**Chronology of Digital Computing Machines**

**(earlier up to 1952)**

**Mark Brader**

For some time Mark Brader has maintained a chronology of digital computing machines. Resulting from a break in his Internet access, Mark is no longer posting updates regularly to Usenet; instead, I am maintaining this copy on the WWW for him. This page is based on his final posting of the chronology, but has undergone subsequent updating and minor editing (note that the document is deliberately kept in plain text, not HTML).

**Please note that Mark's email address has changed again, to <msb@vex.net>.**

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A Chronology of Digital Computing Machines (to 1952)

Last posted June 25, 1997, by Mark Brader

to alt.folklore.computers,comp.misc,soc.history.science

with Message-ID <1997Jun25.194812.28073@sq.com>

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As I am leaving SoftQuad (and Usenet, at least for the moment) today,

I thought I would take this opportunity to repost the current version of

the following article which I have been maintaining and which has

appeared several times in these newsgroups.

Followups this time are directed to soc.history.science; if someone else

wants to grab this document and take over maintenance of it, they are

welcome to do so. As it says at the end, it's in the public domain.

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[Canned article follows -- last substantively modified June 8, 2000.]

[This article was prepared using the ISO 8859-1 character set. If you

see an i-circumflex in "naquît" and a u-umlaut in "Tübingen",

that's correct. If not, be aware that several other words and names here and

there through the article will also look wrong for you. This should not

be an issue with the WWW version of this document.]

What was the first computer and who built it?

It turns out that this is more a question of definition than a

question of fact. The computer, as we now understand the word,

was very much an evolutionary development rather than a simple

invention. This article traces the sequence of the most important

steps in that development, and in the earlier development of

digital calculators without programmability. It may help you

to decide for yourself whether you think the first computer was

the ABC, the Z3 (aka V3), the ENIAC, the SSEC, the Manchester

Mark I (aka Baby), the EDSAC, or perhaps yet another machine --

and how to apportion the honor of invention among John Atanasoff,

Charles Babbage, Presper Eckert, John Mauchly, Alan Turing, John

von Neumann, Konrad Zuse, and others.

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This article has evolved from an original version that I drafted

in 1988, and has been posted to various Usenet groups several times.

It has been prepared primarily from two sources:

"Bit by Bit: An Illustrated History of Computers"

by Stan Augarten

1984, Ticknor and Fields, New York

ISBN 0-89919-268-8, 0-89919-302-1 paperback

"A History of Computing Technology"

by Michael R. Williams

1985, Prentice-Hall, Englewood Cliffs, NJ

ISBN 0-13-389917-9

Either of these books is well worth a trip to the library to read.

(Unfortunately, finding either one in a bookstore today would be an

unlikely proposition.) Augarten is a journalist; he writes very

readably, but occasionally does not say exactly what he means.

Williams is a computer science professor; his book is superior in

technical depth, and covers additional subject areas including

analog computing and computing in ancient times.

For some material I also consulted the following books.

"The Dream Machine: Exploring the Computer Age"

by Jon Palfreman and Doron Swade

1991, BBC Books, London

ISBN 0-563-36221-9

The book of the TV series of the same title, which changed to "The

Machine that Changed the World" when it was shown in the US on PBS.

I enjoyed the content but found the typographic design so hideously

mannered as to be distracting. This book has less technical detail

than the two mentioned above, and a greater emphasis on the impact of

computers on the modern world; a considerable fraction of its length

is about the uninteresting :-) period after the end of this chronology.

"Portraits in Silicon"

by Robert Slater

1987, MIT Press, Cambridge, MA

ISBN 0-262-69131-0

Articles about, and interviews with, 34 of the people to whom goes

much of the credit for the computer world being the way it is, from

Charles Babbage to Donald Knuth.

"The Computer Pioneers"

by David Ritchie

1986, Simon & Schuster, New York

ISBN 0-671-52397-X

This one concentrates in the late 1930s and the 1940s, with one chapter

for each of the key inventors or groups of that period. The author is

a journalist and the book is very readable.

"The Computer -- My Life"

Original German version by Konrad Zuse:

"Der Computer -- mein Lebenswerk"

1993, Springer-Verlag, Berlin

ISBN 3-540-56292-3

English translation by Patricia McKenna and J. Andrew Ross

1993, Springer-Verlag, Berlin and New York

ISBN 0-387-56453-5 (New York), 3-540-56453-5 (Berlin).

An autobiography.

"Encyclopedia of Computer Science and Engineering", 2nd ed.

editor Anthony Ralston, associate Editor Edwin D. Reilly Jr.

1983, Van Nostrand Reinhold, New York

ISBN 0-442-24496-7

The title is self-explanatory.

"The Computer Comes of Age"

Original French version by R. Moreau:

"Ainsi naquît l'informatique"

1981

English translation by J. Howlett

1984, MIT Press, Cambridge, MA

ISBN 0-262-36103-2

Concentrating on the period from the mid 1940s to mid 1960s, and

with a noticeably IBMish viewpoint.

"ENIAC: The Triumphs and Tragedies of the World's First Computer"

by Scott McCartney

1999, Walker and Co., New York

ISBN 0-8027-1348-3

This book has somewhat a wider scope than the title suggests, covering

events in the lives of Presper Eckert and John Mauchly over several decades.

However, it is strictly centered on the two men and tends to "prove" their

pioneering status by omitting any developments they weren't involved with.

Two articles from Scientific American were also sources. One in the

August 1988 issue was about the Atanasoff-Berry machines, and one in the

February 1993 issue of was about Babbage's difference engines and the

modern-day completion of one of them.

Information about the cipher-breaking machines came primarily from

two books:

"Seizing the Enigma: the Race to Break the German U-Boat Codes,

1939-1943"

by David Kahn

1991, Houghton Mifflin, Boston

ISBN 0-395-42739-8

"Codebreakers: The Inside Story of Bletchley Park"

edited by F.H. Hinsley and Alan Stripp

1993, Oxford University Press, Oxford and New York

ISBN 0-19-820327-6

Kahn is also the author of the monumental cryptological history "The

Codebreakers"; this book is oriented more to a popular readership but

still contains plenty of technical detail. The second book collects

articles by various individuals involved with the cipher-breaking work;

some are quite technical and others not.

A few items of information come from other sources, not listed individ-

ually here. One correction about Konrad Zuse came from his son Horst.

And finally, the book

Faster than Thought

editor B. V. Bowden

1953, Pitman, New York and London

provided an interesting early perspective, and the signature quote.

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I've tried to mention in this chronology each machine within the

relevant time period that meets the following criteria. First, it

must use a digital technique to do arithmetic or other logic. This

eliminates, for instance, the slide rule and the differential analyzer,

while allowing the cipher-breaking machines of the Second World War

to be included.

Second, it must actually do the arithmetic or other work rather than

just assisting the user's memory. I consider this to eliminate the

abacus as well as, say, Napier's Bones.

Third, to count as being able to do an operation, the machine must do

essentially the whole computation, with little or no assistance from the

user. You could subtract 16 on a 6-digit Pascaline by adding 999,984,

but this doesn't mean we should say that a Pascaline could subtract.

Fourth, it must work on user-supplied operands. In 1364, Giovanni

de Dondi completed a clock where chains of various lengths, advancing

in discrete annual steps to represent calendar cycles, computed the

date of Easter; but this still does not qualify. (For details of

this clock see "Some Outstanding Clocks over Seven Hundred Years,

1250-1950" by H. Alan Lloyd, 1958, Leonard Hill.)

And finally, the machine must have either been technologically

innovative, or else well known and influential. For certain concepts

of special importance, I have also listed the first time they were

\*described\*, although they were not implemented at that time.

Where I do not describe the size of a machine, it is generally

suitable for desktop use if it has no memory and is unprogrammable

or if it is a small prototype, but would about fill a small room if

it has memory or significant programmability.

The term "full-scale" is used, in contrast to "prototype", to refer

to a machine with sufficient capacity to do regular useful work.

For the sorts of machines described toward the end of the chronology,

I generally consider them "completed" when they first run a program,

even though they may be subject to further modifications and debugging.

Unfortunately, sources referring to the "completion" of a machine are

not always clear as to exactly what they mean by it.

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A Chronology of Digital Computing Machines (to 1952)

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1623. Wilhelm Schickard (1592-1635), of Tübingen, Württemberg

(now in Germany), makes his "Calculating Clock". This is a

6-digit machine that can add and subtract, and indicates overflow

by ringing a bell. Mounted on the machine is a set of Napier's Rods

(or Bones), a memory aid facilitating multiplications. The machine

and plans are lost and forgotten in the war that is going on.

The plans will finally be rediscovered in 1935, only to be lost in war

again, and then re-rediscovered in 1956 by the same man! The machine

will be reconstructed in 1960, and found to be workable.

(Schickard is a friend of the astronomer Kepler.)

(According to an informal communication, Schickard sometimes uses

the device for 7-digit calculations, counting rings of the overflow

bell by putting rings on one of his, uh, personal digits...)

1644-5. Blaise Pascal (1623-62), of Paris, makes his "Pascaline".

This 5-digit machine uses a different carry mechanism from

Schickard's, with rising and falling weights instead of a direct

gear drive; it can be extended better to support more digits, but

it cannot subtract, and probably is less reliable than Schickard's

simpler method.

Where Schickard's machine is forgotten -- and indeed Pascal is

apparently unaware it ever existed -- Pascal's becomes well known

and establishes the computing machine concept in the intellectual

community. He makes more machines and sells about 10-15 of them,

some supporting as many as 8 digits. (Several survive to the

present day.) Patents being a thing of the future, others also

sell copies of Pascal's machine.

(Pascal is also the inventor of the bus.)

c.1668. Sir Samuel Morland (1625-95), of England, produces a

non-decimal adding machine, suitable for use with English

money. Instead of a carry mechanism, it registers carries on

auxiliary dials, from which the user must reenter them as addends.

1674. Gottfried Wilhelm von Leibniz (1646-1716), of Leipzig,

designs his "Stepped Reckoner", which is constructed by a

man named Olivier, of Paris. It uses a movable carriage so that it

can multiply, with operands of up to 5 and 12 digits and a product

of up to 16. The user has to turn a crank once for each unit in

each digit in the multiplier; a fluted drum translates the turns

into additions. But the carry mechanism requires user intervention,

and doesn't really work in all cases anyway.

Leibniz's machine doesn't get forgotten, but it does get misplaced

in an attic within a few years -- and will stay there until 1879 when

it will be noticed by a man working on the leaky roof!

(Leibniz, or Leibnitz, is also the co-inventor of calculus.)

1775. Charles, the third Earl Stanhope, of England, makes a

successful multiplying calculator similar to Leibniz's.

1770-6. Mathieus Hahn, somewhere in what will be Germany, also makes

a successful multiplying calculator.

1786. J. H. Müller, of the Hessian army, conceives the idea of

what came to be called a "difference engine". That's a

special-purpose calculator for tabulating values of a polynomial,

given the differences between certain values so that the polynomial

is uniquely specified; it's useful for any function that can be

approximated by a polynomial over suitable intervals. Müller's

attempt to raise funds fails and the project is forgotten.

1820. Charles Xavier Thomas de Colmar (1785-1870), of France,

makes his "Arithmometer", the first mass-produced calculator.

It does multiplication using the same general approach as Leibniz's

calculator; with assistance from the user it can also do division.

It is also the most reliable calculator yet. Machines of this general

design, large enough to occupy most of a desktop, continue to be sold

for about 90 years.

1822. Charles Babbage (1792-1871), of London, having reinvented

the difference engine, begins his (government-funded)

project to build one by constructing a 6-digit calculator using

gear technology similar to that planned for the difference engine.

1832. Babbage and Joseph Clement produce a prototype segment of

his difference engine, which operates on 6-digit numbers

and 2nd-order differences (i.e. can tabulate quadratic polynomials).

The complete engine, which would be room-sized, is planned to be

able to operate both on 6th-order differences with numbers of about

20 digits, and on 3rd-order differences with numbers of 30 digits.

Each addition would be done in two phases, the second one taking

care of any carries generated in the first. The output digits

would be punched into a soft metal plate, from which a plate for a

printing press could be made.

But there are various difficulties, and no more than this prototype

piece is ever assembled.

1834. George Scheutz, of Stockholm, produces a small difference

engine in wood, after reading a brief description of

Babbage's project.

1834. Babbage conceives, and begins to design, his "Analytical

Engine". Whether or not this machine, if built, would

constitute a computer depends on exactly how "computer" is being

defined. One essential feature of present-day computers is absent

from the design: the "stored-program" concept, which is necessary

for implementing a compiler. The program would have been in

read-only memory, specifically in the form of punch cards. (In

this chronology, such machines will be called "programmable cal-

culators".)

Babbage continues to work on the design for years, though after

about 1840 the changes are minor. The machine would operate on

40-digit numbers; the "mill" (CPU) would have 2 main accumulators

and some auxiliary ones for specific purposes, while the "store"

(memory) would hold perhaps 100 more numbers. There would be

several punch card readers, for both programs and data; the cards

would be chained and the motion of each chain could be reversed.

The machine would be able to perform conditional jumps. There

would also be a form of microcoding: the meaning of instructions

would depend on the positioning of metal studs in a slotted

barrel, called the "control barrel".

The machine would do an addition in 3 seconds and a multiplication

or division in 2-4 minutes.

1842. Babbage's difference engine project is officially canceled.

(The cost overruns have been considerable, and Babbage is

spending too much time on redesigning the Analytical Engine.)

1843. Scheutz and his son Edvard Scheutz produce a 3rd-order

difference engine with printer, and the Swedish government

agrees to fund their next development.

1847-9. Babbage designs an improved, simpler difference engine,

which will operate on 7th-order differences and 31-digit

numbers, but nobody is interested in paying to have it built.

(In 1989-91, however, a team at London's Science Museum will do

just that. They will use components of modern construction, but

with tolerances no better than Clement could have provided... and,

after a bit of tinkering and detail-debugging, they will find that

the machine does indeed work.)

1853. To Babbage's delight, the Scheutzes complete the first

full-scale difference engine, which they call a Tabul-

ating Machine. It operates on 15-digit numbers and 4th-order

differences, and produces printed output as Babbage's would have.

A second machine is later built to the same design by the firm

of Bryan Donkin of London.

1858. The first Tabulating Machine is bought by the Dudley

Observatory in Albany, New York, and the second one by

the British government. The Albany machine is used to produce

a set of astronomical tables; but the observatory's director is

then fired for this extravagant purchase, and the machine is

never seriously used again, eventually ending up in a museum.

(The second machine, however, will have a long and useful life.)

1871. Babbage produces a prototype section of the Analytical

Engine's mill and printer.

1878. Ramon Verea, living in New York City, invents a calculator

with an internal multiplication table; this is much faster

than the shifting carriage or other digital methods. He isn't

interested in putting it into production; he just wants to show that

a Spaniard can invent as well as an American.

1879. A committee investigates the feasibility of completing the

Analytical Engine and concludes that it is impossible now

that Babbage is dead. The project is then largely forgotten and is

unknown to most of the people mentioned in the last part of this

chronology -- though Howard Aiken is an exception.

1885. A multiplying calculator more compact than the Arithmometer

enters mass production. The design is the independent, and

more or less simultaneous, invention of Frank S. Baldwin, of the

United States, and T. Odhner, a Swede living in Russia. The fluted

drums are replaced by a "variable-toothed gear" design: a disk with

radial pegs that can be made to protrude or retract from it.

1886. Dorr E. Felt (1862-1930), of Chicago, makes his "Comptometer".

This is the first calculator where the operands are entered

merely by pressing keys rather than having to be, for example, dialed

in. It is feasible because of Felt's invention of a carry mechanism

fast enough to act while the keys return from being pressed.

1889. Felt invents the first printing desk calculator.

1890. US Census results are tabulated for the first time with sig-

nificant mechanical aid: the punch card tabulators of Herman

Hollerith (1860-1929) of MIT, Cambridge, MA. This is the start of

the punch card industry. The cost of the census tabulation is 98%

\*higher\* than the previous one, in part because of the temptation to

use the machines to the fullest and tabulate more data than formerly

possible, but the tabulation is completed in a much shorter time.

Another precedent is that the cards are read electrically.

(Contrary to popular impression and to earlier versions of this

chronology, Hollerith's cards of 1890 are not the same size as

US paper money of the time; they are much smaller. Other sizes of

punch cards will also appear within a few years.)

1892. William S. Burroughs (1857-98), of St. Louis, invents a

machine similar to Felt's but more robust, and this is the

one that really starts the office calculator industry.

(This machine is still hand powered, but it won't be many years

before electric calculators appear.)

1906. Henry Babbage, Charles's son, with the help of the firm of

R. W. Munro, completes the mill of his father's Analytical

Engine, just to show that it would have worked. It does. The

complete machine is never produced.

1919. W. H. Eccles and F. W. Jordan publish the first flip-flop

circuit design.

c.1920. Eugène Carissan of France constructs a machine for factoring

whole numbers, based on 14 rotating metal rings studded with pegs.

1926. Derrick Henry Lehmer, at Berkeley, CA, constructs a machine for

factoring whole numbers, based on 19 bicycle chains. A later

machine will use punched tape -- not paper tape, but film stock.

(Lehmer is the son of mathmatician Derrick Norman Lehmer.)

1931-2. E. Wynn-Williams, at Cambridge, England, uses thyratron

tubes to construct a binary digital counter for use in

connection with physics experiments.

1932. Lehmer adds an optical reader to his punched-film factoring

machine. It is now capable of 5,000 operations per second.

1935. International Business Machines introduces the "IBM 601",

a punch card machine with an arithmetic unit based on relays

and capable of doing a multiplication in 1 second. The machine

becomes important both in scientific and commercial computation,

and about 1,500 of them are eventually made.

Jun 1937. Konrad Zuse (1910-95) of Berlin writes in his diary a

synopsis of the stored-program concept: "Die Operationen

folgen einem Plan ähnlich einem Rechenplan. Mit Ausgangsbedingungen

und Resultat. Dementsprechend Speicherplan. Jedoch kann der

Speicher- oder Arbeitsplan sich aus den vorhergehenden Operationen

ergeben (z.B. die Nummern der Speicherzellen) und sich so aus sich

selbst aufbauen (vgl. 'Keimzelle')." That is, "The operations follow

a plan similar to a computing plan. With initial conditions and

result. Accordingly, a storage plan. However, the storage or work

plan can still result from the preceding operations (e.g. the

numbers in the storage cells) and in this way be built from itself

(cf. 'germ cell')."

Nov 1937. George Stibitz (c.1904 - 1995) of the Bell Telephone Labor-

atories (Bell Labs), New York City, constructs on his kitchen

table the "K-Model": a demonstration 1-bit binary adder using relays.

1937. Alan M. Turing (1912-54), of Cambridge University, England,

publishes a paper on "computable numbers". This paper solves

a mathematical problem, but the solution is achieved by reasoning

(as a mathematical device) about the theoretical simplified computer

known today as a Turing machine.

Nov 1938. Marian Rejewsky (a man, 1905-80) and his group, working

for Poland's Biuro Szyfrów (Cipher Office), complete the first

"bomba", a machine using electromechanical digital logic for trying

out combinations of letters to solve the Germans' Enigma cipher.

The Enigma machine uses a series of disks ("rotors") with sets of

26 contacts wired so as to permute and repermute the alphabet; the

sequence of rotors and their initial settings are changed from time

to time, forming a key.

The bomba contains its own set of rotors like the Enigma's, and its

function is to determine, through a combination of logic with an

exhaustive search of rotor positions, whether a particular short

piece of guessed plaintext and a particular piece of encrypted text

could correspond. If the plaintext was correctly guessed, then the

key can be derived from the bomba results, and not only the rest of

that message, but all others using the same key can then be decrypted.

And if it wasn't, then the same guess will be tried against other

messages.

(But the next month, the Germans will add a selection of additional

rotors to their Enigma machines. The Poles, not having the resources

to build more bomby, in July 1939 will turn over all their discoveries

to the British and the French.)

1938. Claude E. Shannon (1916-2001) publishes a paper on the

implementation of symbolic logic using relays.

1938. Helmut Schreyer, of Berlin, designs logic circuitry based on

a combination of vacuum tubes and neon lamps. (By 1940 he

will have produced a 10-bit adder and a prototype memory unit.)

1938. Zuse, with some assistance from Schreyer, completes a

prototype electromechanical binary programmable calculator,

called the "V1" at the time but retroactively renamed "Z1" after the

war. It works with floating point numbers having a 7-bit exponent,

16-bit mantissa, and a sign bit. The memory uses sliding metal parts

to store 16 such numbers, and works well; but the arithmetic unit,

using secondhand relays and stepping switches, is less successful.

The program is read from punched tape. Like Lehmer, Zuse uses film

rather than paper for his tape; specifically, discarded 35 mm movie

film. Data values can be entered from a numeric keyboard, and

outputs are displayed on electric lamps.

Nov 1939. John V. Atanasoff (1903-95) and graduate student Clifford

Berry (1918-63), of Iowa State College (now the Iowa State

University), Ames, Iowa, complete a prototype 25-bit adder. This

is the first machine to calculate using vacuum tubes. To store the

operands, it has 2 25-bit words of memory in the form of capacitors

(with refresh circuits using more vacuum tubes -- the first regen-

erative memory) mounted one word on each side of a revolving disk.

There is no input device; the user enters the operands directly into

memory, by tapping the appropriate capacitors with a wire!

Nov 1939. At Bell Labs, Samuel Williams and Stibitz complete a

calculator which can operate on complex numbers, and give it

the imaginative name of the "Complex Number Calculator"; it is later

known as the "Model I Relay Calculator". It uses telephone switching

parts for logic: 450 relays and 10 crossbar switches. Numbers are

represented in "plus 3 BCD"; that is, for each decimal digit, 0 is

represented by binary 0011, 1 by 0100, and so on up to 1100 for 9;

this scheme requires fewer relays than straight BCD.

Rather than requiring users to come to the machine to use it, the

calculator is provided with three remote keyboards, at various

places in the building, in the form of teletypes. Only one can be

used at a time, and the output is automatically displayed on the

same one.

1939. Zuse and Schreyer begin work on the "V2" (later "Z2"),

which will marry the Z1's existing mechanical memory unit to

a new arithmetic unit using relay logic. The project is interrupted

for a year when Zuse is drafted.

Early 1940. Turing and Gordon Welchman (1906-85), working for

the British government codebreaking department deceptively

named the Government Code and Cypher School, at Bletchley Park,

Bletchley, England, successively improve the design of the bomba

by adding further logic circuits. These greatly reduce the number

of false solutions. With quantity production of these machines, now

called bombes, the full-scale breaking of Enigma ciphers becomes a

practical proposition.

(After the US joins the war, they will make and use them too.

Improvements on the machines will continue, as the Germans also

improve the cipher.)

1940. Zuse is released from the army and completes the Z2.

It works better than the Z1, but isn't reliable enough.

(Later he is drafted again, and released again.)

Sep 1940. Stibitz, attending a mathematical conference in Hanover,

NH, to present a paper on the Complex Number Calculator,

demonstrates operation of the machine from a remote location by

teletype connection.

Summer 1941. Atanasoff and Berry complete a special-purpose calcu-

lator for solving systems of simultaneous linear equations,

later called the "ABC" ("Atanasoff-Berry Computer"). This uses the

same regenerative capacitor memory as their prototype, but with 60

50-bit words of it, mounted on two revolving drums. The clock speed

is 60 Hz, and an addition takes 1 second. (For the purposes of this

calculator, multiplication is not required.) There are circuits to

convert between binary and decimal for input and output; the machine

includes several hundred vacuum tubes altogether.

For secondary memory the ABC uses punch cards, moved around by the

user. The holes are not actually punched in the cards, but burned

by an electric spark. The card system is a partial failure; its

error rate of 0.001% is too high to solve large systems of equations.

(Atanasoff will leave Iowa State after the US enters the war, and

this will end his work on digital computing machines. The ABC will

largely forgotten within a few years, and dismantled in 1946 when

the storage space is needed.)

Dec 1941. Now working with limited backing from the DVL (German Aero-

nautical Research Institute), Zuse completes the "V3" (later

"Z3"): the first operational programmable calculator. It works with

floating point numbers having a 7-bit exponent, 14-bit mantissa

(with a "1" bit automatically prefixed unless the number is 0),

and a sign bit. The memory uses relays; with a capacity of 64 words,

it needs over 1,400 of them. There are 1,200 more relays in the

arithmetic and control units. The machine is the size of a closet.

The program, input, and output are implemented as described above for

the Z1. Conditional jumps are not available. The machine can do 3-4

additions per second, and takes 3-5 seconds for a multiplication.

Zuse considers the machine a prototype; it doesn't have enough memory

to be much use for the equation-solving problems that the DVL was

mostly interested in.

(In 1943, an air raid will destroy Zuse's workshop, and the Z3 with

it, as well as his home nearby. A replica Z3 will be built in 1960

for the Deutsches Museum in Munich. And in 1967, the Patent Office

of West Germany will finally rule on Zuse's 1941 application for a

patent on the Z3, rejecting it "mangels Erfindungshöhe": "for an

insufficient degree of invention"!)

1942. Zuse completes the S1, the first digital machine for process

control. Attached sensors measure the profile of the wing of

a flying bomb under construction; the readings are converted to dig-

ital and computations are run to determine how much the wing deviates

from the ideal shape and needs to be adjusted. (This is cheaper than

making it accurately in the first place.) The machine contains 800

relays; the program is literally wired in, each instruction being read

by advancing a set of stepping switches.

Jan 1943. Howard H. Aiken (1900-73) and his IBM-backed team at

Harvard University, Cambridge, MA, complete the "ASCC Mark I"

("Automatic Sequence-Controlled Calculator Mark I"), also called the

"Harvard Mark I". This electromechanical machine is the first pro-

grammable calculator to be widely known: Aiken is to Zuse as Pascal

to Schickard.

The machine is 51 feet long, weighs 5 tons, and incorporates 750,000

parts. It includes 72 accumulators, each incorporating its own arith-

metic unit as well as a mechanical register with a capacity of 23

digits plus sign. (See the ENIAC entry, below, for a more detailed

description of such an architecture.) The arithmetic is fixed-point,

with a plugboard setting determining the number of decimal places.

I/O facilities include card readers, a card punch, paper tape readers,

and typewriters. There are 60 sets of rotary switches, each of which

can be used as a constant register -- sort of a mechanical read-only

memory. An addition takes 1/3 second, and a multiplication, 1 second.

The program is read from one paper tape; data can be read from the

other tapes, or the card readers, or from the constant registers.

Conditional jumps are not available. However, in later years the

machine is modified to support multiple paper tape readers for the

program, with the transfer from one to another being conditional,

sort of like a conditional subroutine call. Another addition allows

the provision of plugboard-wired subroutines callable from the tape.

Apr 1943. Max Newman, Wynn-Williams, and their team at Bletchley

Park, complete the "Heath Robinson". This is a prototype

machine for breaking the new German ciphers collectively codenamed

the "Fish" ciphers, which are based on bit-level manipulations rather

than permutations of the alphabet. The machine uses a combination

of electronics and relay logic. It reads data optically at 2,000

characters per second from 2 closed loops of paper tape, each

typically about 1,000 characters long.

(Newman had taught Turing at Cambridge, and had been the first person

to see a draft of Turing's 1937 paper. Heath Robinson is the name of

a British cartoonist known for drawings of comical machines, like

the American Rube Goldberg. Two later machines in the series will be

named for London stores with "Robinson" in their names!)

Apr 1943. John W. Mauchly (pronounced Mawkly; 1907-80), J. Presper

Eckert (1919-95), and John Brainerd at the Moore School of

Electrical Engineering, of the University of Pennsylvania, Phila-

delphia, write a "Report on an Electronic Diff. Analyzer" for the

US Army's Ballistics Research Lab. The abbreviation "Diff." is

intended to reflect the fact that the proposed machine, eventually

named the ENIAC ("Electronic Numerator, Integrator, Analyzer, and

Computer"; some sources omit "Analyzer" or have "Calculator" as the last

word), is to use \*differences\* to compute digitally the same results

that a \*differential\* analyzer would compute by analog means. The BRL,

which has a great interest in calculating shell trajectories to produce

gun aiming tables, accepts the proposal and work on the ENIAC begins in

secret.

Sep 1943. Williams and Stibitz complete the "Relay Interpolator",

later called the "Model II Relay Calculator". This is a

programmable calculator; again, the program and data are read from

paper tapes. An innovative feature is that, for greater reliability,

numbers are represented in a biquinary format using 7 relays for

each digit, of which exactly 2 should be "on": 01 00001 for 0,

01 00010 for 1, and so on up to 10 10000 for 9.

(Some of the later machines in this series will use the biquinary

notation for the digits of floating-point numbers.)

Dec 1943. Tommy Flowers (1905-98) and his team at Bletchley Park

complete the first "Colossus". This full-scale successor to

the "Robinson" series machines is entirely electronic, incorporating

2,400 vacuum tubes for logic. It has 5 paper tape loop readers,

each working at 5,000 characters per second.

(10 Colossi will eventually be built, then destroyed after the war

to maintain secrecy. Turing also has an important role at Bletchley

Park, but does not work directly on the machines. In the 1990s

Bletchley Park will become a museum, and in 1996 a replica Colossus

will be completed there.)

1944-5. Zuse almost completes his first full-scale machine, the "V4"

(later "Z4"), which resembles his earlier designs. Its

memory reverts to the Z1's mechanical design, storing 1,000 words of

32 bits in less then a cubic meter; the equivalent in relays would

have filled a large room.

As the war begins to go very badly for Germany, Zuse's work suffers

major disruptions. The Z4 is moved three times within Berlin, then

to Göttingen, and finally to the Bavarian village of Hinterstein

where it is hidden. Here it survives the war, but the Allies don't

understand what it is, and nobody in Germany is in a position to pay

Zuse for more work.

1945. Zuse invents a programming language called Plankalkül.

Jun 1945. John von Neumann (1903-57), having joined the ENIAC

team, drafts a report describing the future computer

eventually built as the "EDVAC" ("Electronic Discrete Variable

Automatic Computer" (!)); this is the first detailed description

of the design of a stored-program computer, and gives rise to the

term "von Neumann computer".

The first draft of the report fails to credit other team members

such as Eckert and Mauchly; when this version becomes widely

circulated, von Neumann gets somewhat too much credit for the

design. The final version corrects the oversight, but too late.

(Von Neumann, also noted for his mental calculating ability, is

the only one of the principal computer pioneers in the US familiar

with Turing's 1937 paper.)

Nov 1945. Mauchly and Eckert and their team at the Moore School

complete the ENIAC. It's too late for the war, and the

total cost of $486,800 far exceeds the original budget of $150,000

(problems that Eckert and Mauchly will face again on later projects),

but it works.

The ENIAC's architecture resembles that of the Harvard Mark I, but

its components are entirely electronic, incorporating 17,468 vacuum

tubes and more than 80,000 other components. The machine weighs 30

tons, covers about 1,000 square feet of floor, and consumes somewhere

between 130 and 174 kilowatts of electricity (sources differ). Many

of the modules are made to plug into the mainframe, to shorten the

repair time when a tube or other component fails. The cost and

downtime are further reduced by using circuits designed to work even

if the components are off-specification, and wire of the type least

preferred by hungry mice in experiments.

The machine incorporates 20 accumulators (the original plan was for 4).

The accumulators and other units are all connected by several data

buses, and a set of "program lines" for synchronization. Each accum-

ulator stores a 10-digit number, using 10 bits to represent each digit,

plus a sign bit, and also incorporates circuits to add a number from

a bus ("digit trunk") to the stored number, and to transmit the stored

number or its complement to a bus.

A separate unit can perform multiplication (in about 3 milliseconds),

while another does division and square roots; the inputs and outputs

for both these units use the buses. There are constant registers, as

on the Harvard Mark I: 104 12-digit registers forming an array called

the "function table". 100 of these registers are directly addressable

by a 2-digit number from a bus (the others are used for interpolations).

Finally, a card reader is available to input data values, and there

is a card punch for output.

The program is set up on a plugboard -- this is considered reasonable

since the same or similar program would generally be used for weeks

at a time. For example, connecting certain sockets would cause

accumulator 1 to transmit its contents onto data bus 1 when a pulse

arrived on program line 1; meanwhile several accumulators could be

adding the value from that data bus to their stored value, while

others could be working independently. The program lines are pulsed

under the control of a master unit, which can perform iterations.

The ENIAC's clock speed is 100 kHz.

Mauchly and Eckert apply for a patent. The university disputes this

at first, but they settle. The patent is finally granted in 1964,

but is overturned in 1973, in part because of the previous work by

Atanasoff, whom Mauchly had visited in June 1941.

Feb 1946. The ENIAC is revealed to the public. A panel of lights is

added to help show reporters how fast the machine is and what

it is doing; and apparently Hollywood takes note.

Jul-Aug 1946. The Moore School gives a course on "Theory and Techniques

for Design of Electronic Computers"; lectures are given by

Eckert, Mauchly, Stibitz, von Neumann, and Aiken among others. The

course leads to several projects being started, among them the EDSAC.

Jul 1947. Aiken and his team complete the "Harvard Mark II", a large

programmable calculator using relays both for its 50 floating-

point registers and for the arithmetic unit, 13,000 of them in all.

Sep 1947. A moth (?-1947) makes the mistake of flying into the Harvard

Mark II. A whimsical technician makes the logbook entry "first

actual case of bug being found", and annotates it by taping down the

remains of the moth.

(The term "bug" was of course already in use; that's why it's funny.

Grace Murray Hopper (1906-92), a programmer on the machine, will tell

the story so many times in later years that people will come to think

she found the moth herself.)

Oct 1947. Freddie C. Williams (1911-77) and Thomas Kilburn (1921-),

working under Newman at Manchester University, complete a new

type of digital memory (possibly from an original suggestion by Presper

Eckert), which comes to be called the Williams tube or CRT memory.

It uses the residual charges left on the screen of a CRT after the

electron beam has been fired at it; the bits are read by firing

another beam through them and reading the voltage at an electrode

beyond the screen, then rewriting. The technique is a little

unreliable, but is fast, and also relatively cheap because it can

use existing CRT designs; and it is much more compact than any other

memory existing at the time. A further advantage is that if the CRT

face is exposed to view, the values in the memory are visible!

1947. Frederick Viehe (?-1960), of Los Angeles, applies for a patent

on an invention which is to use magnetic core memory.

1947. Aiken predicts that the United States will need a total of six

electronic digital computers.

c.1947. The magnetic drum memory is independently invented by several

people, and the first examples are constructed.

(As noted below, some early machines will use drums as main memory

rather than secondary memory.)

Jan 1948. Wallace Eckert (1902-71, no relation to Presper Eckert)

of IBM, with his team, completes the "SSEC" ("Selective

Sequence Electronic Calculator"). This technological hybrid has

8 vacuum tube registers, 150 words of relay memory, and 66 paper

tape loops storing a total of 20,000 words. The word size is

20 digits, stored in BCD in the registers.

As with the Harvard Mark I in its later form, the machine can be

switched to read instructions from any of the paper tapes. There

is also some use of plugboards in its programming. But it can

also cache some instructions in memory and read them from there;

thus, in effect, it can operate either as a stored-program computer

(with a very small program memory) or not. Because it can do this,

IBM's point of view is that this is the first computer.

Jun 1948. Williams, Kilburn, and their team complete a prototype

computer. This is the first machine that everyone would

call a computer, because it's the first with a true stored-program

capability. At this point it has no formal name, though one paper

calls it the "Small-Scale Experimental Machine"; later the machine

will become known as the "Manchester Mark I", while its initial

form at this date will be nicknamed the "Baby".

The machine's main memory of 32 32-bit words occupies a single

Williams tube. (There are others on the machine, but less densely

used: one contains only an accumulator.)

The machine's programs are initially entered in binary on a keyboard,

and the output is read in binary from the face of another Williams

tube. Later Turing joins the team (see also the "Pilot ACE", below)

and devises a primitive form of assembly language, one of several

developed at about the same time in different places.

(In the 1990s a replica of the Baby is to be constructed, with

completion scheduled for the 50th anniversary year of 1998.)

Sep 1948. The ENIAC is improved, using ideas from Richard F. Clipper

of the BRL and Nicholas Metropolis of Los Alamos. Each program

line is permanently wired for a different operation, and a new converter

unit allows them to be addressed by a program, the way the function

table can -- thus implementing, in effect, opcodes. With this change,

the program can now be entered via the \*function table\*.

(This conversion will sometimes be described as making the ENIAC into a

stored-program computer, but the program memory is still read-only.

However, setting up a program now takes a matter of hours, rather than

days as before. The ENIAC will also acquire a magnetic core memory in

1952, but will survive only until 1955.)

Fall 1948. IBM introduces the "IBM 604", a programmable calculator

and card punch using vacuum tubes. It can read a card,

perform up to 60 arithmetic operations in 80 milliseconds, and punch

the results on the same card. The programming is by plugboard.

All machines first mentioned in the chronology from here on are

stored-program computers.

1949-51. Jay W. Forrester and his team at MIT construct the

"Whirlwind" for the US Navy's Office of Research and

Inventions. The vague date is because its advance to full-time

operational status is gradual. Its original form has 3,300 tubes

and 8,900 crystal diodes. It occupies 2,500 square feet of floor.

Its 2,048 16-bit words of CRT memory use up $32,000 worth of tubes

each month. There is also a graphical I/O device consisting of a

CRT (only one dot can be displayed at a time) and a light pen.

This allows the machine to be used for air traffic control.

The Whirlwind is the first computer designed for real-time work;

it can do 500,000 additions or 50,000 multiplications per second.

Spring 1949. Forrester conceives the idea of magnetic core memory as

it is to become commonly used, with a grid of wires used to

address the cores. The first practical form, in 1952-53, will replace

the Whirlwind's CRT memory and render obsolete all types of main

memory then existing.

April 1949. The Manchester Mark I, no longer the Baby as its main

memory has been upgraded to 128 40-bit words (on two CRTs),

acquires a secondary memory in the form of a magnetic drum holding

a further 1,024 words. Also at about this time, two index registers

are added to the machine.

(The index register's contents are added, not to the address taken

from an instruction, but to the entire instruction, thus potentially

changing the opcode! Calling Mel...)

May 1949. Maurice Wilkes (1913-) and his team at Cambridge Uni-

versity complete the "EDSAC" ("Electronic Delay Storage

Automatic Computer"), which is closely based on the EDVAC design

report from von Neumann's group -- Wilkes had attended the 1946

Moore School course. The project is supported both financially

and with technical personnel from J. Lyons & Co. Ltd., a large

British firm in the food and restaurant business.

This is the first operational full-scale stored-program computer,

and is therefore the final candidate for the title of "the first

computer".

Its main memory is of a type that had existed for some years, but

had not been used for a computing machine: the "ultrasonic delay

line" memory. It had been invented originally by William Shockley

of Bell Labs (also one of the co-inventors of the transistor, in

1948), and improved by Presper Eckert for use with radar systems.

It works by repeatedly converting from the usual electrical data

pulses to ultrasonic pulses directed along, typically, the length

of a tank of mercury; on arrival at the other end, the pulses are

converted back to electrical form. The memory must be maintained

at a particular temperature, and only the few bits currently in

electrical form are accessible. In the EDSAC, 16 tanks of mercury

give a total of 256 35-bit words (or 512 17-bit words).

The clock speed of the EDSAC is 500 kHz; most instructions take

about 1.5 ms to execute. Its I/O is by paper tape, and a set of

constant registers is provided for booting.

The software eventually supports the concept of relocatable proce-

dures with addresses bound at load time.

Aug 1949. Presper Eckert and Mauchly, having formed their own company,

complete the "BINAC" ("Binary Automatic Computer") for the

US Air Force. Designed as a first step to in-flight computers, this

has dual (redundant) processors each with 700 tubes and 512 31-bit

words of memory. Each processor occupies only 4 square feet of floor

space and can do 3,500 additions or 1,000 multiplications per second.

The designers are thinking mostly of their forthcoming "UNIVAC"

("Universal Automatic Computer") and don't spend much time making

the BINAC as reliable as it should be, but the tandem processors

compensate somewhat.

Sep 1949. Aiken's team completes the "Harvard Mark III". This

computer has separate magnetic drum memories for data and

instructions. Only some of the data drums can be addressed by

the CPU; the others serve as secondary memory. The total memory

capacity is 4,000 instructions, 350 16-bit words in the main data

drums, and 4,000 words more in the secondary memory. The machine

contains over 5,000 vacuum tubes and 2,000 relays, and can do about

80 multiplications per second.

May 1950. A group at the National Physical Laboratory, Teddington,

England, complete the "Pilot ACE" (pilot project for an

"Automatic Computing Engine"). This had been largely designed by

Turing when he was there in 1945-47; he had left and gone to Manches-

ter because the designs were not being implemented. The main memory

of this computer is in the form of 200 separate ultrasonic delay

lines, thus allowing better addressability than other ultrasonic-

based machines. An additional group of short delay lines serve as

registers, each of which performs a particular operation automatic-

ally on a number directed to it. Most operations then consist simply

of routing a number, or a counted stream of numbers, from one delay

line to another. Punch cards are used for input and output; a drum

will be added later for secondary memory.

(A successor to this machine will be named "DEUCE".)

May 1950. A group at the US National Bureau of Standards, Washington,

which had found itself unable to wait for commercial computers

to appear, completes "SEAC" (Standards Eastern Automatic Computer").

The design was kept simple for the sake of rapid implementation.

To keep the number of vacuum tubes down, 12,000 of the new germanium

diodes are used. The ultrasonic delay line memory holds 512 45-bit

words.

July 1950. SEAC's western counterpart "SWAC", in Los Angeles, is

completed and becomes the fastest computer in the world.

It has Williams tube memory, which has problems because the tubes'

phosphor layers were contaminated by lint at the former mattress

factory where the tubes were made, and only 256 37-bit words of

main memory are operable. But it can do an addition in 64 micro-

seconds, and a drum is added later to augment the memory.

1950. Zuse's Z4 is finally completed and goes into service at

ETH (Federal Polytechnical Institute) in Zurich, Switzerland.

The design is modified so that it can do conditional jumps. The

machine also implements a form of instruction pipelining, with the

program tape being read 2 instructions ahead and various optimiz-

ations performed automatically.

The Z4 remains in use for 5 years at ETH and 5 more in France, and

Zuse soon begins making his machines commercially. He eventually

sells some 300 machines before being bought out by Siemens.

1950. Douglas Hartree (the leading expert in the country on the

specialized computing machines called differential analyzers)

gives his professional opinion to Ferranti Ltd., of Manchester:

as the 3 existing computer projects will suffice to handle all the

calculations that will ever be needed in England, Ferranti would be

well advised to drop the idea of making computers for commercial sale.

Feb 1951. A rather more optimistic Ferranti Ltd. completes the first

commercial computer. This is yet another "Mark I", but is

also known as the "Manchester Mark II", "MUDC", "MUEDC", and "MADAM"!

It has 256 40-bit words of main memory and 16K words of drum, and

includes 8 index registers (they work the same way as on the Manchester

Mark I, which this machine was derived from). An eventual total of 8

of these machines are sold.

Mar 1951. Presper Eckert and Mauchly, having sold their company to

Remington Rand, complete the first "UNIVAC", which is the

first US commercial computer. (The US census department is the first

customer.) It has 1,000 12-digit words of ultrasonic delay line memory

and can do 8,333 additions or 555 multiplications per second; it con-

tains 5,000 tubes and covers 200 square feet of floor. For secondary

memory it uses 1/2 inch magnetic tapes of nickel-coated bronze, which

store 128 characters per inch; 10,000 characters can be read per second.

Fall 1951. The Lyons company receives its reward for supporting the

EDSAC, as T. Raymond Thompson, John Simmons, and their team

complete the "LEO I" ("Lyons Electronic Office I"), which is modeled

closely after the EDSAC. Its ultrasonic memory is 4 times as large,

and avoids the usual temperature dependency by using one delay line

as a master and synchronizing the others to it instead of to a clock.

The Lyons company wants the LEO I for its own use -- payroll, inven-

tory, and so on; it is the first computer used for commercial calcul-

ations. But other companies now turn out to be interested in the LEO,

and Lyons will soon find itself in the computer manufacturing business

as well.

1951. Grace Murray Hopper, now of Remington Rand, invents the

modern concept of the compiler.

1952. The EDVAC is finally completed. It has 4,000 tubes, 10,000

crystal diodes, and 1,024 44-bit words of ultrasonic memory.

Its clock speed is 1 MHz.

1952. The IBM "Defense Calculator", later renamed the "701", the

first IBM computer unless you count the SSEC, enters

production at Poughkeepsie, New York. (The first one is delivered

in March 1953; 19 are sold altogether. The machine is available

with 2,048 or 4,096 36-bit words of CRT memory; it does 2,200 multi-

plications per second.)

(IBM stayed out of the computer market for some time because its

president, Thomas Watson Sr., didn't want the company competing

against its own business machines. His son and eventual successor,

Thomas Jr., disagreed, and realized that if it was the US \*military\*

that wanted to buy a computer, Thomas Sr. would not say no to them.)

1952. Grace Murray Hopper implements the first compiler, the "A-0".

(But as with "first computer", this is a somewhat arbitrary

designation.)

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A few things have happened since then, too, but this margin is too

narrow...

--

Mark Brader \"The age of chivalry is gone. That of sophisters, econ-

formerly msb@sq.com, \ omists, and calculators, has succeeded; and the glory

SoftQuad Inc.,Toronto \ of Europe is extinguished for ever." -- Burke, 1792

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