used this von Neumann architecture.

However, even now, it is difficult to know just how great was the contribution John von Neumann (a brilliant mathematician but a great publicist) made to these important ideas, since so much originated from Mauchly and Eckert. This question of priority of ideas has remained a matter of bitter dispute for decades.

Von Neumann had met Turing (and Newman) prior to 1939, and was familiar with his work. However, though Turing influenced some of von Neumann's work, it is unclear how far he may have influenced von Neumann's EDVAC report.
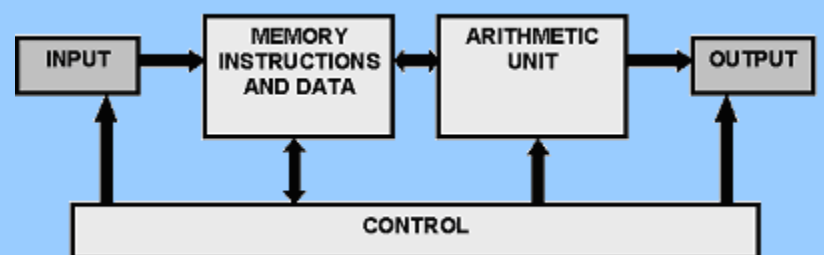
The von Neumann Architecture

John von Neumann

THE MANCHESTER COMPUTERS

After his success with COLOSSUS, Max Newman, Turing's old lecturer, moved to a chair at Manchester University in late 1945 where he worked on the design of an electronic digital computer. Through Hartree (see next section) and Flowers, he was introduced to the ideas of the EDVAC report.

In the summer of 1946 Freddie Williams (of the Telecommunications Research Establishment) started work on an electronic storage device based upon the use of the Cathode Ray Tube (an idea from the Radiation Laboratory at MIT in the USA) - the same device that allows you to see pictures on your television screen. Later that year he moved to Manchester and largely took over the computer work, working closely with Tom Kilburn, also from T.R.E.

The Manchester Prototype (or 'Baby'), which was the first Manchester machine, had a store of only 32 words and no form of mechanised input or output. Consequently its usefulness was very limited as compared to the ENIAC.

Nevertheless, when it first ran a program on 21st June 1948 it became the first working stored program electronic computer to hold its program in a read-write store. Its distinction from the ENIAC, which ran the very first stored program, is that the Manchester Baby, unlike ENIAC, had a read-write store, thus allowing the programs to modify themselves as they ran and making them more versatile.

Frederic C. Williams

Tom Kilburn

Following the construction of the prototype, Williams and Kilburn went on to construct two more, improved specification computers based on the design of the Manchester Baby. One of these computers began operation just before EDSAC (the Manchester Mark I) but did not become fully operational with input and output until somewhat after EDSAC, in the summer of 1949.

This machine attracted Government attention and Ferranti Ltd was given Government funding to support the production of a computer. The Ferranti Mark I was delivered in February 1951 and is believed to have been the first commercially available stored program electronic digital computer.

The early Manchester series of machines, starting with the Prototype and the Manchester Mark I (which itself went through several versions) had an advantage over other early machines in using the fast Williams store.

THE FIRST FULLY OPERATIONAL COMPUTER

In 1945 Douglas Hartree had been Professor of Theoretical Physics at Manchester for some 14 years. He was one of the world's experts in numerical computation, having played a major part in developing the Hartree-Fock method of investigating complex atomic systems.

In 1946, Hartree was asked by Colonel Paul Gillon to visit the Moore School in the USA to help with the application of ENIAC to scientific calculations in which he was a world leader. In the course of this work he became the first European to program ENIAC. When he returned to the UK he encouraged Maurice Wilkes to attend a course at the School in the autumn of that year. Wilkes returned to Cambridge intent on constructing a computer to the von Neumann 'specification'.


Wilkes, working with his chief engineer, Renwick, achieved his aim in about 30 months and in May 1949 the EDSAC (Electronic Digital Store And Computer) became the first fully practical, operational, working, digital, electronic, automatic computer with conditional branching, a stored program in a read-write store and (unlike the Manchester 'Baby') good input/output facilities. Essentially EDSAC was the first fully-fledged computer, as we understand them today.

EDSAC used a store based on pulses circulating through mercury tanks known as delay lines. The design for these delay lines was another product of the Second World War which had seen the advent of Radar. Wilkes was lucky enough to find that another Cambridge man, Tom Gold, had worked on Radar's development at the Admiralty Signal Establishment, and subsequently Gold gave Wilkes the blueprint design for the store.

Maurice Wilkes

The contribution of Radar to the Allied Forces' victory on D-day and to saving lives throughout the war was at least as great as that of COLOSSUS, and its contribution to the history of computing is yet a further testament to the ingenuity of the men and women who worked at the Telecommunications Research Establishment. As a result of this collaboration Wilkes and Gold worked together on the delay lines, with Wilkes improving the performance of the mercury storage device Gold had helped design.

Wilkes and his team achieved 2 other firsts. From day one, unlike a number of other early computers, EDSAC was used to pre-process its own programs and thus the difficulty of programming it was reduced significantly. Also, from its very early days, EDSAC was used to provide a computing service for others in the University who normally wrote their own programs. Later, with D. J. Wheeler (who did much of the initial programming for EDSAC) and S. Gill, Wilkes wrote the first textbook on computer programming to be published though this was preceded in 1947/48 by Goldstine and von Neumann in a circulated account.
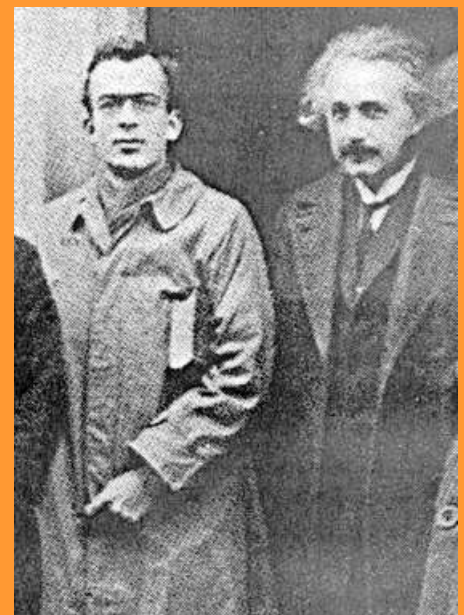
*Douglas Hartree and Albert Einstein together at Leiden*

TURING'S OWN COMPUTER

In the USA a number of teams worked on ideas contained in von Neumann's Draft Report. Von Neumann himself worked on one, but the first to produce an operational machine was the National Bureau of Standards, where the SEAC (Standards Eastern Automatic Computer) came into being in the summer of 1950. SEAC was a very well engineered machine with many of the latest techniques for memory storage, including some pioneering ones, all used successfully in its construction.

In the UK meanwhile, again with Hartree's encouragement, at the National Physical Laboratory (NPL), Turing had been working on the design of the pilot ACE (Automatic Computing Engine) in 1946. He produced a report on the ACE in which he acknowledged some influences from the EDVAC report (his was to be read in conjunction with the EDVAC report), but which had a much greater founding in his own Universal Turing Machine.

The ACE was about 5 to 7 times faster in operation than most other early machines (particularly those at Manchester and Cambridge), but this was at the expense of increased difficulty in programming. Because Turing had made no attempt to make the programmer's life easy, ACE was quite unlike EDSAC (which was designed to ease the difficulty of programming a machine). In fact, ACE's programmer (like early programmers at Manchester) had to write everything in binary notation, backwards! The Pilot ACE first worked on May 10th 1950 and started doing useful work in the summer of that year, shortly after SEAC. Because of the difficulty in programming ACE, it was EDSAC and not the Pilot ACE which set the standards for operation and programming for future machines.

Though Turing designed the ACE, he actually left NPL in 1948 long before its construction was complete. He moved to a readership at Manchester University, though he did not arrive there until after June, after the Manchester Baby had been constructed. However, he did do a considerable amount of work on programming the subsequent machines and also assisted with the design of the paper tape input, although Williams and Kilburn did not allow any interference with their actual machine design and construction.
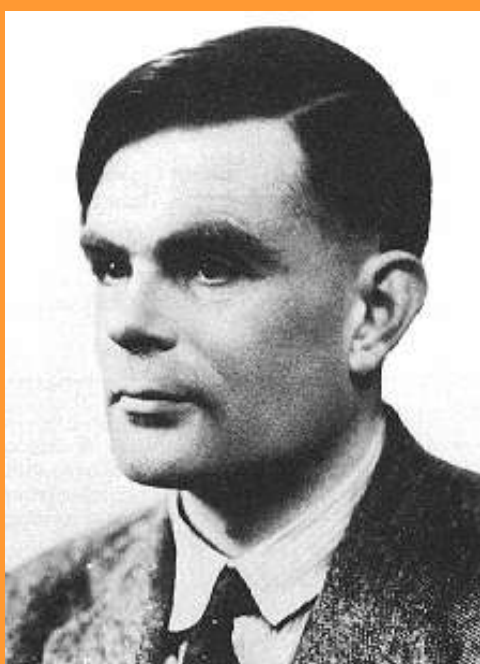
Alan Turing

Turing himself, a great mathematician and philosopher, refused to behave within the then perceived confines of his class. In the 1950's homosexuality was a crime and as a result Turing was tried for committing an act of gross sexual indecency with a young man from Manchester. However, his spirit was not broken and he continued his research in earnest. His death two years after the trial, aged 41, was therefore a shock to his close friends. The coroner recorded a verdict of suicide.

His achievements are so remarkable, not only because they are so numerous, but also because they are so profound. In different ways he was involved with three of the first six computers ever built. He was so remarkable because he designed the computer first as a thought exercise, and then helped to do the same as a reality. This is an amazing feat if we consider, for example, the first steam engine which was built in 1712. The actual theory of the way in which it worked was not described until 1824! His achievements are then surely among the more outstanding feats science has seen and it is for this reason that we remember him specially here.

WHOSE WORK WAS GREATEST?

So, in mid-1950, the computer age had begun to grow up. Of the 6 machines that had been built, 4 were British. But who had been the greatest individual achiever in those early years?

Sir Gordon Radley (front)

There will be several opinions on this subject, but Tommy Flowers must be high on the list. He had the vision to see that a machine with 1,500 valves could be built and operated to provide continuous reliability. When Bletchley Park declined to back the expenditure, he persuaded the Director of the Post Office Research Station to take responsibility for it. With his colleagues he built COLOSSUS in 11 months and COLOSSUS II in 3 months. Both machines operated from day one and both produced results of the highest importance for world history. It is seldom the case that the first prototype for hundreds of millions of machines fulfils one of the most vital practical tasks of all.

As for the greatest influence on the future, it was John Mauchly and Presper Eckert, together perhaps with John von Neumann and Herman Goldstine who must be selected. The ENIAC was the first true number cruncher from spring 1948, the first computer in a modern sense, and the practical origin of the crucial stored program concept from which a great industry sprang. It might have been otherwise if COLOSSUS had not been so shrouded in secrecy, but the early history of computing is full of "ifs". Mauchly and Eckert's achievement was the greater because they started off with the disadvantage that they, and the Moore School, were poorly regarded by the US scientific community leaders.

Yet despite the undeniable genius of the mathematicians and engineers who designed and built the COLOSSUS and ENIAC, neither could have been built without funding and support. In this regard then, there are two men who stand out as having had the foresight to understand how necessary these machines were. They had the faith to back their engineers financially and logistically and the courage to do it against a background of war, the incredulity of 'educated' men and unprecedented leaps of engineering and scientific faith which were more than likely to result in failure. Those two men are: (Sir) Gordon Radley, wartime head of Dollis Hill who backed and cleared funding for the COLOSSUS, and Colonel Paul Gillon of the US War Department's Ordnance Division, who supported the development of ENIAC.

Finally it was Wilkes, Williams and Kilburn who first built the computers to resemble more closely what we know today. However, they had two advantages over Flowers, Mauchly and Eckert. Firstly, they already knew that a machine with many hundreds of valves could be operated successfully over long periods. Secondly, they had the advantage of being able to draw on much greater sources of electronics research and knowledge through the Radiation Laboratory at MIT (in the USA), the Telecommunications Research Establishment (in the UK) and the Admiralty Signal Establishment (also in the UK).


Paul Gillon (right)

OTHER EARLY COMPUTERS

From the mid-1940s there was a flurry of creative design and engineering resulting in many more computers than we have mentioned so far. Each of these machines, though not the first of their kind, was valuable in some way and for the sake of completeness we record them here in brief.

WHIRLWIND was developed at the Digital Computer Laboratory at the Massachusetts Institute of Technology (MIT) from 1945 and began working by 1950.

It was the first computer to operate in real-time and to output real-time text and graphics to a video display. It was also the first to use magnetic core memory which was much faster than the Williams tubes used by other machines at the time. It was the direct predecessor of the US Air Force's air defence system: SAGE.
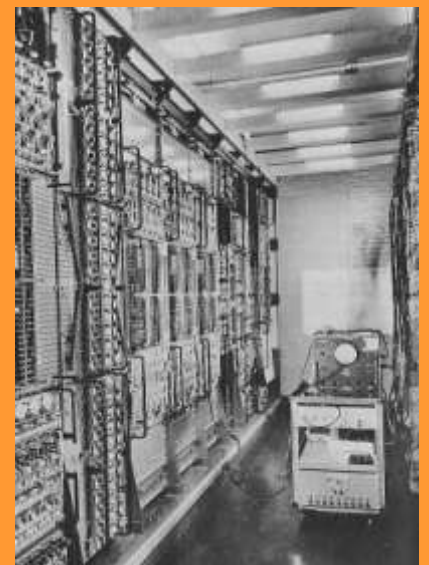
Thermionic Valve (vacuum tube)

BINAC was completed in 1949 by the Eckert Mauchly Computer Corporation in the USA and was the first dual-processor computer, though it was not a truly general purpose computer.

UNIVAC I was funded by Remington Rand Inc., which had bought the Eckert Mauchly Computer Corporation in 1950. The first was installed by 1951.

LEO I was built by J. Lyons and Company and was the first machine used for business calculations. It was closely modelled on Cambridge University's EDSAC. The first was operational by 1951.

ORDVAC and ILLIAC were both built by the University of Illinois in the USA and were installed by the end of 1952.

MANIAC was built at Los Alamos in the USA and completed in 1952. It was responsible for calculations of Mike, the first hydrogen bomb.

A FINAL THOUGHT

Let us leave you with this thought: the calculating ability of the computer - which is initially what they were designed for - has given the ability to quickly break the German wartime codes, help solve the equations needed to make the Hydrogen Bomb, put a man on the moon, and answer fundamental questions about the age and nature of the universe.

The table below shows the difference in calculating power between manual, mechanical, electro-mechanical and electronic methods using the speed of a single multiplication of two, ten digit numbers as the test benchmark.

METHOD	TIME FOR MULTIPLICATION (milliseconds)
By Hand	300000
By Calculator (1943)	15000
ENIAC	2.8
EDSAC	5.4
Manchester Mark 1	10
Pilot ACE	2
SEAC	2.98

So it seems clear that, without the computer, many of the great achievements and discoveries of this century would not have been possible (or would have taken much longer to achieve). The ENIAC realised a speed increase of 100,000 times over calculations by hand. In comparison, following a further 50 years of development by the turn of the millennium, the Pentium 233 MHz was only roughly 240,000 times faster than the ENIAC itself was.

As a result the computer has provided us with the speed necessary to produce, in real time, the answers to questions and the solutions to equations that would have taken many human calculators many hundreds of years to obtain.

Imagine a problem that might take the ENIAC a day to solve… a succession of scientists and mathematicians working by hand would still be doing the calculations for that same problem one hundred years from now, and even then they would be more likely to make a mistake than any computer ever would (mistakes made by computers are generally programmed in by humans). But even now there are problems which our fastest computers cannot solve without centuries of calculation.

This history has concentrated on the first fifty years of the computer's development (1900 - 1950) - from a simple calculating machine to a machine so advanced that it had all the recognisable features of a computer today. It hasn't touched on the later developments of the GUI (Graphical User Interface) and microchip technology that have made the machines of today so easy to use. Nor has it mentioned the software and hardware companies who fought for the monopoly to bring computers to the general public. These battles and developments pale in comparison to the unprecedented, difficult and ingenious work done to turn the computer from an abstract mathematical proof into a physical, almost limitless reality.

THE MONUMENT

To the right you can see a complex timeline showing what are arguably the most important machines, ideas and moments in the development of the computer.

The full lines, linking machines/ideas to one another, represent influence which is relatively certain. However, it must be appreciated that some of these influences are much more powerful than others. A dotted line represents an influence which is either relatively weak or uncertain.

By no means does this diagram incorporate everything in the history of computing, but even at a simple level you can see how complex and diverse the relationships were between the men and the machines.

These three monoliths…

The shapes cut out of the three vertical pieces of the central structure are called conics. They are formed by 'cutting' a cone (see below). They are a PARABOLA, a CIRCLE (a special case of the ellipse) and a RECTANGULAR HYPERBOLA (a special case of the hyperbola).

The distinction between the three types of conic is that the circle cuts the line at infinity in two imaginary points, the hyperbola in two real points, and the parabola at two coincident points.

These three curves are selected as being one of the simplest and oldest pieces of mathematical knowledge applied to curves in two dimensions. This was a subject likely to have been studied at school by Turing, the common school text on the subject at the time having been published when he was 15 years old.
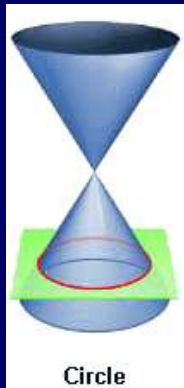
The circle can be taken to epitomise perfection on a limited scale - the European contribution and, in particular, the Colossus.

Circle
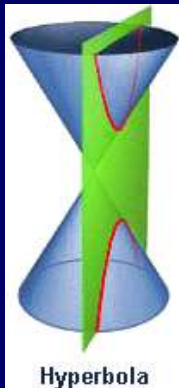
The hyperbola can be taken to illustrate the huge US contribution to computing which took it into some many millions of homes by the turn of the century.

Hyperbola
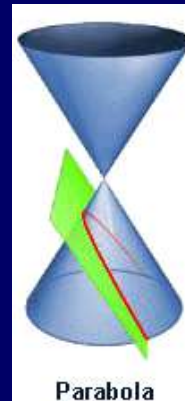
The parabola (which has its centre at infinity) can be taken to epitomise the almost unbounded possibilities for the future of computing.

Parabola

You may also have noted that the posts on which these stations stand make a 17 sided polygon. It was Gauss, possibly the greatest mathematician who ever lived, who discovered that this particular complex shape could be drawn with only a ruler and a pair of compasses.

Key

(orange box)	An event or idea of importance
(pink box)	An idea of great importance
(blue box)	A pioneering/ advanced machine
(cyan box)	An early/ incomplete/ basic machine

A Direct influence/ relationship/ link via which ideas and machines were discussed and progressed

A less important or more uncertain influence / relationship

(pink square) An important convergence of ideas and the main focus of US influence on Europe

The events/ ideas and machines on the right hand side of the chart occurred or were built in the USA. All events/ ideas and machines on the left hand side of the chart, including EDSAC, occurred or were built in the UK or Europe.

Timeline (left column): 1900 – 1928, 1931, 1935, 1936, 1939, 1943, 1944, 1945, 1946, 1947, 1948, 1949, 1950

Hilbert - 3 problems in the foundations of mathematics

Gödel resolves problem of completeness and consistency

Newman lectures Turing re: Hilbert/ Gödel

Turing's paper: *On Computable Numbers* resolves Hilbert's decision problems/postulates Turing Machine

Aiken works on Mark I Electro-mechanical computer

Atanasoff part completes special-purpose computer

Stibitz Model III electro-mechanical computer built

Mauchly/ Eckert/ (Goldstine) conceive ENIAC at Moore School (USA)

Flowers/ Newman/ Turing COLOSSUS

Flowers/ Newman COLOSSUS II

HARTREE ORGANISING

Newman at Manchester (UK)

Von Neumann EDVAC report, based on Mauchly/ Eckert ideas

Von Neumann designing EDVAC

Mauchly/ Eckert ENIAC operational at Moore School

Turing Report on Proposed Automatic Computer (UK)

Williams/ Kilburn (& Newman) at Manchester

Turing designs Pilot ACE at National Physical Laboratory

Williams Tube operational

Wilkes designs EDSAC at Cambridge (UK)

ENIAC operates in stored program mode

Williams/ Kilburn Manchester Prototype

Williams/ Kilburn/ Manchester Mark I (Newman & Turing)

Wilkes EDSAC operational at Cambridge (UK)

Pilot ACE operational at NPL (UK)

SEAC operational at the National Bureau of Standards (USA)

Computer Features Achieved By Early Machines

COMPUTER	COLOSSUS I	COLOSSUS II	ENIAC	Manchester Prototype	EDSAC
COMPUTER AIDS PROGRAMMING					☒
STORED PROGRAM			☒ Spring 1948	☒	☒
FULL INPUT/OUTPUT	☒	☒	☒		☒
USEFUL WORK	☒	☒	☒		☒
ARITHMETIC INSTRUCTIONS			☒	☒	☒
LOGICAL INSTRUCTIONS	☒	☒		☒	☒
CONDITIONAL BRANCHING	+	+	☒	☒	☒
DIGITAL ELECTRONIC AUTOMATIC	☒	☒	☒	☒	☒
DATE	Dec 1943	June 1st 1944	Dec 1945	June 21st 1948	May 6th 1949

+ Conditional branching may have been possible in Colossus
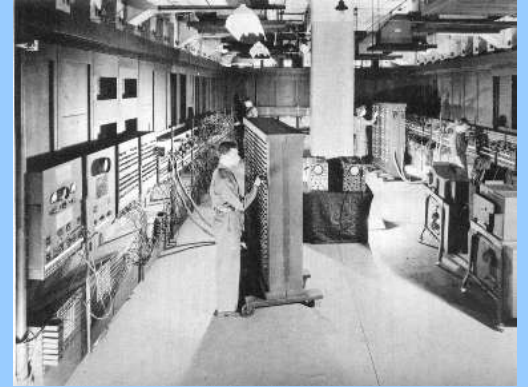
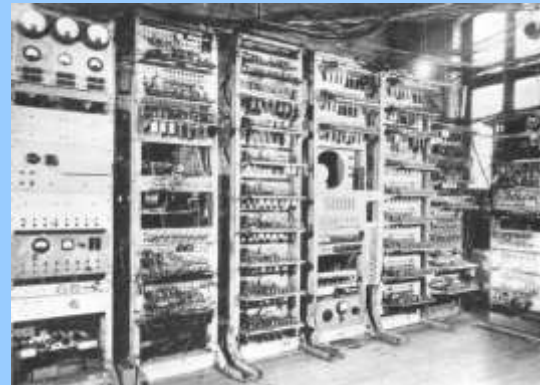# SOME OF THE EARLY COMPUTERS
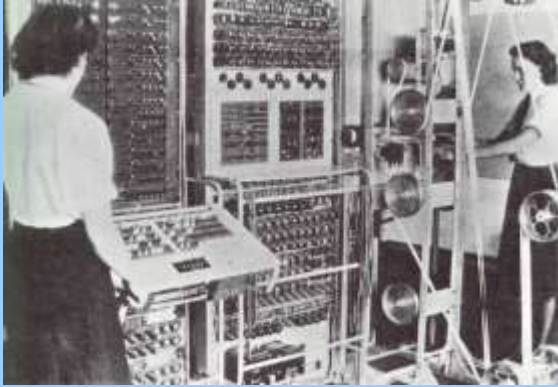
COLOSSUS - 1943
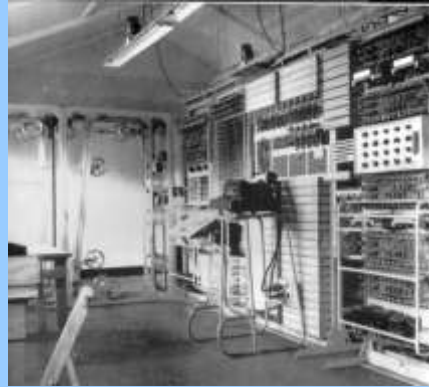
COLOSSUS II

ENIAC - 1945

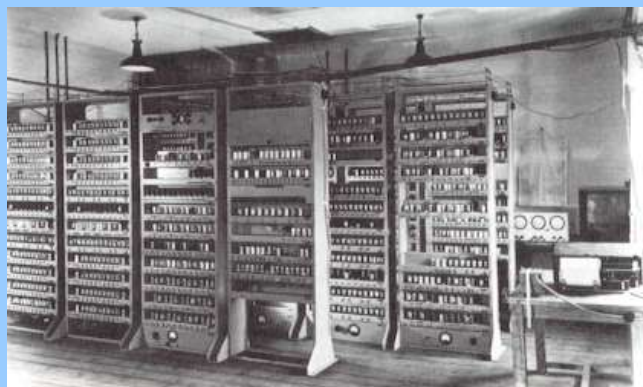From the Collections of the
University of Pennsylvania
Archives

MANCHESTER 'BABY'

MANCHESTER MARK I - 1949

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EDSAC - 1949

Displayed by permission of The
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of Cambridge

SEAC - 1950

Pilot ACE - 1950

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