



Počítací stroje

Analytical Engine – Charles Babbage, čtyřicátá léta 19. století

Z3 – Konrad Zuse, 1941

ASSC = Automatic Sequence-Controlled Calculator (= Harvard Mark I) – Howard Aitken, 1943

Colossus Mark I, II – Bletchley Park, 1943, 1944

ENIAC = Electronic Integrator and Computer – John Mauchley, Moore School, Pennsylvania, 1945

Počítače

SSEM = Small-Scale Experimental Machine (= Baby), Manchester University, 21. června 1948, experimentální počítač

EDSAC = Electronic Delay Storage Automatic Calculator, Cambridge University, 6. května 1949, první plně funkční počítač

CSIRAC = Council for Scientific and Industrial Research Automatic Computer, Sydney, listopad 1949

SEAC = Standard's Eastern Automatic Computer, American National Bureau of Standard, Washington, květen 1950 (patrně první plně funkční americký počítač)

SWAC = Standard's Western Automatic Computer, Los Angeles, srpen 1950 (tým vedl Harry Huskey, 1947 byl National Physical Laboratory v Turingově skupině – Pilot Ace)

Pilot **ACE** = Automatic Computing Engine, National Physical Laboratory, Teddington u Londýna, 19. února 1946 přeložil výboru NPL úplný návrh počítače (odhadl na £11 200), pilotní model ale až 1950

Ferranti **Mark I**, následovník SSEM jako Manchester Mark I, podzim 1949, začal vyrábět Ferranti – Ferranti Mark I, první dodán Manchester University v únoru 1951

UNIVAC = UNIVersal Automatic Computer, Presper Eckert a John Mauchley, vlastní firma, počítač pro komerční praxi, zpracovával písmena a měl magnetické pásky; první dodali do United States Census Bureau 31. března 1951

IAS = Institute for Advanced Study, Princeton University. John von Neumann, měli vlastní počítač ISA, léto 1951

THE NATIONAL PHYSICAL LABORATORY.

CONFIDENTIAL

UNCONFIRMED

EXECUTIVE COMMITTEE

Minutes

At a meeting of the Executive Committee held at the Rooms of the Royal Society, Burlington House, London, W.1, on Tuesday, 19th March, 1946, at 11.30 a.m. and 2 p.m.

Present: Professor A. M. Tyndall, F.R.S. in the Chair
Sir Alfred Egerton, Sec.R.S. (part of afternoon)
Sir Thomas Merton, Treas.R.S.
Sir Westcott Abell
Mr. H. W. Cremer
Professor D. R. Hartree, F.R.S.
Sir Melvill Jones, F.R.S.
Sir George Nelson
Dr. R. V. Southwell, F.R.S. (afternoon only)

Dr. J. A. Carroll
(representing Mr. C. S. Wright - Assessor)
(afternoon only)

Dr. D. Hollingdale
(representing Sir B. Lockspeiser - Assessor)
(afternoon only)

Sir Edward Appleton, F.R.S., Secretary, D.S.I.R.
Sir Charles Darwin, F.R.S., Director, National Physical Laboratory
Mr. E. S. Hiscocks, Secretary, National Physical Laboratory

Communications expressing regret at inability to be present were received from Sir Arthur Fleming, Professor J. H. Andrew, Dr. H. L. Guy, Sir Noel Ashbridge, Professor Willis Jackson, Professor D. Brunt, Mr. E. Barnard and Dr. E. T. Paris (Assessor)

A. DOMESTIC

(1) Minutes

The Minutes of the meeting held on 19th February were signed as correct.

(2) Matters arising from the Minutes

Minute 3(e). Whitworth and other Prizes. The Committee's congratulations have been sent to Mr. Gladman, Dr. Clayton and Mr. Fogg.

Minute 3(g). Conference on Metallic Creep. Sir Westcott Abell enquired if any arrangements had yet been made for further Conferences on Metallic Creep. Director stated that plans are now being discussed for the reservation of a proportion of the Laboratory's machines for research purposes, but that no formal arrangements had yet been made for a further meeting to discuss these proposals.

B. TECHNICAL

(9) Mathematics Division

(a) Large Electronic Calculating Machine ACE

The Committee had before it Paper E.881 (Memorandum by Mr. J. R. Womersley, Superintendent, Mathematics Division, concerning the "ACE" Machine Project) and Paper E.882 (Report by Dr. A. M. Turing on Proposals for the Development of an Automatic Computing Engine (ACE)).

The Chairman invited Mr. Womersley to outline the reasons why a machine of the type proposed by Dr. Turing should be constructed for the Mathematics Division.

He advocated the building of a large D.A. and in this was supported by Mr. Womersley, who said that the present estimate of £54,000 plus £30,000 for contingencies appeared to him to be too high, and that this aspect of the matter should be re-considered, particularly when Dr. Porter joined the Laboratory staff.

It was agreed that the order of priority for the larger projects in Mathematics Division should be -

- (1) ACE
- (2) Small Fourier synthesis machine for use by X-ray crystallographers in their own laboratories
- (3) Production Model D.A.
- (4) Gossor-Jofeh machine to combine the functions of
 - (a) Fourier Analysis
 - (b) Fourier Synthesis
 - (c) Electric Isograph
- (5) Large Differential Analyser

(10) Any other business

None.

616/2/2
1

- 1 -

PART I.

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PROPOSED/

PROPOSED ELECTRONIC CALCULATOR.

PART I.

Descriptive Account.

1. Introductory.

Calculating machinery in the past has been designed to carry out accurately and moderately quickly small parts of calculations which frequently recur. The four processes addition, subtraction, multiplication and division, together perhaps with sorting and interpolation, cover all that could be done until quite recently, if we except machines of the nature of the differential analyser and wind tunnels, etc. which operate by measurement rather than by calculation.

It is intended that the electronic calculator now proposed should be different in that it will tackle whole problems. Instead of repeatedly using human labour for taking material out of the machine and putting it back at the appropriate moment all this will be looked after by the machine itself. This arrangement has very many advantages.

(1) The speed of the machine is no longer limited by the speed of the human operator.

(2) The human element of fallibility is eliminated, although it may to an extent be replaced by mechanical fallibility.

(3) Very much more complicated processes can be carried out than could easily be dealt with by human labour.

Once the human brake is removed the increase in speed is enormous. For example, it is intended that multiplication of two ten figure numbers shall be carried out in 500 μ s. This is probably about 20,000 times faster than the normal speed with calculating machines.

It is evident that if the machine is to do all that is done by the normal human operator it must be provided with the analogues of three things, viz. firstly, the computing paper on which the computer writes down his results and his rough workings; secondly, the instructions as to what processes are to be applied; these the computer will normally carry in his head; thirdly, the function tables used by the computer must be available in appropriate form to the machine. These requirements all involve storage of information or mechanical memory. This is not the place for a detailed discussion of the various kinds of storage available* and the considerations which govern their usefulness and which limit what we can expect. For the present let us only remark that the memory needs to be very large indeed by comparison with standards which prevail in most valve and relay work, and that it is necessary therefore to look for some more economical form of storage.

It/

* See § 16.

BRITAIN TO MAKE A RADIO BRAIN

“Ace” Superior
To U.S. Model

BIGGER MEMORY STORE

Britain is to make a radio “brain” which will be called “Ace,” at a cost of between £100,000 and £125,000, it was announced by the Department of Scientific and Industrial Research last night. Only one will probably be made.

Ace stands for automatic computing engine. The machine will work at least as fast as the American invention called Eniac (electronic numerical integrator and computer).

The invention of Eniac was disclosed by Viscount Mountbatten when he spoke at the dinner of the British Institution of Radio Engineers last Thursday. The machine, which cost £100,000, used 18,000 valves and 5,000 switches and consumed as much power as 100 electric radiators.

The memory storage of Ace will be higher than the American invention—75,000 decimal digits compared with 200, and by means of an exhaustive library of prefabricated instructions contained on specially punched cards, the English machine will be able to deal with more complex instructions.

TIME SAVED

The organisation of these prefabricated instructions will obviate the laborious system of plugs and switches employed in Eniac, that British scientists of the mathematics division of the National Physical Laboratory feel that they have made an important new contribution.

Instructions may take a couple of minutes compared to two hours on Eniac.

Numbers are represented by a series of 1's and 0's, and answers will be given in the decimal system. The machine will multiply two 10-figure numbers in 2,000ths of a second.

Well within its scope will be the class of problem which, by its extreme complexity and the enormous length of time needed to solve it, is almost an impossibility for the pencil and paper worker. It will, for instance, be able to tackle simultaneous equations with 50 or 100 unknowns.

THREE YEARS TO BUILD

It will be able to cope by itself with all the abstruse problems for which it is designed. Further advances will probably enable production of machines designed to do even more than Ace. It will take two or three years to build.

Leading the team working on the “brain” are Sir CHARLES DARWIN, Director of the laboratory; Dr. A. M. TURING, who is 34 years old and conceived the idea of Ace; Dr. J. R. WOMERSLEY, superintendent of the division, and Prof. D. HARTREE, of Cambridge University, the only man in Britain who has worked Eniac in the United States.

MONTH'S WORK IN A MINUTE

ACE CALCULATOR

FROM OUR SPECIAL CORRESPONDENT

TEDDINGTON, Nov. 29

With the completion of the pilot model of the National Physical Laboratory's automatic computing engine, known as Ace, the Department of Scientific and Industrial Research will be glad to hear of problems the solving of which requires long and intricate arithmetical calculations. The Ace itself will be built later, but the model demonstrated here to-day is none the less a complete electronic calculating machine, claimed as one of the fastest and most powerful computing devices in the world.

Its function is to satisfy the ever-increasing need in science, industry, and administration, for rapid mathematical calculation which in the past, by traditional methods, would have been physically impossible or required more time than the problems justified. The speed at which this new engine works, said Dr. E. C. Bullard, F.R.S., director of the laboratory, could perhaps be grasped from the fact that it could provide the correct answer in one minute to a problem that would occupy a mathematician for a month. In a quarter of an hour it can produce a calculation that by hand (if it were possible) would fill half a million sheets of foolscap paper.

The automatic computing engine uses pulses of electricity, generated at a rate of a million a second, to solve all calculations which resolve themselves into addition, subtraction, multiplication, and division; so that for practical purposes there is no limit to what Ace can do.

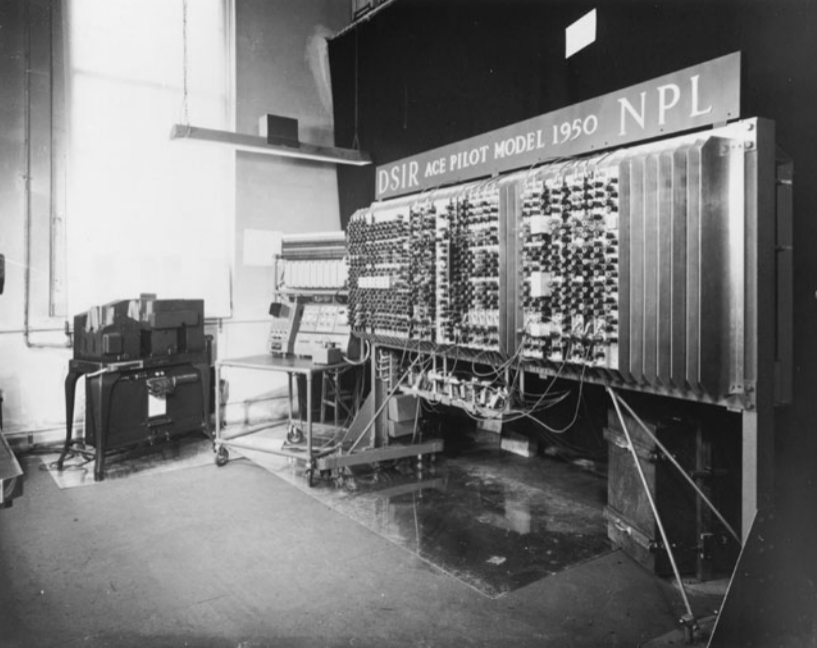
HOLED CARDS

On the machine the pulses are used to indicate the figure 1, while gaps represent the figure 0. All calculations are done with only these two digits in what is known as the binary scale. When a sum is put into the machine the numbers are first translated into the binary scale and coded; instructions are also given to the machine by coding them as holes in cards. To carry out long sequences of operations the engine must be endowed with a "memory."

This "memory" section is highly complicated. It depends upon the slower time of travel of supersonic waves, into which the electric pulses are converted, through a column of mercury. One thousand pulses—representing digits—can be stored in this way and extracted at the precise moment when they are needed by the "arithmetic section," which handling pulses of electricity, is working 100,000 times faster than the supersonic section. The completed calculation appears in code as a holed card, representing the answer in the binary scale, which is translated back into ordinary numbers.

When experience has been gained some improvements will doubtless be made to the pilot Ace and embodied in the first standard prototype model. The cost of development and construction of the pilot model, which uses some 800 thermionic valves, was about £40,000. Now it is ready to "do business" and is expected to more than earn its keep.

DSIR ACE PILOT MODEL 1950 NPL



*Alan Turing's
Automatic Computing
Engine*

*The Master Codebreaker's Struggle to Build
the Modern Computer*

Edited by
B. Jack Copeland

OXFORD
UNIVERSITY PRESS





44. The Manchester 'Baby'. The first electronic stored-program general-purpose computer, the Baby ran its first program in June 1948, in Newman's Computing Machine Laboratory.

Electronic Digital Computers

A SMALL electronic digital computing machine has been operating successfully for some weeks in the Royal Society Computing Machine Laboratory, which is at present housed in the Electrical Engineering Department of the University of Manchester. The machine is purely experimental, and is on too small a scale to be of mathematical value. It was built primarily to test the soundness of the storage principle employed and to permit experience to be gained with this type of machine before embarking on the design of a full-size machine. However, apart from its small size, the machine is, in principle, 'universal' in the sense that it can be used to solve any problem that can be reduced to a programme of elementary instructions; the programme can be changed without any mechanical or electro-mechanical circuit changes.

The essential parts of such a machine are:

1. a store for information and orders;
2. various arithmetical organs (for example, adders, multipliers);
3. a control unit¹.

The present machine contains the minimum set of facilities for a universal machine, namely:

- (a) If x is any number in the store, $-x$ can be written into a central 'accumulator' A ; or x can be subtracted from what is in A .
- (b) The number A can be written in an assigned address in the store. (By means of (a) and (b) addition or direct writing into A can be programmed.)
- (c) The content of A can be tested for whether $x \geq 0$, or $x < 0$; if $x < 0$ the order standing next in the store is passed over. This gives the essential power of branching routines.
- (d) Control can be shifted to an assigned order in the table.
- (e) The machine can be ordered to stop.

¹ For a fuller discussion see, for example, the Royal Society discussion on computing machines, summary in *Nature*, **161**, 712 (1948)

The capacity of the store is at present only 32 'words', each of 31 binary digits, to hold instructions, data and working. Hence only simple arithmetic routines devised to test the machine can be run. Examples of problems that have been carried out are:

1. Long division by the standard process. (For $(2^{30} - 1)/31$, this took $1\frac{1}{2}$ seconds, the quotient being given to 39 significant binary figures of which the 13 least significant, to the left of the binary point, were zero, since 31 is a factor of $2^{30} - 1$.)
2. H.C.F. by the standard process. (For 314,159,265 and 271,828,183, which are co-prime, approximately 0.5 second.)
3. Factorizing an integer. For (3) the method was deliberately chosen to give a long run the result of which could be easily checked. Thus the highest proper factor of 2^{18} was found by trying in a single routine every integer from $2^{18} - 1$ downward, the necessary divisions being done not by long division, but by the primitive process of repeated subtraction of the divisor. Thus about 130,000 numbers were tested, involving some 3.5 million operations. The correct answer was obtained in a 52-minute run. The instruction table in the machine contained 17 entries.

It will, of course, be understood that it is intended to have other arithmetical facilities, as well as a much larger store, in a full-sized machine; and that even on the present machine quicker routines could have been used. At present routines are chosen with the sole object of testing the machine as thoroughly as possible.

The development of this machine has been very actively supported by the Telecommunications Research Establishment, Great Malvern.

F. C. WILLIAMS

T. KILBURN

Electrical Engineering Laboratories,
University, Manchester 13.
Aug.3.

19/7/49

Kilburn Highest Factor Routine (amended) -

function	C	25	26	27	line	0	1	2	3	4	5	13	14	15
-24 to C	$-b_1$	-	-	-	1	0	0	0	1	1	0	0	1	0
2 to 26			$-b_1$		2	0	1	0	1	1	1	1	1	0
-26 to C	b_1				3	0	1	0	1	1	1	0	1	0
2 to 27			$-b_1$	b_1	4	1	1	0	1	1	1	1	1	0
-23 to C	a	T_{23}	$-b_n$	b_n	5	1	1	1	0	1	1	0	1	0
subr. 27	$a - b_n$				6	1	1	0	1	1	1	0	0	1
Test					7	-	-	-	-	-	-	0	1	1
add 20 to 14					8	0	0	1	0	1	1	1	0	0
subr. 26	T_n				9	0	1	0	1	1	1	0	0	1
2 to 25		T_n			10	1	0	0	1	1	1	1	1	0
-25 to C					11	1	0	0	1	1	1	0	1	0
Test					12	-	-	-	-	-	-	0	1	1
stop	0	0	$-b_n$	b_n	13							1	1	1
-26 to C	b_n	T_n	$-b_n$	b_n	14	0	1	0	1	1	1	0	1	0
subr. 21	b_{n+1}				15	1	0	1	0	1	1	0	0	1
2 to 27	b_{n+1}			b_{n+1}	16	1	1	0	1	1	1	1	1	0
-27 to C	$-b_{n+1}$				17	1	1	0	1	1	1	0	1	0
2 to 26			$-b_{n+1}$	b_{n+1}	18	0	1	0	1	1	1	1	1	0
22 to 16		T_n	$-b_{n+1}$	b_{n+1}	19	0	1	1	0	1	1	0	0	0

or 000

20	-3	10111 etc
21	1	10000
22	4	00100

23	-a
24	b_1

	init.	final
25	-	$T_n(b_1)$
26	-	$-b_n$
27	-	b_n

or 10100

Instrukce:

000 $CI = S$

001 $A = A - S$

010 $A = -S$

011 if $A < 0$, $CI = CI + 1$

100 $CI = CI + S$

101 totéž jako 001

110 $S = A$

111 HALT

17-ti řádkový program – Kilburn a Tootill
rekonstrukce 1996
IEEE Annals of the History of Computing
Vol. 20 No. 3 1998

1	$A = -0$	
2	$A = -a$	
3	$A = A - b$	
4	if $A < 0$ skip	
5	goto 3	
6	$A = A - c$	
7	$r = A$	
8	$A = -c$	
9	$A = A - 1$	
10	$b = A$	
11	$A = -b$	
12	$c = A$	
13	$A = -r$	
14	if $A < 0$ skip	
15	goto 17	
16	goto 2	
17	stop	

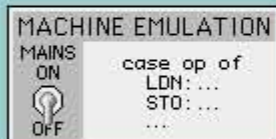
počáteční hodnoty:

18	a	$-a$
19	b	$a - 1$
20	c	$-a + 1$

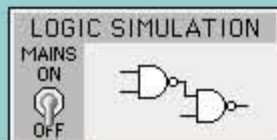
Program 16 řádků

Mgr. Vladimír Pelikán, Ústav termomechaniky AV ČR, Plzeň

	$A = -a$
L1	$A = A - (-1)$
	$r = A$
	$A = -r$
	$b = A$
	$A = -a$
L2	$A = A - r$
	if $A < 0$ skip line
	goto L3
	goto L2
L3	$r = A$
	$A = -r$
	if $A < 0$ skip line
	HALT
	$A = -b$
	goto L1



A 'conventional' emulation of the SSEM machine. Faster than the logic simulation.



A SSEM-equivalent machine designed in modern binary logic gates and run in a logic simulator.

This program was developed in Macromedia Director, and is written in Lingo, the object-oriented scripting language of Director.



The SSEM (Small Scale Experimental Machine) (aka: "the Baby") was a computer constructed at the University of Manchester in 1948 to test the "Williams-Kilburn Tube" memory system in preparation for the construction of the Manchester Mark 1 computer.

On June 21, 1948 the SSEM became the first stored-program (Von Neumann architecture) machine to run a program and so claimed it's niche in the history of computing.

To start the simulation, click on one of the "MAINS" switches a the left. Some explanation and help is displayed in the text box at the bottom-left of the screen as you roll over elements of the simulation.

26 Nov 2000

B. Hilpert

www.cs.ubc.ca/~hilpert

SIMULATION CONTROL

0.000 S TARGET EXEC
 0.026 S ACTUAL EXEC
 694 IPS TARGET RATE
 0 IPS ACTUAL RATE
 INF IPS DESIRED RATE

CLOCK RATE

PROGRAMS

PASTE

COPY

SSEM CONTROL PANEL

MAINS ON STOP EXEC RUN DATA

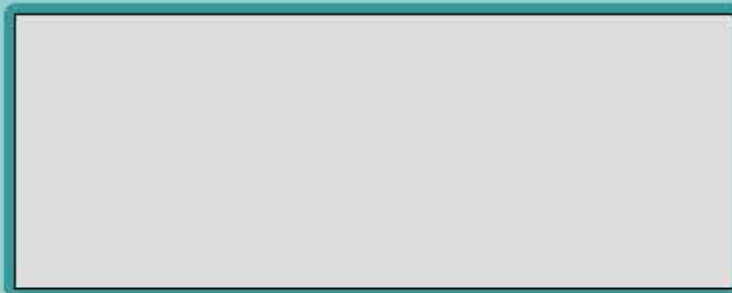
OFF STOP STOP

LINE 1 2 4 8 16

KCC KCS KCL WRITE ERASE

0	8	16	24
1	9	17	25
2	10	18	26
3	11	19	27
4	12	20	28
5	13	21	29
6	14	22	30
7	15	23	31

Instruction	Opcode
JMP	000
JPR	100
LDN	010
STO	110
SUB	001
SKN	011
HLT	111



Memory Dump

0-31

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

A

CI

PI

0 4 8 12 16 20 24 28 31

SIMULATION CONTROL

0.000 \$ TARGET EXEC
 0.192 \$ ACTUAL EXEC
 694 IPS TARGET RATE
 0 IPS ACTUAL RATE
 INF IPS DESIRED RATE

RUN READY

CLOCK RATE

PROGRAMS

SSEM CONTROL PANEL

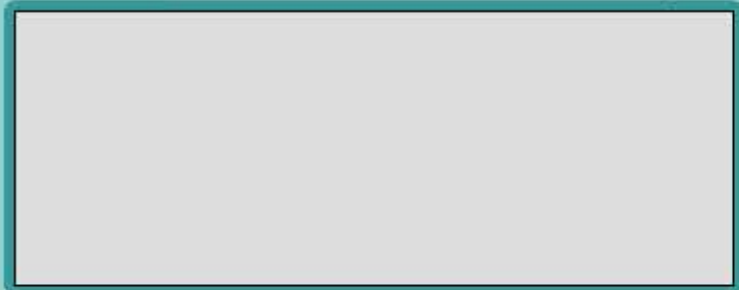
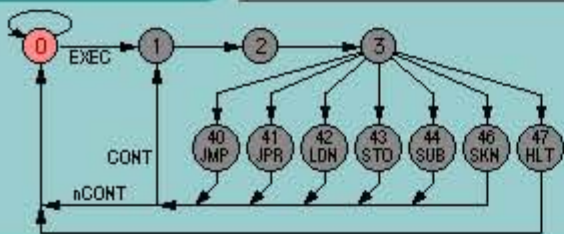
MAINS ON STOP EXEC RUN DATA

OFF STOP STOP

LINE 1 2 4 8 16

KCC KCS KCL WRITE ERASE

0	8	16	24
1	9	17	25
2	10	18	26
3	11	19	27
4	12	20	28
5	13	21	29
6	14	22	30
7	15	23	31



DATA MEMORY DISPLAY

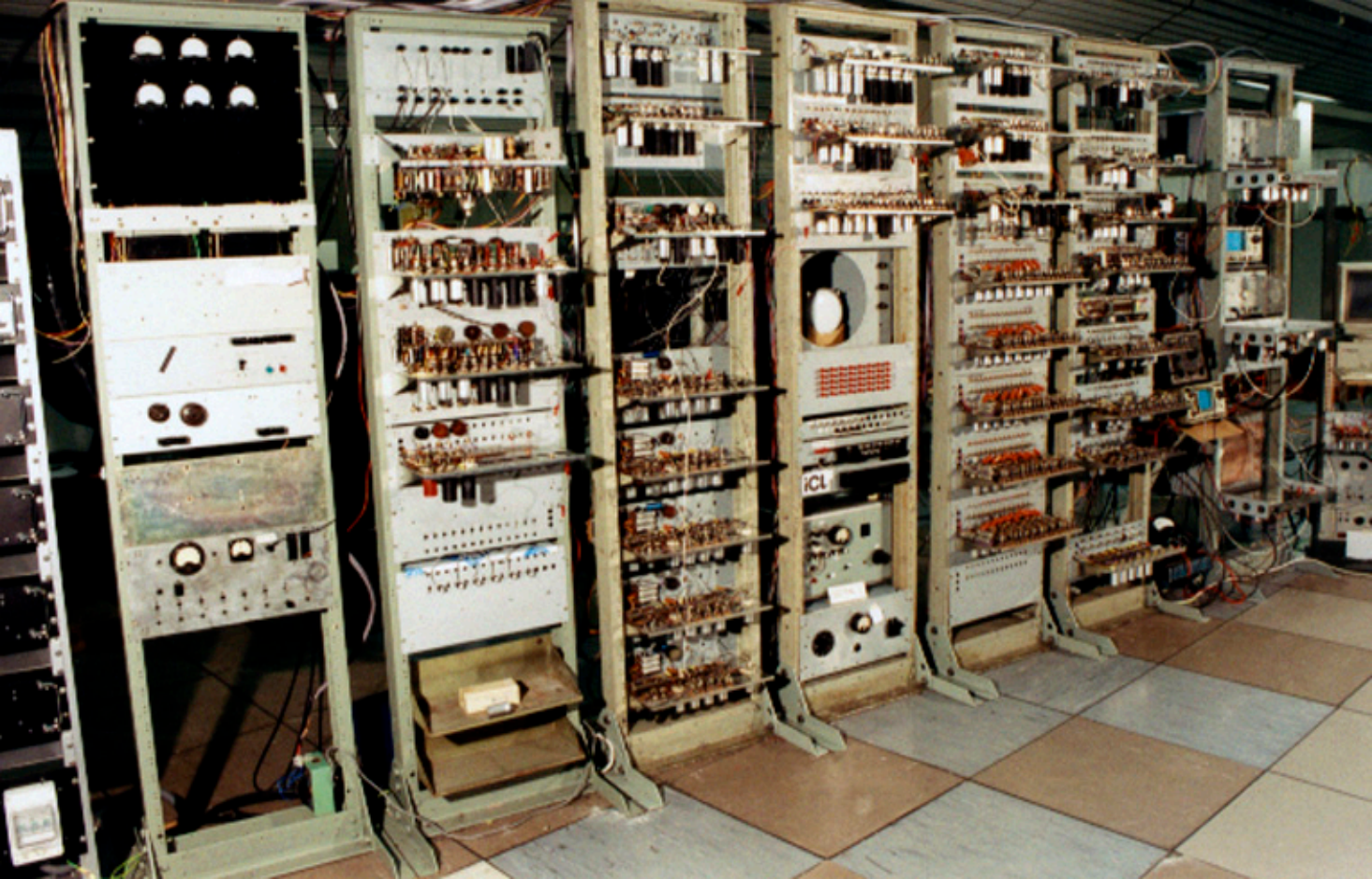
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			

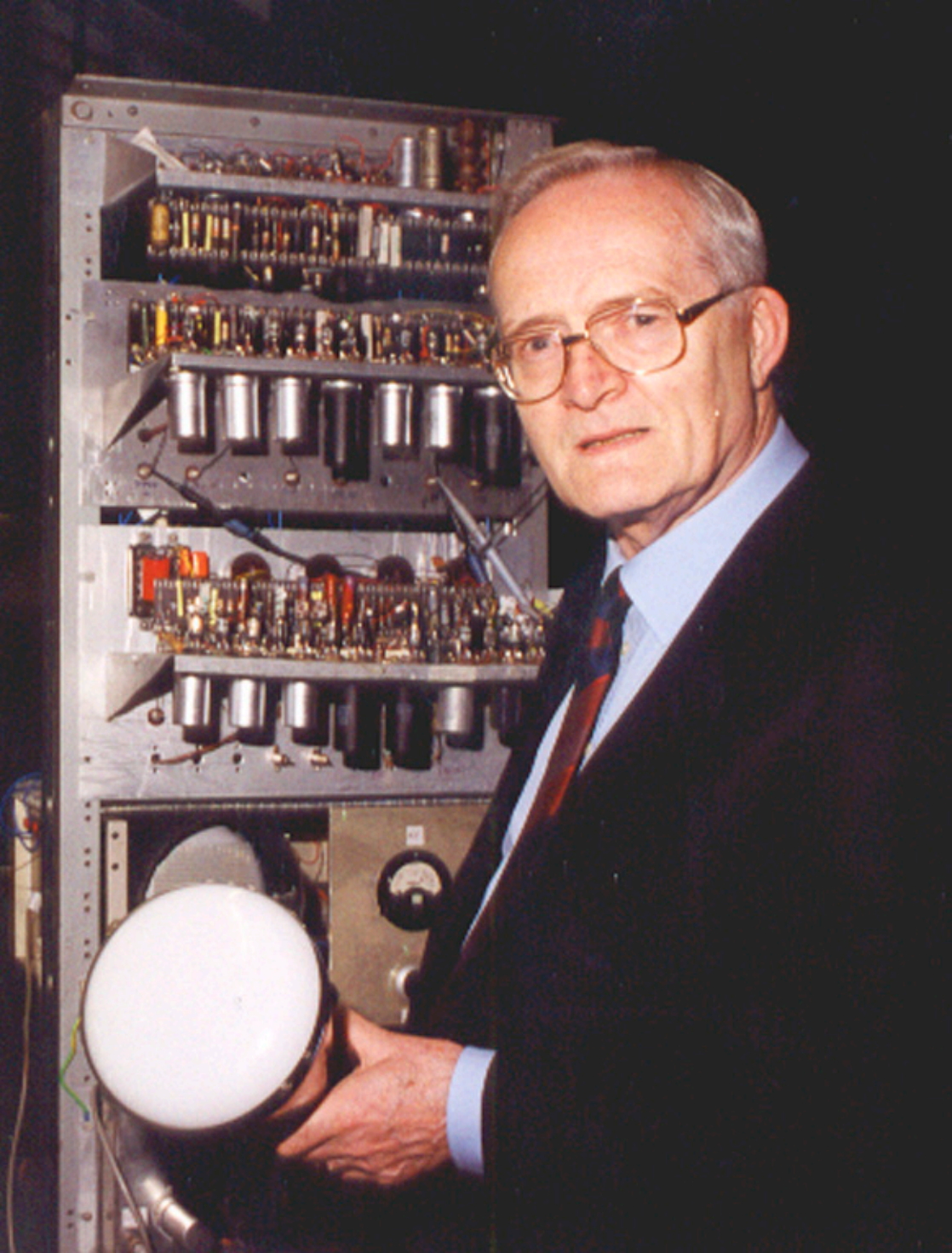
A:

CI:

PI:

<http://www.cs.ubc.ca/~hilpert/e/SSEM/ssemsim.html>





The World's First Stored-Program Computer



Tony Kilburn (1914-1991)

...



Frederick Cillian Williams

...

...
STER



...
ER

98



A HISTORY OF MANCHESTER

COMPUTERS

by Dr. S.H. Lavington

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Introduction

The Mark I

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The Prototype machine

Ferranti and N.R.D.C. involvement

Software development

Meg and Mercury

The transistor computer

Muse and the Atlas

MU5

References

July 1975



S.H. Lavington

Department of Computer Science

The University,

Manchester.

M13 9PL

THE MARK 1

Background

The word 'computer' prior to 1940 meant only one thing: a clerk equipped with a hand calculating machine who would 'compute' the standard calculations required for wages, actuary tables, gunnery, etc. From 1935-1945 the application of electronics to 'automatic computers' generally concentrated on developing faster calculators related to specific problems. Examples are the series of cryptanalysis machines built at Bletchley between 1940-45 for the British Foreign Office (Reference 1), and the huge ENIAC machine commissioned early in 1946 for the U.S. Army Ordnance Department for ballistics calculations (Reference 2). By the end of the war there were thus groups in America, Britain and Germany working relatively independently on automatic electronic calculators. None of these early machines fitted Babbage's concept (Reference 3) of a universal computer and it is clear that the designers were fully aware of the limitations of their projects. These limitations were partly concerned with input/output, partly with the nature of control-transfer (branching) facilities, but mainly with the lack of a suitable internal store.

The need for a storage device had also occurred towards the end of the war in connection with the processing of radar signals. By 1946 two lines of approach were being pursued: one based on acoustic waves propagated down a delay line (e.g. a column of mercury), and the other based on electrostatic charges stored on the phosphor screen of a cathode ray tube (C.R.T.) In early 1946 the delay line technique seemed more practical, since C.R.T. stores suffered from short retention periods due to charge leakage. In Britain at the Ministry of Supply Telecommunications Research Establishment (T.R.E.) - a centre renowned for electronic innovation - a group was working on C.R.T. stores under Dr. F.C. Williams. In the autumn of 1946 F.C. Williams made certain discoveries which resulted in the invention of a method of storing digital data on a C.R.T. screen which differed fundamentally from previous attempts. The first digit was actually stored in November and, with an eye to computer applications already being discussed, the

A.A. Robinson, a research student at the time, has said that the atmosphere at Manchester in 1947 was like that of a nineteenth-century inventor's workshop.

The Mark 1 was built, significantly, in the Freddie C. Williams Physical Laboratories and in fact three versions of the machine were commissioned between 1948 and 1949.

Folklore has it at Manchester that 'F.C.' never wrote a program in his life and

that Tom wrote just one - the world's first!

Tom Kilburn

Table 1.

The original program was written by Tom Kilburn. G.C. Tootill, an engineer on loan to Manchester from T.R.E. from mid-1947 to mid-1949, also wrote programs for the prototype and a notebook kept by him over the period 4th June to 27th October 1948 has survived. From entries in this notebook the best guess is that Kilburn's program was run sometime between 9th to 19th June. Williams has since described their relief at seeing the correct answer! (Reference 19).

Another program, run in mid-July, involved a long division routine written by A.M. Turing (and corrected by Tootill). Turing was appointed 'deputy director' of the Royal Society Computing Machine Laboratory with the status of a Reader in the Mathematics Department under Professor Newman, on 29th September, 1948. (His salary was the first call upon the Royal Society grant.) Turing had resigned and also been dismissed from N.P.L. during the summer (Reference 20) and before arriving in Manchester had written asking for details of the prototype computer's order code. He sent Tootill the long division routine in July.

10/7/48 Turing Long Division Routine.

(Proposed by A.M. Turing; 9/7/48)

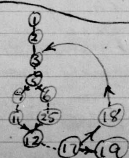
corrected version:-

Ins. no.	Ins.	C	28	31	line	
1	-315C	$-a_0$	0	a_0	0	(19)
2	$c \leq 31$			$-a_0$	26	(2)
3	-315C	a_n	q_n	$-a_n$	27	(11)
4	sub 30	$a_n - b$			29	2^d
5	Test \rightarrow $\rightarrow a_n - b < 0$				30	b
6	-315C	a_n				
7	$c \leq 31$			a_n		
8	-285C	$-q_n$				
9	sub 28	$-2q_n$				
10	$c \leq 28$			$-2q_n$		
11	Test \rightarrow $\rightarrow a_n - b \geq 0$					
12	-315C	$\frac{1}{2}a_{n+1}$		$\frac{1}{2}a_{n+1}$		
13	sub 31	$-a_{n+1}$				
14	$c \leq 31$			$-a_{n+1}$		
15	-285C	q_{n+1}	$-q_{n+1}$			
16	$c \leq 28$			q_{n+1}		
17	Test \rightarrow $\rightarrow q_{n+1} \geq 2^{31}$					
18	stop	q_{N+1}	q_{N+1}	$-a_{N+1}$		

Defining $a_{n+1} = \begin{cases} 2a_n & \text{if } a_n < b \\ 2(a_n - b) & \text{if } a_n \geq b \end{cases}$

Defining $q_{n+1} = \begin{cases} 2q_n & \text{if } a_n < b \\ 2^d + 2q_n & \text{if } a_n \geq b \end{cases}$

$\rightarrow q_{n+1} < 2^{31}$



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