Lecture 5. The Dawn of Automatic Computing

Introduction

By the 1930s, mechanical and electromechanical calculators from Burroughs, Felt & Tarrant, Marchant, Monroe, Remington, Victor, and other manufacturers had penetrated all aspects of a modern office operations. It seemed that the mathematical tables could handle the rest in science and engineering.

However, certain branches of science and engineering reached a calculating barrier that prevented further progress unless an automated method of dealing with complex operations, such as solving linear equalities, differential equations, etc. could be found.

What was needed was a new type of a calculating machine that could perform large-scale error-free calculations by following, in a mechanical way, a predefined sequence of operations, that is, by following a program.

The 1930s was a crucial period in the development of computing. Not only the first designs of computers started to appear in Europe and the US but also a groundbreaking theoretical research on computing was initiated.

In this lecture we shall take a look at the pioneering work on digital computers. We shall discuss the origins of the first computers and their intended use. We shall talk about people and events leading to the first designs and their impact on society and on the development of future computer industry.

What calculators cannot do

Let us begin with a simple computational task that is simple to describe but difficult to solve on a mechanical calculator.

EXAMPLE 1. The problem deals with two numbers, x and y, which are to be manipulated following these simple steps:

1. accept two numbers x and y
2. multiply x by y and store the result as x
   $x \times y \longrightarrow x$
3. repeat operation described in 2 three more times
4. subtract 2 from x and store the result as x
   $x - 2 \longrightarrow x$
5. print the value of x.

Assuming that $x = 2$ and $y = 3$ on input, the value of x printed at the end of this computation is 160.

In the language of computing, the instructions 1,..., 5 in the above example constitute an algorithm for computing the value of x from the initial values of x and y. Clearly, a mechanical calculator cannot be instructed to execute such an algorithm in an automated way. An automated execution of algorithms would require a different type of calculating devices can execute not only a single instruction but sequences of such instructions specified in advanced by an operator (a programmer). An automated execution of algorithms requires devices that we now call computers.

Alan Turing on Computing

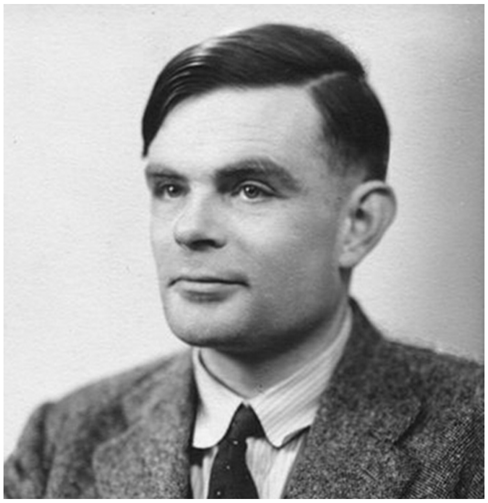

Fig. 1. Alan Turing. Source: unknown.

We begin a story about automatic computing with a portrait of Alan Turing – a British computer pioneer who was not an engineer by training but a mathematician, logician, and cryptanalyst. His contributions to the science of computing were not only large in scope but also groundbreaking.

Turing is perhaps best known for his outstanding contributions to cryptography during the WWII when at Bletchley Park–the wartime headquarters of the UK Government Code and Cipher School–he (and others) worked successfully on breaking German ciphers.

However, we shall concentrate on his work on the mathematics of computing that led him to the creation of one of the most powerful computing devices ever conceived. One can safely claim that the first general-purpose programmable computer ever devised was that created by Turing out of a few symbols written on a piece of paper. In honour of its inventor, that device is now called the *Turing Machine*.

In spite of the fact that Turing did his groundbreaking research on "abstract" computing machines at a time when there were no "real" computers (he published his results in 1936-37), his work is considered among the most significant contributions to the discipline of computing for this day.

The Hilbert Program

To appreciate Turing's contributions fully, we have to temporarily switch the focus of our narrative to another outstanding scientist David Hilbert, who was among the most influential mathematicians in the first decades of the 20th century.

In 1928, Hilbert suggested that the entire mathematics could be "mechanized". Speaking very(!) informally, according to Hilbert, the entire mathematics could be done on some sort of an algorithm-following calculating machine and the job of a mathematician would be to discover the appropriate algorithms.

Many mathematicians agreed with Hilbert but not all. In 1936, Turing published a paper "On Computable Numbers, with an Application to the Entscheidungsproblem" ('Entscheidungsproblem' in German means 'decision problem').

In his paper, Turing demonstrated that, informally speaking, there are mathematical problems that are unsolvable, that is, putting it differently and informally, could not be solved in an algorithmic way as envisioned by Hilbert.

We shall postpone a detailed analysis of Turing's result until the next semester. For now, let us only mention that to prove his result Turing designed an abstract computer – a simple mathematical concept but a powerful computing device sketched in Figure 2. Turing proved on paper that a computing machine could perform very complex tasks but not all such tasks.

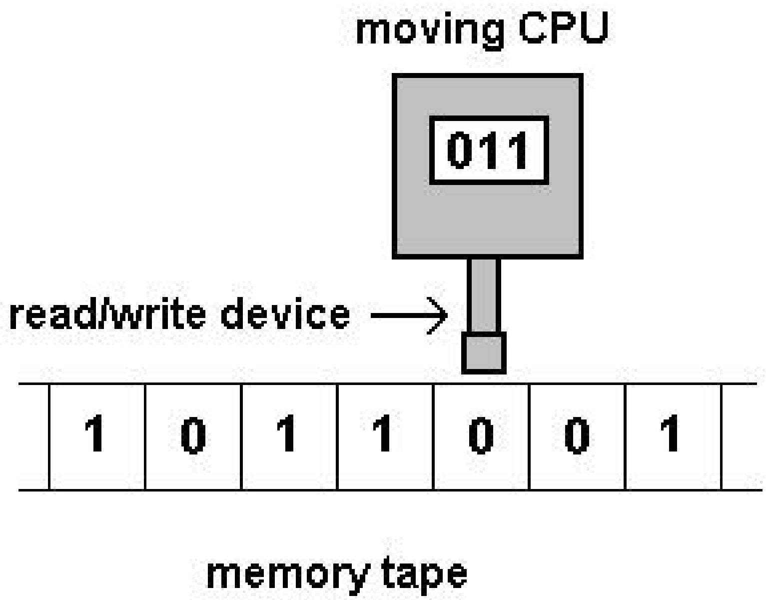

Fig. 2. A sketch of a Turing Machine. Source: Ryan Somma,
http://ideonexus.com/2009/02/05/javascript-turing-machine.

At the time when Turing published his work, there were no computers. But when they started to appear and when the discipline of computer science was born, Turing machines had helped to define and understand the notions fundamental to computing such as an algorithm, a computer, a computation and its complexity.

The Turing Machine remains a fundamental concept of theoretical computer science – a discipline that provides foundations for the entire discipline of computing.

To honour Turing's achievements, in 1966 the ACM established the A.M. Turing Award to recognize the most outstanding contributions to computer science. The award is recognized as the highest distinction in Computer Science (often referred to as "Nobel Prize of computing").

Automatic Computing in the 1930s, 40s, and 50s: an overview

In our analysis of the first computers it would be helpful to focus on specific technological, scientific, and political conditions that shaped the design and application decisions for these early computing devices, such as:

- design motivation: individual curiosity, an experimental device (a proof of concept), to perform specific tasks, etc.;
- intended applications;
- impact on society, future generation of computer engineers and scientists, the creation of computer industry world-wide;

We shall also look at technical features such as:

- what technology was used to build a computer (mechanical components exclusively, electro-mechanical, or electronic (vacuum tubes);
- how was memory implemented?
- how was a computer programmed: did it store a program in its memory (stored-program computer) or was a computer programmed by other means such as wiring modules, setting external switches, etc (non stored-program computer)?
- how were numbers represented in computer's memory: in decimal or binary?
- was a computer a general-purpose device capable of solving a variety of problems or a special-purpose device (a programmable calculator) built to solve only one class of problems?

Was Konrad Zuse's Z1 the first computer?

The earliest computers ever designed and built could be better classified as programmable calculators than computers as they were not designed to be general- but special-purpose devices, that is, they were designed to perform specific computations only.

Our discussion of the first program-controlled calculating devices (computers) will not be chronological but, instead, will follow computer development in several countries.

The first German computers

Possibly the world's earliest programmable calculating machine ever built was the Z1 designed and completed by the German engineer Konrad Zuse between 1936 and 1938. The computer was mechanical but powered by electricity. The programs were presented to the Z1 on a paper tape. The computer could store a few numbers in a mechanical memory (metal sticks!).

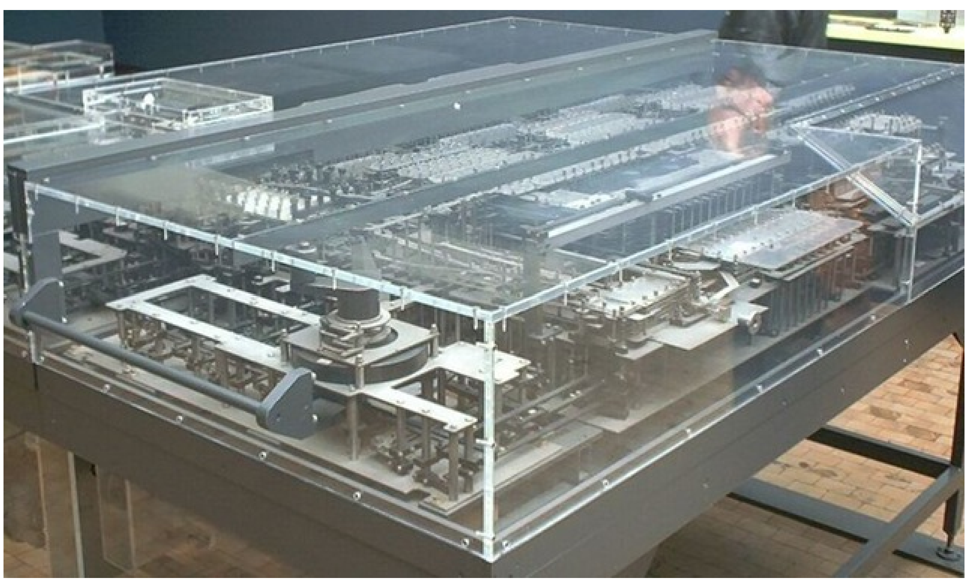

Fig. 3. The replica of Konrad Zuse's Z1 computer displayed at the German Museum of Technology in Berlin. Source: unknown.

The Z1 was unreliable and suffered from the same problems as early mechanical calculators: the operation of the device applied excessive mechanical stress on the moving parts. It is not known weather the Z1 was ever used as a problem solving tool.

Between 1938 and 1941, Zuse improved his designs coming up with the electro-mechanical equivalent of the Z1 in 1941. Instead of mechanical components that he used to implement the processor of the Z1, his Z3 computer used electro-magnetic relays readily available from the telephony industry.

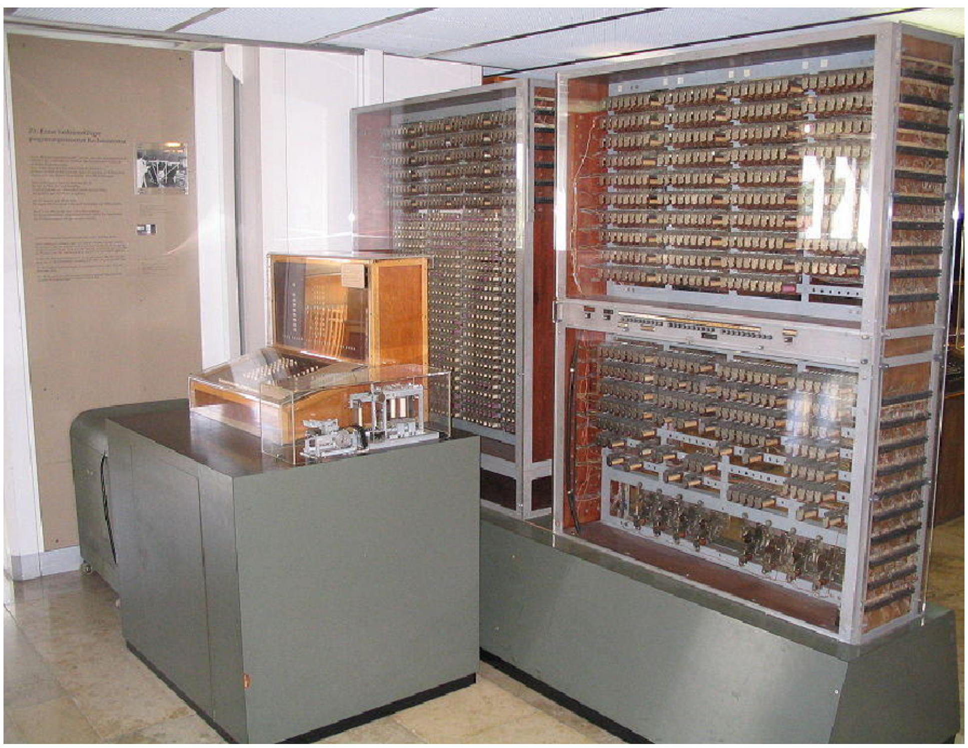

Fig. 4. The replica of Konrad Zuse's Z3 computer displayed at the Deutsches Museum in Munich. Source: unknown.

Both the Z1 and Z3 were destroyed during the WW2.

After the war, Zuse continued his work on computers by building other electro-mechanical machines–the Z4 (1950)–and his first electronic computer –Z22–that used vacuum tubes instead of electro-magnetic relays. Since 1955, a number of Z22s were manufactured.

The first British computers

The Colossus

Colossus Mark-1 (1943) and Mark-2 (1944) calculating machines were designed by Tommy Flowers and built at the Post Office Research Lab in London to help with the war effort in decoding intercepted German telegraphic messages.

During WWII, Germans were using a number of cipher machines including the SZ42 manufactured by the Lorenz Company. Colossus computers installed at Bletchley Park were breaking the Lorenz cipher for two and a half years.

The computers were designed for one purpose only – to help with deciphering codes (hence, they were ”special-purpose”).

Each Colossus consisted of interconnected hardware modules implemented using vacuum tubes (so, it was "electronic").

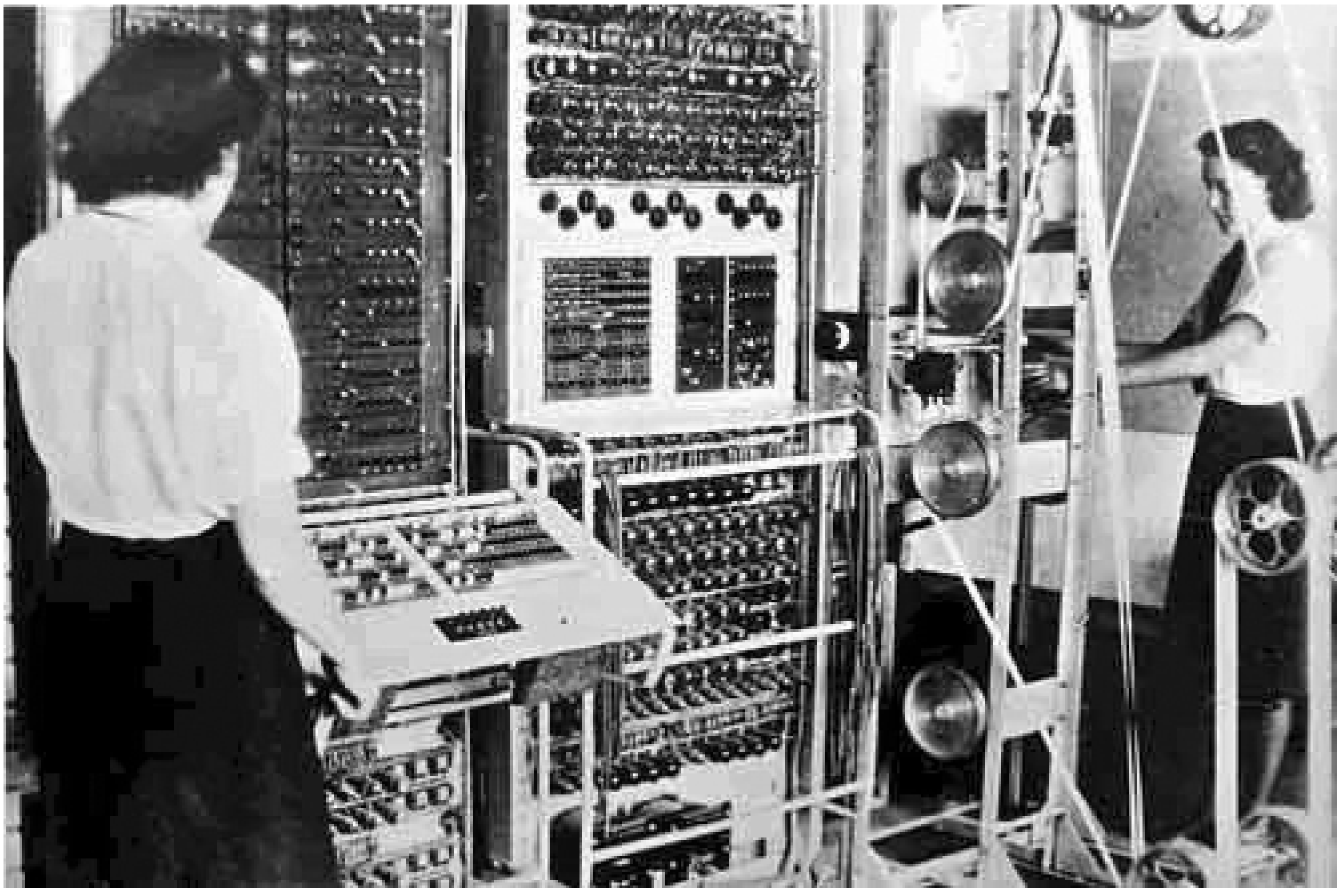

Fig. 5. One of the Colossus Mark-2 computers at Bletchley Park.
Source: en.wikipedia.org/wiki/Colossus_computer

These computers were programmed by interconnecting various hardware modules with wires and by using switches (hence, they were not of "stored-program" type).

The machines were reading inputs from paper tapes that contained characters of a ciphered text represented as columns of punched holes (see Figure 6).

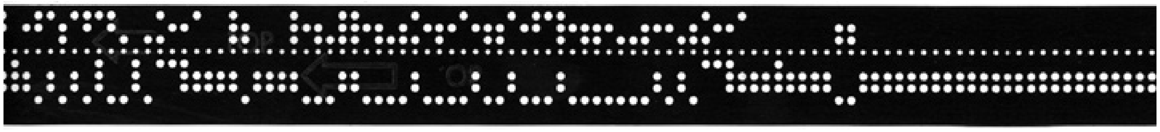

Fig. 6. An example of a computer punched paper tape. Source: YUCoM.

After the war, all machines were dismantled by 1960 and all documentation destroyed. The computer was ”rediscovered” in the 1970s and reconstructed in the 1990s.

<u>Significance of the Colossus computers</u>:

- first significant application of a programmed calculating machine; the results obtained with the help of the Colossus computers gave Allied forces vital information prior to D Day (e.g. that all efforts to deceive Germans about place and direction for invasion, etc. did work);

- the construction and use of the Colossus machines trained the first generation of British computer experts.

<u>The Manchester Mark 1</u>

One of the early problems faced by computer designers was how to store information in a computer so that it could be used at some later time during a computation. Zuse's Z1, Z3, and Z4 computers had mechanical "stick-like" memories.

Between 1946 and 1948, a team of researchers at the University of Manchester, UK, lead by F.C. Williams, developed a fast, fully electronic "mass-storage" device (memory) – the so-called Williams tube. To test the memory, a team of researchers (Williams, Tom Kilburn, and G.C. Tootill) built a rudimentary computer called Small Scale Experimental Machine (SSEM or "The Baby", Kilburn's design).

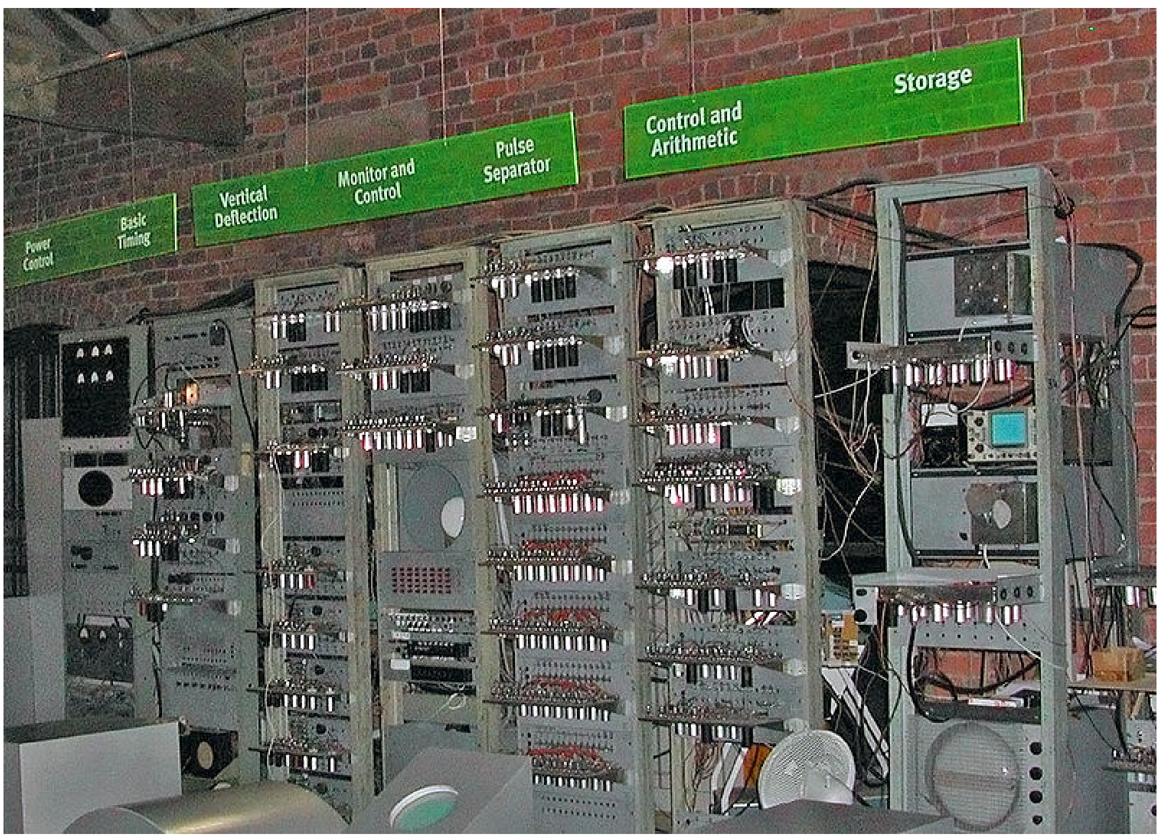

Fig. 7. Replica of the Manchester University SSEM 'Baby' on display at the Museum of Science and Industry in Manchester.
Source: sv.wikipedia.org/wiki/Manchester_Baby

On June 21 1948, the team executed the world's first program stored in a computer memory, in the same way as modern computers. Neither Zuse's Z1 or Z3 computers, nor Colossus machines at Bletchley Park, nor even the ENIAC (still to be discussed) were designed to execute programs that way.

The success of the SSEM and Williams storage device prompted the University of Manchester to initiate the work on extending the SSEM to a complete, full-sized computer. With the help of the UK government (funding), Kilburn's new design–the Manchester Mark 1–was converted into a commercial product by Ferranti Ltd, enhanced and sold as Ferranti Mark 1. The first machine was delivered to the University of Manchester in 1951.

The significance of the SSEM: the first computer with electronic storage, the first stored-program computer.

The significance of the Ferranti Mark 1: the first commercially sold computer.

The first computers in the US

The Atanasoff Berry Computer (ABC)

In the 1930s, an American physicist John Atanasoff realized that a range of significant mathematical problems cannot be solved in an automated way efficiently using traditional calculators; what was needed was a new type of a calculating device: fast, with internal memory, and capable of executing a range of mathematical operations as instructed by an operator.

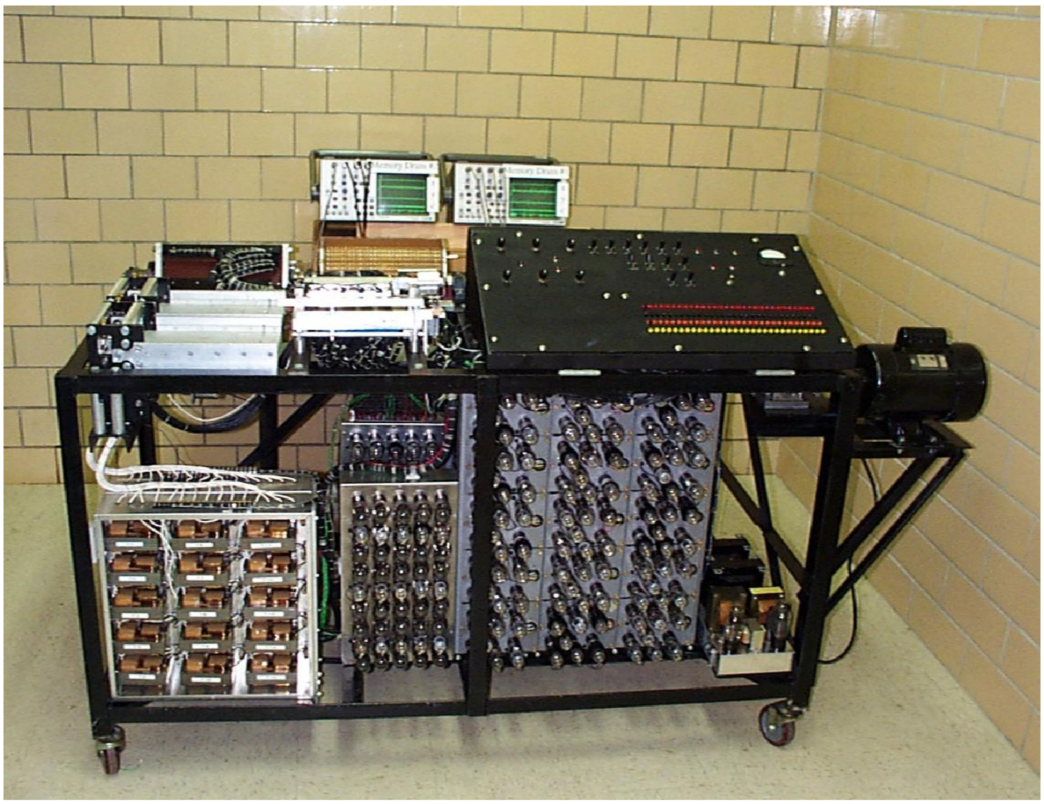

Fig. 8. The ABC computer reconstructed at Ames Laboratory.
Source: http://www.scl.ameslab.gov/Projects/ABC

In the late 1930s, assisted by his grad student Clifford Berry, Atanasoff started building a programmable computing device (the ABC) at Iowa State University. The computer was completed around 1942 and was used (sporadically) to perform some statistical calculations.

The ABC computer was a small-scale electronic digital computing machine designed for a very specific purpose – to solve some mathematical problems using the method called Gauss elimination (as with Babbage Differential Engines designed to perform calculations using the so called "difference method").

The computer could not be programmed but interactively instructed by its operator what to do, step by step.

Significance/Impact: first binary electronic computing device; possible impact on the general design ideas behind the ENIAC (some historians suggest that various ideas concerning the ABC were communicated by Atanasoff to Mauchly, one of the architects of ENIAC, cf. http://www.scl.ameslab.gov/ABC/).

Aiken's Mark 1 computer

Howard Aiken was a Harvard university professor and a pioneer of computing who not only constructed several advanced calculators and computers but also initiated a pioneering academic program that we now refer to as computer science. His interests also extended to the use of computing machinery in business, economics, and other applied areas.

Already in the 1930s, Aiken was of an opinion that efficient problem solving in science and engineering would never be accomplished with traditional calculators but with machines that could execute sequences of operations in a controlled and pre-programmed manner.

By 1937, Aiken had figured out the general architecture of such a programmable calculator and started to look for a manufacturer. He found IBM that built and delivered the machine, called the Harvard Mark 1 or IBM Sequence Controlled Calculator, in 1944.

Fig. 9. Harvard Mark 1. Source: unknown.

In many respects, Aiken's calculator was more like Babbage's Analytical Engine than a modern electronic computer. His machine was a huge and complex mechanical device. It was 8 feet high, almost 3 feet deep, and 51 feet in length! Its 760,000 individual components and 530 miles of wires added to 5 tons of weight. The device was also very slow because of the electro-magnetic technology employed in its construction.

Aiken's device was not electronic as it was made of electro-mechanical components. However, it was programmable using punched paper tape.

While Zuse's Z3 and the Colossus were shrouded in the WWII secrecy, the Harvard Mark 1 was unveiled with big fanfares and announcements of the new era of programmable calculating machines.

Aiken designed other calculators/computers: Mark II, III, and fully electronic Mark IV that introduced many students at Harvard to computing.

Significance of the Mark 1:

- one of the very first programmed calculating machines,
- introduced many to computing,
- extensively used for military applications during the WWII including the design of the atomic bomb.

The ENIAC (Electronic Numerical Integrator and Computer)

Possibly the best known early electronic computer is the ENIAC. It was designed and built during the WWII between July 1943 and November 1945 at the Moore School of Electrical Engineering at the University of Pennsylvania. Its primary purpose was to speed up the calculations required by the Ballistic Research Lab.

The Lab wanted a new calculating machine that would be fast and reliable in operation and built in a short period of time. The short time allowed for the computer's design and construction resulted in some of the ENIAC's shortcomings.

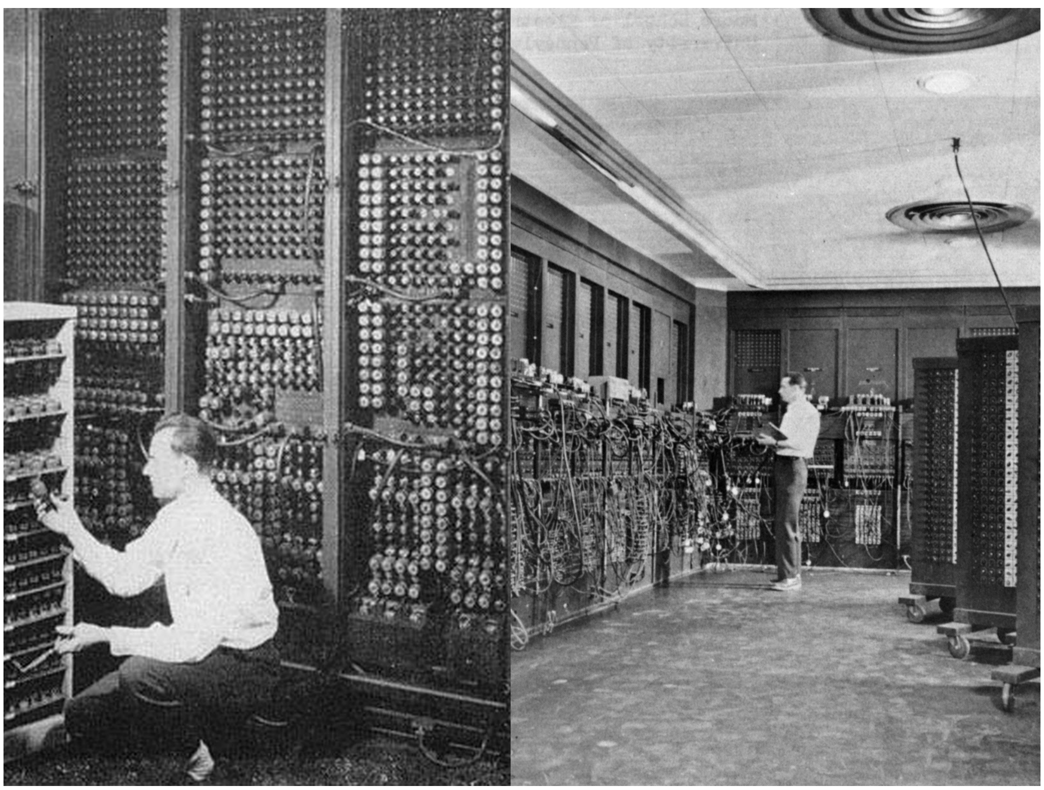

Fig. 10. The ENIAC computer. Source: unknown.

Although ENIAC was designed with specific applications in mind, it could be "programmed" to execute instructions to solve a range of problems. In that way it was a general-purpose computer.

The main architects behind the ENIAC projects were:

- J. Presper Eckert (chief engineer),
- John. W. Mauchly (consulting engineer)
- John G. Brainerd (administrative supervisor)
- Herman H. Goldstine (representative of the Ballistic Research Lab of the US Ordnance Department of the War Department)

Although ENIAC was an electronic computing device, its design was, to a large extent, shaped by the electric calculator technologies developed by companies such as Friedn, Marchant, and Monroe as well as by data processing and telecommunication technologies of that era as represented by tabulating and telecommunication equipment from companies such as IBM and Bell Telephone Labs.

The ENIAC was unveiled to the public on February 14, 1946. It was a large machine that weighted 30 tons and occupied a room of 170 square meters. It utilized vacuum tubes (17,468!!) as its primary technology.

The ENIAC was "programmed" by physically connecting various modules using wires and setting all sorts of switches (this was done differently for every application).

Although the ENIAC had internal memory to store intermediate results of calculations, it could not use its memory to store programs for execution. In the language of computer science, ENIAC was not a stored-program computer. It was not a binary computer either as it operated with numbers represented in decimal.

In 1946, the team working on the ENIAC computer embarked on a new computer project called EDVAC (Electronic Discrete Variable Automatic Computer). One of the most novel features of EDVAC was that application programs were stored in the computer's memory for execution. We shall discuss this kind of stored-program computers later.

<u>ENIAC's significance:</u>

- it was a proof of principle that a large-scale, super-fast electronic calculating devices were possible to built: ENIAC could perform 5000 additions per second which was approximately 1000 times faster than the top calculating speed of the time;
- generated interest in electronic computers in many countries; the ENIAC team gave a number of lectures; one of them given at the University of Pennsylvania was attended by M.V. Wilke of Cambridge University who, influenced by the EDVAC's design principles, designed his computer, EDSAC, in late 1940s.
- it convincingly demonstrated to the public (i.e. to the scientific, military, and industrial communities) that the construction of such devices should be desirable (because of speed, scope of problem solving, and accuracy); ENIAC could solve problems which were beyond the scope of traditional calculating machines.

<u>ENIAC's use</u>: primarily for military applications (weapons design, e.g. computation of ballistic tables, calculations related to thermonuclear reactions).

The IAS computer

The next computer we are about to discuss was completed 8 years after the ENIAC but its genesis is of utmost importance to the understanding of the creation of the modern computer industry. Let us begin with an inventor: John von Neumann.

John von Neumann was a Hungarian-born and educated mathematician who emigrated to America in 1930 where he continued his active research program in mathematics at Princeton University.

As Turing in the UK, von Neumann, too, was supporting military efforts during WWII. His work on atomic bombs at the national laboratory in Los Alamos, New Mexico, focused his research interests on computing.

He realized how significant the computer technology would become to science and the society and that explains his involvement with the EDVAC ENIAC's successor) computing project at the University of Pennsylvania.

In June 1945, von Neumann wrote the "First Draft of a report on the EDVAC" memorandum (published by the University of Pennsylvania). It contained the "basic plan" for a modern computer. Incorporating ideas formulated by Turing, Mauchly, and Eckert, "von Neumann's architecture" (as it is now called) called for a central arithmetic unit, a central control unit, provisions for input/output, and, most significantly, a memory for storing program.

Once an application program is deposited into computer memory, the execution of such a program is accomplished by consulting this memory to determine which instruction of the program should be executed next. Computers that implement this idea of program storage and execution are called stored-program.

Von Neuman's memorandum would not be worth mentioning if it were not for the fact that even today the design of computer architectures continues to be influenced by the von Neumann architecture.

The ENIAC was not a stored-program computer as the instructions constituting a program were arranged by linking hardware modules with wires and by setting switches. However, the computer that von Neumann constructed at the Institute for Advanced Studies (IAS) in Princeton between 1948 and 1952 was. The computer was successfully operated from 1952 until 1960.

IAS computer's impact:

- it represented modern principles of computer design that are followed for this day; by the end of the 1960s, there were approximately 6,000 general purpose electronic computers installed in the US, almost all of them based on the stored-program ideas first introduced with the designs of the EDVAC and IAS;
- IAS project was an important source of information about electronic computers and their use, disseminated freely through America and Europe as the designers not only delivered lectures on the IAS computer but also shared circuit designs; there were also many visiting scholars to the IAS interested in computing; for instance, the University of Illinois ILLIAC 1 computer was based on the IAS computer's design, also a visit of a team of Swedish researchers to IAS resulted in the development of Swedish first electronic computer BESK in 1953;
- a new generation of computer experts were trained (numerical analysts, computer engineers, and computer scientists); after the end of the IAS project, they moved to other organizations to start their computer projects and helped to create the foundation of the computer industry;
- important scientific work done on this computer.

IAS applications:

- test-bed for further computer designs and applications (military and atomic energy applications)
- various scientific theories were created and investigated using the IAS computer (in astrophysics, numerical meteorology, etc.)

Early computers elsewhere

USSR

Our analysis of the early computer activities clearly demonstrates that the work on computers started almost concurrently in many regions of the world, in Germany, England, U.S.A.

The end of the Cold War and the changes in the former Eastern Block resulted in the opening of many governmental archives and that allows historians to look into the development of computing in the former USSR and other counties of the so-called Soviet block.

The use of computers in the American nuclear program and the desperate attempt of the USSR to get an atomic bomb as soon as possible had to initiate Russian computer program. Since the architectures of the early American computers such as ENIAC and EDVAC were not kept a secret, one may only conclude that some of that computer architectures and technologies were reflected in the early Russian computers. This, however, is only a hypothesis to be answered by historical research.

The most influential early Russian computer designer was S.A. Lebedev. According to some sources (e.g. [2]), he started his work on his first electronic computer in the late 1930s in Moscow but his work was interrupted by the Russian-German war that started in 1941. Not much is known about Lebedev's early work.

After the war, Lebedev re-initiated his work on computers in 1947 (under the influence of the ENIAC's announcement?) at the Institute of Electrical Engineering of the Ukrainian Academy of Science in Kiev. By 1951, Lebedev's team finished the MESM computer.

MESM was not a useful computer. As with Williams and Kilburn's Small Scale Experimental Machine ("The Baby") constructed at the University of Manchester in 1948, Lebedev's MESM was a proof of concept, a proof that a useful electronic computer could be built in the USSR.

Lebedev's second computer–BESM-1–was completed in 1952 and was successfully used in many applications.

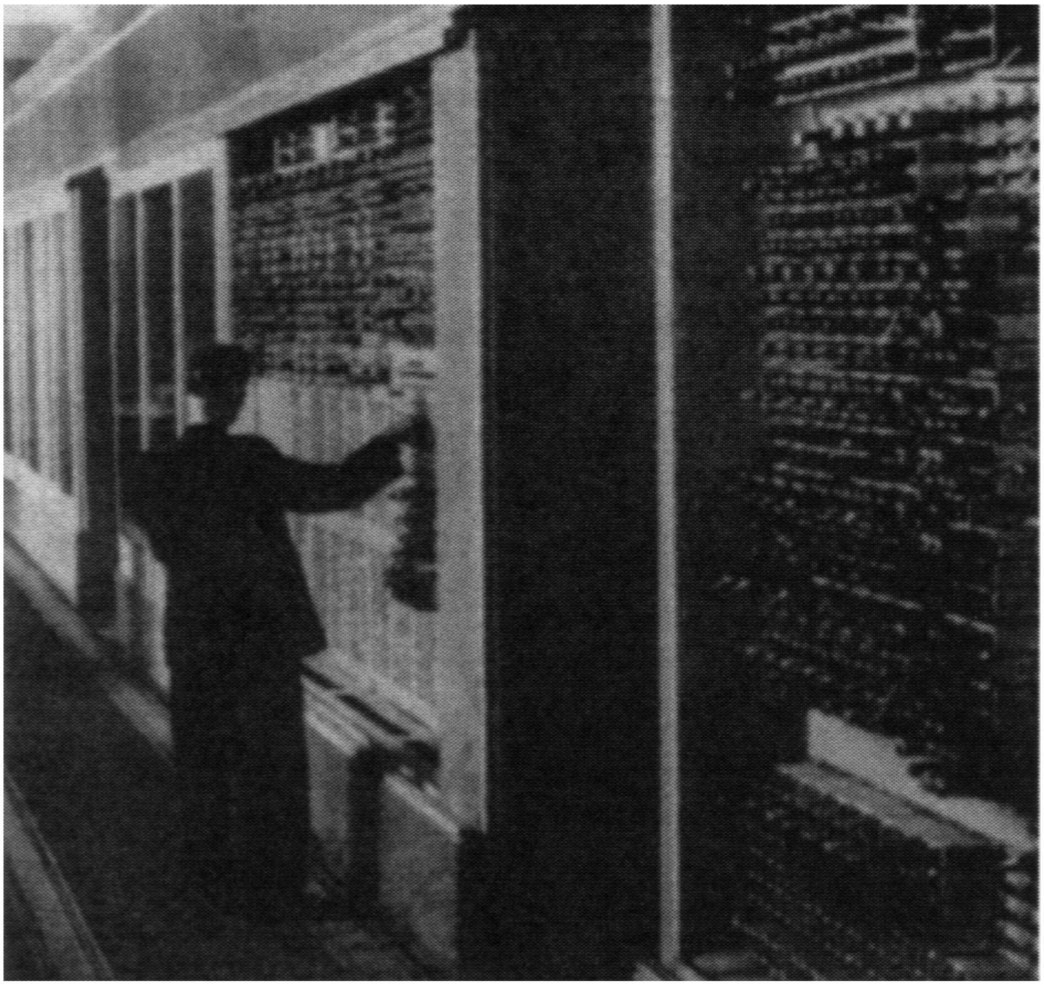

Fig. 11. Lebedev's BESM computer. Source: [3].

In the first three years of the 1950s a number of other computers were completed in the USSR. They were: the M1 (1951, Isaak Bruk's team at the Power-engineering Institute of the Academy of Science of USSR), the M2 (1952, the same team as for the M1), STRELA (1953, Yuriy Bazilevskiy and Bashir Ramayev, Special Design Bureau-245). The STRELA (which means "arrow") was the first computer in the USSR manufactured in small series.

Japan

Japan started manufacturing its first computers in the second half of the 1950s. Companies such as Fuji Film Company, Nippon Telegram and Telephone Public Corporation as well as universities: Tokyo University, Osaka University, and Keio University designed and built their first hardware. Since the 1960s, Japanese computer industry began to develop at a remarkable rate.

Other European Countries

In the 1950s, a large number of countries (in addition to US, UK, Germany, Japan, and USSR) had at least one digital electronic computer to their credit. The (incomplete) list includes: Canada (the UTEC, 1952), France (the Bull Gamma 60, 1956), Czechoslovakia (the SAPO, or Samočinný počítač, 1956), Sweden (The BARK, or Binr Automatisk ReläKalkylator, 1950; the BESK, or Binär Elektronisk Sekvens-Kalkulator, 1953), Norway (the NUSSE, or Norsk Universell Siffermaskin, 1953), Denmark (the DASK, or Dansk Automatic Eskvens Kalkulator, 1956), Poland (the XYZ, 1958).

Conclusions

The development of first practical computers was driven by a range of factors. One was scientific curiosity (e.g. the ABC computer or Zuse's Z1). Other projects were initiated to help with war efforts and defense systems (Colossus, ENIAC, EDVAC).

During the WWII there were about 15 computers, some operational some not, some were using traditional electro-mechanical technology and some, like ENIAC, were electronic. Some of these computers supported the war efforts in a direct and important way (e.g. Colossus computers). The role of other computers was to demonstrate how important the new computer technology would become in the near future, to disseminate the knowledge about computers and to educate the first generation of computer experts.

In just a few years after the end of the WWII, the first computers would be sold commercially and the computer industry would be born. From that time on, these would be the computers and not calculators to take on complex data processing tasks for scientific, business, and governmental applications.

But the creation of the first computers also demonstrated that further advancement in the design and use of powerful programmable calculating devices would also require theoretical studies of computers and computation, studies such as those initiated by Alan Turing and John von Neumann.

It is not a surprise that the majority of early computers were designed at Universities and other academic/research institutions rather than in garages and mechanical shops of early calculator inventors.

As a result, a new academic discipline of computer science was formed (there was never an academic discipline of "calculator science")

Appendix A: a list of early computers, 1938-1949

computer	produced by	technology	country	completion	purpose	nr
Z1	Konrad Zuse	mechanical programmable binary	Germany	1938	general calculations	1
Z3	Konrad Zuse	electro-mechanical programmable binary	Germany	1941	scientific calculation	1
ABC	Iowa State University	electronic binary not programmable special-purpose	USA	1942	scientific computing (Gauss elimination)	1
Colossus 1 (Mark-1)	Post Office Research Lab	electronic binary not stored-program	UK	1943	code breaking	1
Colossus 2 (Mark-2)	Post Office Research Lab	electronic binary not stored-program	UK	1944	code breaking	10
Mark 1	Harvard University IBM	electro-mechanical programmable not stored-program decimal	USA	1944	scientific computing engineering (differential equations)	1
ENIAC	University of Pennsylvania	electronic decimal not stored-program	USA	1946	military applications	1
SSEM	Manchester University	electronic binary stored-program	UK	1948	experimental	1
EDSAC	Cambridge University	electronic binary stored-program	UK	1949	general purpose	1
EDVAC	University of Pennsylvania	binary electronic stored-program	US	1949	military applications	1

Table 1. Early computers, 1938-1949.

Appendix B: a list of early computers, 1950-1953

computer	produced by	technology	country	completion	purpose	nr
Z4	Konrad Zuse	electro-mechanical programmable binary	Germany	1950	numerical analysis	1
BARK	Swedish Board for Computing Machinery	electro-mechanical binary	Sweden	1950	?	1
Manchester Mark 1 (Ferranti Mark 1)	Manchester Un./Ferranti	electronic binary stored-program	UK	1951	general purpose applications	9 (1 sold in Canada)
UNIVAC	Remington Rand	electronic binary stored-program	USA	1951	general purpose	several
UTEC Mark 1	Uni verity of Toronto	electronic binary stored-program	Canada	1951	scientific computing	1
MESM	USSR Academy of Science	electronic binary stored-program	USSR	1951	unknown experimental	1
ILLIAC 1	University of Illinois	electronic binary stored-program	USA	1951	general purpose	1
BESM	USSR Academy of Science	electronic binary stored-program	USSR	1952	unknown experimental	1
Johniac	Remington Rand	electronic binary stored-program	USA	1953	general purpose	1
BESK	Swedish Board for Computing Machinery	electronic binary stored-program	Sweden	1953	scientific computation	1

Table 1. Early computers, 1950-1953.

References

1. R. Rojas and U. Hashagen, *The First Computers: History and Architectures*, The MIT Press, 2000.

2. B.J. Copeland (ed), *Colossus: The Secrets of Bletchley Park's Codebreaking Computers*, Oxford University Press, 2010.

3. G. Trogemann and W. Ernst (eds.), *Computing in Russia: The History of Computer Devices and Information Technology revealed*, Vieweg (2001).