

checked by: (1) comparing with ANDOYER's 20D table of these functions for $x = 0(1^{\circ})50^{\circ}$; (2) differencing, exposing the error in $\cos 0^{\circ}.114$, for 98400 96253 51140, read 98400 96256 51140; and (3) extensive spot checking with the aid of Andoyer's series. Subtabulation to 25ths, with an IBM tabulator by my expeditious self-checking method of the Lick Observatory, *Bull.*, v. 17, 1935, p. 65-74, gave 15D values which are subject to an error occasionally somewhat exceeding the usual .5 unit rounding error.

The 10 tables derived from these values, contain sines and cosines, with Δ^2 when significant:

15D, 12D, 10D, 8D, 7D, 6D: $0(0^{\circ}.00001)0^{\circ}.125$, 250 p., 12500 cards, each
 6D, 5D, 4D: $0(0^{\circ}.0001)0^{\circ}.125$, 25 p., 1250 cards, each
 4D: $0(0^{\circ}.001)0^{\circ}.125$, $2\frac{1}{2}$ p., 125 cards.

The circle is the most practical unit of angular measure in essentially every respect, especially for any computing device—desk computer, punched card machine, etc. It eliminates striking out multiples of 360° , 24^h , 4^s , 6400^m , and $2\pi^r$, and the constant reduction from one unit to another or to a larger unit because the advantage of decimalization is completely realized. The number before the decimal point denotes whole circles, cycles, revolutions, or days, and the decimal is the angle for which functions may be wanted.

E. C. BOWER

EDITORIAL NOTE: The Callet error noted above was corrected in the 1899 *tirage*, and possibly much earlier. There is a copy of the 15D table, for $x = 0(0^{\circ}.00001)0^{\circ}.125 = 0(0^{\circ}.004)50^{\circ}$, 250 p., 36.7×28 cm., in the Library of Brown University.

78[K].—J. ARTHUR GREENWOOD, *Table of the Double Exponential Distribution*, Ms. in possession of the author, 25 Winthrop St., Brooklyn 25, N. Y.

This table was computed for use in the theory of statistical extreme values. The functions $V(y) = \exp[-e^{-y}]$ and $v(y) = \exp[-y - e^{-y}]$ were introduced by R. A. FISHER & L. H. C. TIPPETT, in *Camb. Phil. Soc., Proc.*, v. 24, 1928, p. 180-190. They were further discussed by E. J. GUMBEL (Institut Henri Poincaré, *Annales*, v. 5, 1935, p. 115-158), who has given (*Annals Math. Statistics*, v. 12, 1941, p. 163-190) a table of $V(y)$ for $y = [-2(.25) + 6; 5D]$.

The present table gives $V(y)$ and $v(y)$, for $y = [-3(.1) - 2.4(.05)0(.1)4(.2)8(.5)17; 7D]$, with modified second differences.

In addition to its statistical use, this table may be used as an inverse log log table (*MTAC*, Q 4, v. 1, p. 131; QR 9, 12, 30, 38, v. 1, p. 336, 373, v. 2, p. 374, v. 3, p. 398). If $y = -x \ln 10 - \ln \ln 10 = \text{approx. } -2.30258\ 50930\ x - 0.83403\ 24452$, then $V(y) = \text{illog } x$ (in CHAPPELL's notation, *MTAC*, Q 4 note; red lologs must be used in entering CHAPPELL, who gives them with positive mantissae).

J. C. P. MILLER (*Camb. Phil. Soc., Proc.*, v. 36, 1940, p. 286) gives 4S values of $\exp \exp x$, $\exp \exp \exp x$, $\exp \exp \exp \exp x$, for $x = -4(1) + 5$, $-4(1) + 3$, $-4(1) + 1$, respectively.

J. A. GREENWOOD

AUTOMATIC COMPUTING MACHINERY

Edited by the Staff of the Machine Development Laboratory of the National Bureau of Standards. Correspondence regarding the Section should be directed to Dr. E. W. CANNON, 418 South Building, National Bureau of Standards, Washington 25, D. C.

TECHNICAL DEVELOPMENTS

Our contribution under this heading, appearing earlier in this issue, is "Piecewise Polynomial Approximation for Large-Scale Digital Calculators," by J. O. HARRISON, JR., & Mrs. HELEN MALONE.

DISCUSSIONS

*Conversion of Numbers from Decimal to Binary Form in the EDVAC*¹

All of the electronic high-speed computing machines now under construction or being proposed are able to accept data in some form of the binary-coded decimal notation. The arithmetic units of those machines referred to as "decimal" computers are so designed that they automatically perform the corrections required to yield the results of arithmetic operations in the same form as the original data. Those machines referred to as "binary" computers have arithmetic units which perform true binary addition, multiplication, etc. For the latter, then, it is necessary to translate the original binary-coded decimal number into a true binary number before performing any computations for the problem at hand. Unless auxiliary equipment for this purpose has been provided, this operation must be programed on the computer. It follows, also, that before the final results can be printed, the coder must program the conversion of the binary answers to the binary-coded decimal notation. This paper, however, will present only the conversion of the original data from the decimal to the binary form, as programed for the EDVAC, a binary computer being built at the Moore School of Electrical Engineering, University of Pennsylvania.

The code given is designed for speed in conversion. For any computer, speed can obviously be increased by:

- (1) choosing more rapid orders: e.g., using shift instead of multiplication
- (2) keeping the number of orders to be executed down to a minimum.

For a computer with a delay-line type of memory having appreciable and variable access times, speed can further be improved by:

- (3) choosing the sequence of successive locations for storage of orders and numbers in the memory appropriately.

For a computer having a four-address system of orders, still further speed can be achieved by:

- (4) suitably choosing the location (non-consecutive in general) of successive instructions (fourth-address).

Most of the above is accomplished at the expense of memory space. This is not a drawback, since it is intended that the conversion will be performed when the EDVAC is not simultaneously carrying out any other program. In view of this, although it is possible to set up subiterations and thus reduce the number of order-words and produce a more compact routine, this was deliberately not done where it interfered with obtaining maximum speed.

It is assumed that each ten-digit decimal number, N , is introduced into the EDVAC in binary-coded decimal form with each decimal digit represented by a four-digit binary equivalent (e.g., 1001 for the decimal digit 9, 1000 for 8, etc.), the four binary-digit groups being in the same sequence as the original decimal digits. The sign is recorded in the correct binary sign position as if the number were binary, while the three least significant binary digits are recorded as zeros, making a total of 43 binary digits and a sign. It is further assumed that the decimal point is, in all cases, located immediately to the left of the most significant digit. The unsigned part of the binary-coded decimal number is, therefore, introduced into the computer in the form:

$$N_d = 2^{-4}n_1 + 2^{-8}n_2 + 2^{-12}n_3 + \cdots + 2^{-40}n_{10},$$

where n_i = the i th binary-coded decimal digit. For the purpose of this paper, it is sufficient to consider the unsigned part of the number since the sign and the last three binary zeros do not affect the method of computation.

The true binary representation of the magnitude of the number, N , is

$$N_b = 10^{-1}n_1 + 10^{-2}n_2 + 10^{-3}n_3 + \cdots + 10^{-10}n_{10}.$$

Comparison of the form of the two numbers N_d and N_b indicates one direct method of conversion, as follows: 1) Extract the binary-coded decimal digit n_{10} . 2) Multiply n_{10}

by the binary equivalent of 10^{-1} . 3) Extract the binary-coded decimal digit n_9 . 4) Obtain $n_9 + 10^{-1}n_{10}$. 5) Multiply by 10^{-1} to obtain $10^{-1}n_9 + 10^{-2}n_{10}$, etc.

Each of the steps enumerated above, with the exceptions of the extract operations, can be obtained by the execution of just one command. In order to extract a group of digits contained within a word, with the commands available in the EDVAC, it is necessary to use two shift operations.

A more efficient procedure is to utilize just one shift operation and to derive coefficients (instead of the constant 10^{-1} employed above) that will compensate for the extraneous information introduced by permitting the digits less significant than the required n_i to remain in the computation. Let $a_1, a_2, a_3, \dots, a_{10}$ equal the desired coefficients. Then, following the procedure outlined above, we obtain in succession:

- 1) $2^{-4}n_{10}$, 2) $a_{10}(2^{-4}n_{10})$, 3) $2^{-4}n_9 + 2^{-8}n_{10}$, 4) $2^{-4}n_9 + 2^{-8}n_{10} + a_{10}(2^{-4}n_{10})$,
- 5) $a_9[2^{-4}n_9 + 2^{-8}n_{10} + a_{10}(2^{-4}n_{10})]$, 6) $2^{-4}n_8 + 2^{-8}n_9 + 2^{-12}n_{10}$,
- 7) $2^{-4}n_8 + 2^{-8}n_9 + 2^{-12}n_{10} + a_9[2^{-4}n_9 + 2^{-8}n_{10} + a_{10}(2^{-4}n_{10})]$,
- 8) $a_8\{2^{-4}n_8 + 2^{-8}n_9 + 2^{-12}n_{10} + a_9[2^{-4}n_9 + 2^{-8}n_{10} + a_{10}(2^{-4}n_{10})]\}$.

Continuing the above process, we obtain at the 29th step the number (A),

$$(A) = a_1(2^{-4}n_1 + 2^{-8}n_2 + \dots + 2^{-40}n_{10}) + a_2(2^{-4}n_2 + 2^{-8}n_3 + \dots + 2^{-36}n_{10}) \\ + a_3(2^{-4}n_3 + 2^{-8}n_4 + \dots + 2^{-32}n_{10}) + \dots + a_9(2^{-4}n_9 + 2^{-8}n_{10} + a_{10}(2^{-4}n_{10})) \dots$$

Combining the coefficients of n_i , we readily put (A) in the form:

$$(A) = 2^{-4}a_1n_1 + 2^{-4}a_1(2^{-4} + a_2)n_2 + 2^{-4}a_1(2^{-8} + a_2(2^{-4} + a_3))n_3 \\ + 2^{-4}a_1(2^{-12} + a_2(2^{-8} + 2^{-4}a_3 + a_3a_4))n_4 \\ + 2^{-4}a_1(2^{-16} + a_2(2^{-12} + 2^{-8}a_3 + 2^{-4}a_3a_4 + a_3a_4a_5))n_5 \\ + \dots + 2^{-4}a_1(2^{-36} + a_2(2^{-32} + 2^{-28}a_3 + 2^{-24}a_3a_4 \\ + \dots + 2^{-4}a_3a_4a_5 \dots a_9 + a_3a_4a_5 \dots a_{10}))n_{10}.$$

Equating the coefficients of n_i in (A) with those required for the converted binary number N_b , we get ten equations for the determination of the ten constants a_1, a_2, \dots, a_{10} :

$$2^{-4}a_1 = 10^{-1}, \quad 2^{-4}a_1(2^{-4} + a_2) = 10^{-2}, \quad \text{or} \quad 2^{-4} + a_2 = 10^{-1}, \\ 2^{-8} + a_2(2^{-4} + a_3) = 10^{-2}, \quad 2^{-12} + a_2(2^{-8} + 2^{-4}a_3 + a_3a_4) = 10^{-3} \dots \\ 2^{-36} + a_2(2^{-32} + 2^{-28}a_3 + 2^{-24}a_3a_4 + \dots + a_3a_4 \dots a_{10}) = 10^{-9}.$$

It is apparent that the following is a solution of these equations:

$$a_1 = 8/5, \quad a_2 = 3/80, \quad a_3 = a_4 = \dots = a_{10} = 10^{-1}.$$

The EDVAC operates with a fixed binary point located in front of the most significant digit of the number and is therefore incapable of storing numbers ≥ 1 . It is evident that a_1 exceeds the capacity of the machine. Therefore the routine divides by the reciprocal of a_1 thus keeping all of the numbers within the bounds of the computer.

For those less familiar with the EDVAC, the following details will assist in interpreting the code given:

Data are read into and out of the machine by means of magnetic wires, three of which are used in this routine. The memory of the EDVAC consists of 128 acoustic delay lines, each having 8 words, thus giving a total internal memory capacity of 1024 words. Since this computer operates in the true binary system, orders are written in the octal notation. The word length of both numbers and orders in this machine is 44 binary characters. There is a space of four pulse positions between words. Since the pulse repetition rate is equal to one megacycle, the time it takes to read one word (a minor cycle) is 48 microseconds. A number is represented as 43 binary digits plus a sign—the sign occupies the 44th binary position. Each order word consists of four addresses of ten characters each and an instruction code of four characters. For most instructions, the information is distributed in the following manner:

Address no. 1 (P_1-P_{10}) ²	Address no. 2 ($P_{11}-P_{20}$) ²	Address no. 3 ($P_{21}-P_{30}$) ²	Address no. 4 ($P_{31}-P_{40}$) ²	Operation ($P_{41}-P_{44}$) ²
Memory position from which 1st operand is selected	Memory position from which 2nd operand is selected	Memory position to which result of operation is sent	Memory position at which next order stands	Instruction Code

Instruction Codes used in the conversion of binary-coded decimal numbers to the binary notation:

Note: (M) means contents of memory position M.

	Address no. 1	Address no. 2	Address no. 3	Address no. 4	Operation ³
<i>Addition</i>					
Obtain (X) + (Y) and store the sum in Z.	X	Y	Z	next order	A
<i>Subtraction</i>					
Obtain (X) - (Y) and store the difference in Z.	X	Y	Z	next order	S
<i>Multiplication with round-off</i>					
Obtain the rounded product of (X) and (Y) and store in Z.	X	Y	Z	next order	M
<i>Division with round-off</i>					
Obtain the rounded quotient of (X) ÷ (Y) and store the result in Z. Here (X) must be less than (Y).	X	Y	Z	next order	D
<i>Comparison</i>					
Compare (X) with (Y); if (X) ≥ (Y), the next order is contained in G; if (X) < (Y), the next order is contained in L.	X	Y	L	G	C
<i>Extraction</i>					
a) Shift (X) n places to the left (n is written as two octal digits), replace the digits in the <i>first</i> address of (Y) with the corresponding digits of the shifted (X), and store in Y.	X	0 n 1	Y	next order	E
b) Same as (a) above, except that (X) is shifted to the right.	X	1 n 1	Y	next order	E
c) Shift (X) n places to the left, replace the digits of the third address of (Y) with the corresponding digits of the shifted (X), and store in Y.	X	0 n 3	Y	next order	E
d) Same as (c), except that (X) is shifted to the right.	X	1 n 3	Y	next order	E
e) Shift (X), exclusive of the sign, n places to the left, replace (Y) by the shifted value of (X) with original sign of (X).	X	0 n 7	Y	next order	E
f) Same as (e), except that (X) is shifted to the right.	X	1 n 7	Y	next order	E
<i>Wire Orders</i>					
a) Write on wire n, (n is written as two octal digits) starting with memory position X through Y in sequence.	X	0 1 n	Y	next order	W
b) Read from wire n, read the first word into X, the next word into X + 1, etc., in sequence through Y.	X	0 2 n	Y	next order	W
c) Read from tape n, store the words into the memory address specified by the fifth address of each word until the fifth address = Y, store that word in Y and continue to the next order. X has no significance in this order.	X	0 3 n	Y	next order	W

The following program covers conversion of Input Data on Wire no. 2 in decimal form to equivalent data, similarly arranged, but in binary form on Wire no. 3. Any number of words from 1 to the full capacity of the wire may be converted at one time. The number of words desired is expressed in the form $N = 2^n r$ with n integral and $0 < r \leq 2^9$. The values of n and r are set up respectively in octal form on the "Address no. 1" and "Address no. 3" positions of the "Auxiliary Input" switches of the EDVAC. All the remaining switches are set at zero. These data are read into position 1001 of the internal memory by suitable use of the "Special Order" switches of the machine.

The coding below is typed on the Input Typewriter to form a corresponding wire if one is not already available in the library of routines. This wire is mounted on the EDVAC Drive no. 1, the wire carrying the decimal data on Drive no. 2, and a blank wire (or one carrying data no longer needed) on Drive no. 3. The "Special Order" switches are now set for the order:

W 0000 0301 1042 0000

and the "Initiate" button is again pressed. This will cause the code to be read off Wire no. 1 into the internal memory. When the EDVAC has halted again as indicated by the blue pilot, the operator sets the "Mode of Operation" dial to "Normal-to-Completion" and presses the "Initiate" button once again. This will begin the conversion process and produce binary data on Wire no. 3 equivalent to the decimal data on Wire no. 2 in the corresponding positions, continuing automatically until the number of words specified have been converted, when the blue pilot will light again to indicate completion of the job.

The initial orders of the routine read a group of words from Wire no. 2 into the memory. The first group consists of r words and is stored in memory positions 1, 2, 3, \dots , r . Succeeding groups will consist of 512 words and will be stored in positions 1, 2, 3, \dots , 777 (octal notation). The next 4 instructions modify the subsequent commands for the purpose of storing converted numbers, testing each iteration to determine when converted data are to be read out, testing for the end of the program, etc.

The coding for the actual conversion from the decimal to the binary notation proceeds as outlined above using the coefficients $a_1 = 8/5$, $a_2 = 3/80$, $a_3 = a_4 = \dots = a_{10} = 10^{-1}$. The successive stages of each iteration are coded below in detail in order to save the time required to execute the modifications necessary when a sub-iteration is used. As previously stated, the various addresses have been chosen for optimum speed in execution rather than for compactness. The extreme possible error in conversion by the process given is, closely, $3/2 \times 10^{-13} = 4/3 \times 2^{-43}$.

The speed of conversion is approximately 10 words per second, based on an input-output speed of 30 words per second. If and when the input-output is replaced by more efficient magnetic tape devices, the economies effected in this routine will become more apparent. For example, when an input and output speed of 400 words per second is attained, the rate of conversion will be 27 words per second.

Program for Converting Binary-Coded Decimal Numbers to the True Binary Notation

Time to Perform Operation in Minor Cycles	Memory Posi- tion of Order (5th Address)	Operation	Address no. 1	Address no. 2	Address no. 3	Address no. 4
11	0000	E	1001	0003	1003	1003
**	1003	W	0001	0202	0000	1002
5	1002	E	1003	0241	1006	1007
7	1007	E	1003	0003	1055	1006
10*	1006	E	0000	0007	1054	1005
4	1005	E	1006	1243	1050	1011
11	1011	E	1054	0447	1047	1004
47	1004	M	1016	1047	1052	1013
5	1013	E	1054	0407	1056	1010
10	1010	A	1052	1056	1047	1012
49	1012	M	1016	1047	1052	1023

Time to Perform Operation in Minor Cycles	Memory Posi- tion of Order (5th Address)	Operation	Address no. 1	Address no. 2	Address no. 3	Address no. 4
4	1023	E	1054	0347	1056	1017
13	1017	A	1052	1056	1047	1014
47	1014	M	1016	1047	1052	1033
5	1033	E	1054	0307	1056	1020
13	1020	A	1052	1056	1047	1015
46	1015	M	1016	1047	1052	1043
6	1043	E	1054	0247	1056	1021
9	1021	A	1052	1056	1047	1022
49	1022	M	1016	1047	1052	1053
4	1053	E	1054	0207	1056	1027
13	1027	A	1052	1056	1047	1024
47	1024	M	1016	1047	1052	1063
5	1063	E	1054	0147	1056	1030
13	1030	A	1052	1056	1047	1025
46	1025	M	1016	1047	1052	1073
6	1073	E	1054	0107	1056	1031
9	1031	A	1052	1056	1047	1032
49	1032	M	1016	1047	1052	1103
6	1103	E	1054	0047	1056	1041
8	1041	A	1052	1056	1047	1051
50	1051	M	1026	1047	1052	1113
13	1113	A	1054	1052	1044	1050
57*	1050	D	1044	1035	0000	1045
10	1045	S	1006	1042	1006	1037
14/15	1037	C	1006	1042	1055	1006
**	1055	W	0001	0103	0000	1040
4/6	1040	C	1001	1042	1034	1036
16	1036	S	1001	1042	1001	1046
13	1046	E	1042	1133	1003	1003
	1034	H ⁴	0000	0000	0000	0000

Storage of Constants:

1016	+014 6314 6314 6315	(= 1/10)
1026	+004 6314 6314 6315	(= 3/80)
1035	+120 0000 0000 0000	(= 5/8)
1042	+000 1000 0000 0000	(= 2 ⁻¹⁰)

FLORENCE KOONS & SAMUEL LUBKIN

NBS

¹ The basic idea for the conversion method discussed herein is due to Dr. LUBKIN.² Position (P_1 – P_{10}), etc., are the 10 most significant binary digits of the order word.³ Letters are used instead of the binary notation for easier association.⁴ H signifies Halt Order.* Average for n large. Minimum and maximum may deviate from this by ± 7 minor cycles.

** Time required to execute this operation is essentially time required to move input and output devices.

BIBLIOGRAPHY Z–VII

1. LEON BRILLOUIN, "Les grandes machines mathématiques Américaines," *Atomes*, no. 21, Dec. 1947, p. 400–404, illustrs. 20.3 × 26.7 cm. This paper is preceded by an introductory article entitled, "L'évolution des machines à calculer," by JEAN PÉRÈS, p. 399–400. Both articles appear under the title "Les cerveaux électroniques."

2. W. J. ECKERT, "Electrons and computation," *Sci. Mo.*, v. 68, 1948, p. 315-323. 19 × 26 cm.

A description of the design and operation of the new IBM Selective Sequence Electronic Calculator; see *MTAC*, v. 3, p. 216-217, 326 (6).

3. HARRISON W. FULLER, "Numeroscope for cathode-ray printing," *Electronics*, v. 21, 1948, p. 98-102, illustrs. 27.9 × 20.3 cm.

The Numeroscope, a rapid large-scale computer printer, is an electronic device for tracing upon the screen of a cathode-ray tube the patterns of the Arabic numerals from one to zero. This makes it possible to build a printer that will display the result of a computation upon an assembly of cathode-ray tubes and that will record the displayed quantity on fast film. The article discusses many of the circuit techniques used in the design of the Numeroscope.

MDL

4. HARVARD UNIVERSITY, Computation Laboratory, *Annals*, v. 16: *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery*, Jointly Sponsored by the Navy Department Bureau of Ordnance and Harvard University at the Computation Laboratory, 7-10 January 1947. Cambridge, Mass., Harvard Univ. Press, 1948, xxix, 302 p. 19.7 × 26.7 cm. \$10.00.

This handsome, finely illustrated volume is a detailed report of the Symposium of which we have already published the program, and a list of members registered, in *MTAC*, v. 2, p. 229-238. Other details are now presented in the volume under review, but especially the texts of the 31 scientific papers delivered. We shall now endeavor to suggest the noteworthy contents of these papers.

Mr. R. H. BABBAGE presented an interesting account of some of the difficulties which CHARLES BABBAGE met and overcame in his pioneering efforts in the field of mechanical computation.

Babbage invented two calculating machines: the difference engine (financed by the British Government) and the analytical engine. He was handicapped by the fact that he not only had to design the machine parts but was even forced to design tools for fabricating them. In his notes he states that "some of the most enlightened employers and constructors of machinery, who have themselves contributed to its advance, have expressed to me their opinion that if the calculating engine itself should entirely fail, the money expended by Government in the attempt to make it would be well repaid by the advancement it had caused in the art of mechanical construction."

The construction of the difference engine was carried on during many years, but due to circumstances beyond Babbage's control the engine was not completed. The inventor turned to work on his second invention, a more powerful calculating machine called the analytical engine, which he expected to execute not only such work as the difference engine had been planned to perform, but every kind of analytical operation indicated by formulae. However, he encountered serious obstacles in construction of the analytical engine. The difficulties were not so much in the design of the engine as in its construction. It is interesting to speculate on what might be the present state of the art of numerical computation by large-scale automatic machinery had Babbage been able to accomplish the construction of his analytical engine and put it into active service.

The Mark I, described by Mr. R. M. BLOCH and located at the Harvard Computation Laboratory, is an electro-mechanical device, having an operational speed of 200 cycles per minute, and controlled by coded instructions on a teletype paper tape. The calculator has storage capacity of seventy-two 23-digit numbers, together with their signs. It has three types of input devices: 60 "constant" registers (manually-set 10-pole valve switches), used for storage of numerical constants, tolerances, increments, parametric

values, etc.; two standard IBM card feeds, serving not only to permit the introduction of quantities into the machine from punched cards but also as an extension of the storage unit; and three interpolator mechanisms used for the finding and reading of functional values stored in coded form on "value" tapes. The machine has two output devices: IBM electro-matic typewriters and IBM card punches. Plug boards are provided for controlling the typing so that the output of the machine may be arranged in the exact form desired for publication by photo-photography. The machine performs the basic arithmetical operations of addition, subtraction, multiplication, and division. Various applications of the machine which had been made were mentioned.

The ENIAC (Electronic Numerical Integrator and Computer) which was designed and built in the Moore School, under the sponsorship of the Ordnance Department of the U. S. Army, was described in detail by Dr. L. P. TABOR.

The ENIAC operates on ten-decimal-digit numbers and performs its calculation by counting voltage pulses, which are formed in a cycling unit in groups of 1, 2, 4, 9, and 10. The basic frequency of pulse generation is 100,000 per second. The fundamental cycle of the computer is the addition time, which is 200 microseconds. The remaining built-in operations are performed exceedingly fast: 300 multiplications, 50 or more divisions or square root extractions in a second.

Since an article on the ENIAC has appeared in this journal (see *MTAC*, v. 2, p. 97-110), further details here are unnecessary.

Next, Dr. S. B. WILLIAMS briefly traced the development of the BTL relay computers from the time of the suggestion by Dr. G. R. STIBITZ regarding the use of telephone relays and teletype apparatus for numerical computation through the design of the large-scale Relay Computing System. After mention of the first application of Stibitz's ideas, to the "complex computer," which added, subtracted, multiplied and divided complex numbers, operating from a keyboard and printing results on a teletype printer, and with a preliminary discussion of the "excess-three" representation of decimal digits and the bi-quinary representation of digital values, he explained thoroughly the design features of the Bell Telephone Laboratories' Relay Computing System.¹ This computing system is among the most flexible and reliable of existing large-scale computing systems, and has many novel and interesting features. By the use of diagrams and slides with his talk, Dr. Williams made clear the manner in which this computing system functions.

In his talk, Mr. R. V. D. CAMPBELL described the Dahlgren Calculator—Mark II—which was then under construction at the Harvard Computation Laboratory for the Bureau of Ordnance of the United States Navy.² This machine, of ten decimal-digit capacity, differs from the Mark I among other features in that the arithmetic operations are performed by electro-mechanical relays, not mechanical counters, and manually-set dial switches are used only in a subsidiary capacity. Furthermore it has an increased internal storage and uses a "floating decimal point." An important feature of the calculator is its ability to operate as a unit on one problem or its possible use as two independent halves, each half operating on a separate problem.

A number N , with floating-decimal point, is expressed in the Mark II in terms of another number p , and an integer j , according to the representation

$$N = p \times 10^j, \quad 1 \leq p < 10, \quad \text{and} \quad -15 \leq j \leq +15.$$

A storage register is an assemblage of 62 relays, 16 of which are used for routing of quantities into and out of the register and 46 of which are necessary for the representation of N (one relay for the algebraic sign, 5 relays for j , and 4 relays for each of the ten decimal digits of p). The machine automatically adjusts exponents, j , in addition and multiplication. It has two adders and four multipliers. Subtraction is accomplished by use of complements on nines in the adder; multiplication is compounded from the first five multiples of the multiplicand and algebraic addition.

Permanently available within the calculator are the reciprocal, the reciprocal square root, the logarithm, the exponential, the cosine, and the arctangent. In addition, the machine contains four input devices which supply it with coded tables of functions punched in paper tapes.

Four input mechanisms are available for introducing into the calculator the orders contained in sequence tapes. Also provided are four input devices for introducing quantities into the machine. The output devices consist of four automatic typewriters.

The Mark II contains about 13,000 electro-mechanical relays. These relays, designed especially for the machine, operate in from six to ten milliseconds. About one-third of the relays are of the "latch" type: they can be locked mechanically in position. The storage relays in the internal memory are of this type and thus maintain their position in the event of power failure.

The machine is of the synchronous type having a basic cycle of one second duration. Thirty orders are executed in each cycle, by the machine operating as a whole or by each of the two halves in split operation. Programed checking of machine operations is used. In addition, the machine sounds an alarm in case a number read into one of its units exceeds the capacity of the unit.

The theme of Dr. A. W. WUNDHEILER, in his paper on "Problems of mathematical analysis involved in machine computations" was that "pure numerical computation" cannot replace mathematical analysis. "A bare numerical result without statement of the associated error has no scientific value, and only an analysis in general terms can provide an expression for the associated error." Dr. Wundheiler gave a broad survey of urgent problems in error analysis, stressing the limitation of the "common sense" approach to questions of convergence and illustrating by use of slowly convergent series, the Gibbs phenomena in Fourier's series, and successive approximation formulae yielding non-convergent results. He pointed out the difficulty in determining how fine to make the meshes used in connection with the application of finite-difference techniques to approximate solutions of boundary value problems. Also, the sums of round-off and truncation errors are not independent, as a consequence of which the accuracy available with a given approximation method and a given number of digits may be severely limited.

Perhaps the most urgent need for further development of error analysis, according to Dr. Wundheiler, lies in the field of second-order partial differential equations. A second need is for further analysis of round-off error.

In his talk on "The organization of large-scale calculating machinery" Dr. STIBITZ discussed the "drive" behind numerical computation, namely, the fact that computing is done because the computed results are useful and frequently necessary for the attainment of an important end. Treating the role of large-scale computing machines in important and extensive work programs, from the standpoint of economy and also of effect on the structure of the work group, he discussed external organization of such machines as being influenced by and also tending to mold their environment. In connection with external environment, Dr. Stibitz discussed machine flexibility, repetitive computation versus single problem operation, machine vocabulary, the interpretation of mathematical symbols and instructions by the machine, and diagnostic equipment.

In his discussion of the internal organization of large-scale computing machinery, Dr. Stibitz touched on fixed-cycle and variable-cycle designs, complexity of the control mechanism and flexibility. He pointed out that the internal organization is essentially under the control of the designer, subject to the limitation that interference with requirements of the external organization must be avoided. He proposed a control level of intelligence lying between the control tape and the arithmetic unit, at which level would occur translation from mathematical vocabulary to machine language, and also, the interpretation of instruction, concerning printing and other auxiliary matters.

In his paper on "Mercury delay lines as a memory unit," Dr. T. K. SHARPLESS described a dynamic-type storage unit for electronic digital computers. If provisions are made for recirculating a pulse train repeatedly through a delay device with sufficient control over attenuation and distortion, the device medium serves as a practicable memory unit for electronic computers.

The transmissive losses for acoustic waves in a mercury column are small; a mercury column together with piezo-crystal input and output provides, therefore, a good delay medium for electrical pulses. Delay variation with temperature limits the length of the mercury

column that it is possible to use. A feasible memory system would consist of a bank of mercury delay lines with associated recirculation circuitry, so mounted as to minimize thermal potential differences, and with one line of the bank controlling the frequency of the pulses by means of an automatic frequency control unit, so as to keep constant the storage capacity of each line.

Discussing "Slow electromagnetic waves," Professor L. N. BRILLOUIN stated that the delay of a short pulse, of the type used to represent binary digits in electronic computers requires: (a) a very broad passing band, (b) inclusion of low frequencies, preferably (to avoid the complication of transmission as a modulated carrier), (c) no distortion, hence constant velocity of propagation and constant attenuation for all frequencies passed.

Wave guides, spiral delay lines and lumped artificial lines were discussed as sources of production of slow electromagnetic waves in relation to requirements (a), (b) and (c).

In the case of wave guides, it appears that phase velocity and attenuation depend strongly upon frequency and, therefore, requirement (c) is not met.

The spiral-delay-line method for producing slow waves is a practical one. This type of line yields wide bands with very small phase distortion, but with a certain amount of amplitude distortion.

Filter theory is applicable in the case of lumped artificial lines. The velocity of propagation in a standard low-pass filter does not remain constant throughout the passing band. However introduction of a certain amount of mutual inductance between sections of the filter both improves the delay characteristics and maintains the velocity of propagation constant over a wide range of frequencies.

Included in the printed copy of Professor Brillouin's talk are two appendices giving mathematical analysis of propagation along a solenoid and of a low-pass filter with mutual inductance.

Dr. J. W. FORRESTER's paper, "High-speed electrostatic storage," reviewed requirements which an electrostatic storage device must meet for application to high-speed electronic computation as contemplated in a research program of the Servomechanisms Laboratory sponsored by the Special Devices Division of the Office of Naval Research. Emphasis was being placed on (1) high signal-to-noise ratio; (2) indefinite storage time, no restriction being imposed on the order or number of times a storage position is used; (3) ready accessibility to storage (6 microseconds allotted to storage control and operation); and (4) simple and reliable mechanical and design characteristics.

Dr. Forrester gave a qualitative treatment of a beam-deflection electrostatic storage tube, intended for parallel operation in banks of as many tubes as there are binary digits in the stored numbers, and operating by the utilization of well-known secondary-emission effects. Outstanding problems in the development of the tube were discussed, and the results of experimental work of the Servomechanisms Laboratory were treated briefly.

Dynamic optical and static magnetic storage were discussed by Dr. B. L. MOORE. The optical system consisted of a rotating disc coated with a phosphorescent material, a modulated light source on one side of the drum, a photo-electric cell on the diametrically opposite side, and an erasing and feedback arrangement between the receiving cell and the light source, in the direction of rotation of the drum. The storage device would function much the same as a mercury-delay line storage device with light spots on the face of its rotating drum playing a role similar to that of the acoustic wave trains in the former. Difficulty had been experienced with the erasing and feed-back arrangement.

The well-known magnetic drum storage was described as a more promising device than the phosphor drum or disc. One big advantage of the magnetic-storage is its static feature: power failures do not cause loss of information stored on the magnetic material.

Dr. JAN RAJCHMAN, summarizing the specifications for an ideal memory organ for a digital computing machine, stated "The memory organ should be able to register in as short a writing time as possible any selected one of as many as possible on-off signals and should be able to deliver unequivocally the result of this registration after an arbitrarily long or short time, with the smallest possible delay following the reading call."

The selectron, designed in an attempt to meet these ideal requirements, appeared to

show promise as a memory unit for electronic digital computers. Dr. Rajchman explained very clearly the design and operation of this tube, illustrating his talk effectively by the use of slides. The interested reader will find a complete description of the selectron in an article by Dr. Rajchman in *MTAC*, v. 2, p. 359-361.

Dr. A. W. TYLER discussed the characteristics of photographic emulsions and phosphorescent materials, from the standpoint of their use to provide permanent and supplemental storage for electronic digital computing machinery. He described the handling of photographic film, high-speed scanning techniques, and the like.

He concluded that photographic film would be a useful form of permanent storage for use with electronic computers, and that phosphor-coated film showed promise of developing into a satisfactory supplemental storage medium.

In his paper, "Method of finite differences for the solution of partial differential equations," Prof. R. COURANT briefly indicated some directions in which theoretical mathematical efforts must be turned if new scientific results are to come from the development of high-speed automatic computing machines. He was concerned more specifically with the field of boundary and initial-value problems of partial differential equations of physics. He discussed numerical methods as replacing an analytical problem, P , by an approximate problem P_h , depending on a parameter h , and having a solution S_h obtainable by computational methods. The main question is: "for small values of h , when P_h approximates P , is S_h likewise an approximation to the desired solution S of P ?"

Dr. Courant discussed methods for increasing the speed of convergence of S_h toward S as h approaches zero, for example, by increasing the order of equations, by use of general nets for finite difference schemes, and the like. He mentioned that numerically following the development and propagation of discontinuities (shocks) will probably require extensive theoretical and numerical procedure. The relevance of theoretical questions of existence and uniqueness for an understanding of physical problems was emphasized.

Dr. R. J. SEEGER's remarks concerned computational techniques applicable to problems in the field of explosive phenomena. Problems concerning the thermal sensitivity of an explosive and underwater explosion phenomena were discussed.

The complexity of the problems is sufficiently illustrated by the exhibition of one of the differential equations involved, say the non-dimensional form of the equation involved in the linear case of the first problem:

$$\frac{\partial \theta}{\partial \tau} = \frac{\partial^2 \theta}{\partial \xi^2} + e^{-1/\theta}.$$

Various methods which have been devised for the approximate solution of this and the remaining differential equations were discussed. Approximate solutions obtained by the Naval Ordnance Laboratory, the Harvard Computation Laboratory, the Mathematical Tables Project (now a part of the NBS Computation Laboratory), and the Ballistic Research Laboratory, Aberdeen Proving Ground, were analyzed and discussed in detail.

Typical problems in the field of industrial relationships were formulated mathematically by Prof. W. W. LEONTIEF. The corresponding mathematical problems consisted of solving large systems of linear algebraic equations. Since the most meaningful equations involve forty, a hundred or even more unknowns, the computational task arising in connection with their solution is a formidable one.

An efficient iterative procedure for the solution of large linear systems was mentioned. If the system is

$$[M]\{x\} = \{y^{(0)}\},$$

where $[M]$ is a square matrix of n th degree, possessing an inverse $[M]^{-1}$, and $\{x\}$ and $\{y^{(0)}\}$ are column matrices of n elements each, the solution $\{x\}$ can be obtained as

$$\lim_{n \rightarrow \infty} [\{y^{(0)}\} + \{y^{(1)}\} + \cdots + \{y^{(n)}\}],$$

where $\{y^{(k)}\} = [I - M]\{y^{(k-1)}\}$, for $k \geq 1$, provided the series $\sum_{k=0}^{\infty} \{y^{(k)}\}$ converges. A suffi-

cient condition for convergence is the tending toward zero of all elements of the matrix $[I - M]^k$ as k tends toward infinity.

Prof. H. A. RADEMACHER's remarks concerned truncation and round-off errors, particularly those affecting the accuracy of the numerical integration of ordinary differential equations. It was assumed that numbers were rounded off to k digits in the computations and the accumulation associated with Heun's approximation of first-order linear differential equations was analyzed. The total truncation and probable round-off errors were obtained by use of systems of adjoint differential equations and adjoint difference equations respectively. The orders of the total accumulated errors of the two types were shown to be $(\Delta t)^2$ and $(\Delta t)^{-1}$, a fact which holds true for the method independent of the order or number of the equations. It clearly follows that the assumption frequently made by computers using finite-difference methods that accuracy increases as the size of the interval decreases should not be followed blindly.

The Navier-Stokes equations of flow were discussed by Prof. H. W. EMMONS. Many special analytical solutions of these equations are known, but the speaker believed that no analytical solution of the finite oscillations of turbulent flow had been attempted. He proposed a direct numerical attack on the turbulence problem by the use of the "bigger, better, faster, and more reliable computing machinery" that would become available. One might begin by assuming the fluid flowing initially in Poiseuille flow and try to compute the flow characteristics for later times. At sufficiently high Reynolds numbers the rounding errors should grow in magnitude until the computed flow exhibits the characteristics of turbulence. If a correct numerical procedure were used, Dr. Emons felt it could be used to investigate the adequacy of the continuous treatment of fluid mechanics via the Navier-Stokes equations.

In his talk on "Firing tables," Dr. L. S. DEDERICK described a finite-difference approximation method similar to, but appearing to be substantially superior to, the Heun method. For the equation

$$\frac{dy}{dx} = F(x, y),$$

the typical step taken in accordance with the method treated is illustrated by

$$y_1 = y_0 + hy_0', \quad y_1 = F(x_0 + h, y_1), \quad y_2 = y_0 + 2hy_1'.$$

It had been estimated that the total accumulated error associated with this method was appreciably less than that inherent in the Heun method. Dr. Dederick next considered the approximate solution by numerical methods of the trajectory equations and closed his talk with general remarks on ways of programing the ENIAC to exploit its speed in the computation of firing tables.

Concerning the EDVAC type, Dr. J. W. MAUCHLY discussed its extensive internal memory, its minimum of elementary instructions, and ability to store instructions in the internal memory and to modify instructions as directed by other instructions. He also included a discussion of problem preparation on these computers. Furthermore serial operation, the use of "flow-charts," the use of sub-routines, and the preparation of instruction tapes by use of the computer were treated.

Mr. J. O. HARRISON, JR., in his paper on "The preparation of problems for large-scale calculating machinery," placed emphasis on the analysis which must be performed preliminary to setting up the Mark I computer for a problem. He mentioned four steps: (1) decision upon the exact method of computation, (2) selection of a method of checking, (3) determination of the magnitude of intermediate results, and (4) analysis of error. He discussed mathematical checking by differencing, checking identities and repetition of operations on different equipment within the computer. The design of a sequence tape and setting up the Mark I were also treated in the talk.

The general theme of the next seven papers was "Input and output devices."

In a paper on "Application of printing telegraph techniques to large-scale calculating machinery" Mr. F. G. MILLER described the Western Union teletype equipment used, with appropriate modification, in the Mark II computer system. Included in this equipment were page printers, reperforators, transmitters, distributor-transmitters, and the like.

The talk was well illustrated by slides. Credit was given to Messrs. R. F. DIRKES and A. E. FROST, engineers of the Western Union Telegraph Company, for their assistance in the performance of the engineering work involved in the application of the teletype equipment in the Mark II.

In the second talk. Mr. OTTO KORNEI described perpendicular and longitudinal magnetic recording—the terms applying to direction of magnetization in the recording magnetic medium. Subjection of the recording medium to a bias field during erasing to obtain a linear transfer characteristic was explained together with an analysis of the design characteristics of recording and reproducing magnetic heads. The relation between high frequency response and the ratio of coercive force to remanence of a magnetic material was treated graphically, by consideration, based on the hysteresis loop. High absolute values of these two quantities are desirable: remanence to produce high absolute reproducing level, coercive force to offer resistance to accidental demagnetization. The effect of thickness of the recording medium or response was discussed, with the use of experimental data. Gap-width effect was analyzed. The talk ended with a discussion of various ways of producing commercial magnetic recording media.

The numeroscope described by Mr. H. W. FULLER was developed at the Harvard Computation Laboratory for the purpose of high-speed printing. The device consists of cathode-ray tubes together with deflection voltage circuits which generate voltage patterns for the tracing upon the screen of any one of the decimal digits 0 through 9. Several methods for generating the deflection plate voltages for the tracing of a given digit on the tube end were outlined.

Mr. S. N. ALEXANDER discussed the development work at the National Bureau of Standards on the modification of Teletype Corporation equipment to form an input system for electronic computers.

In one such system two initial teletype tapes are prepared independently from the same manuscript. Errors arising either from operator's mistakes or from the equipment are detected by automatic electrical comparison of the tapes. The magnetic input tape for the electronic computer is in this case prepared automatically from one of the corrected initial tapes.

An alternative tape preparation device consists of a system for preparation of a teletype tape from the original manuscript, and independent preparation from the same manuscript of a magnetic input wire or tape with checking against the paper tape and page printing of the instruction sequence. Design details of the two systems were discussed, with the use of slides.

In Dr. MORRIS RUBINOFF'S talk the properties of multiple gates were emphasized and input devices of design based on the operation of multiple-gate tubes were described as an example of the application of such tubes. The multiple-gate tube is a multi-grid vacuum tube functioning with several grids used as gating grids. The tube responds to input signals only if all gate grids have been placed at "normal" voltage levels. The tube functions for the passage of voltage pulses, as a multiple-control switch. The circuit schematics for an input device using such gates was described.

Mr. R. D. O'NEAL described a photographic film input reader.³ It was stated that as many as 50 channels of information could be stored in readable form, on 35 mm. photographic film. The optical system of the reader was described, and checking methods were explained. Parallel operation of an input reader with a high-speed electronic computing machine was discussed. It was stated that most of the experience required for the construction of an input reader of the type required was at hand.

The concluding talk, by Mr. C. B. SHEPPARD, was concerned with the transfer of information between a slow-speed external memory, such as magnetic wire, and a high-speed internal memory, such as acoustic delay lines or electrostatic storage tubes. Types of computer memory were tabulated and compared from the standpoint of erasability, speed, compactness, and cost. The electrical circuitry for the transfer of signals from acoustic delay lines to magnetic tape was outlined in block form and described.

Prof. S. H. CALDWELL made a thought-provoking talk on the subject "Publication,

classification and patents." He referred to the concern of workers in the field of development of large-scale digital calculating machinery over their lack of current information concerning what their fellow workers in the field are doing. The need for free exchange of information between the groups endeavoring to develop large-scale high-speed computers was stressed. The effect upon dissemination of information of the desire of industrial interests to secure patent protection and the classification of work by military agencies was discussed. Quoting Dr. Caldwell, "It is easy to observe these influences and to call them reactionary and obstructive. They are so conspicuous that it frequently becomes easy to blame them for whatever troubles we may have. When a patent policy is too rigid and when military classification becomes unrealistic, they deserve all the blame we can muster; but I think that if we look further, we will find other major sources of difficulty and other cures than mere condemnation."

Prof. Caldwell proposed as a cure for the communication defects professional organization and a publication medium. He suggested that the National Research Council could be of assistance through two committees under the Division of Physical Sciences: the Committee on Mathematical Tables and Other Aids to Computation, Prof. R. C. ARCHIBALD, Chairman; and the Committee on High-Speed Calculating Machines, Prof. JOHN VON NEUMANN, Chairman. One result of a joint conference of these committees was the establishment in *MTAC* of the new department on "Automatic Computing Machinery."

Included in the publication of the proceedings of the symposium is a paper in absentia by Dr. LOUIS COUFFIGNAL, Centre National de la Recherche Scientifique, Paris, France. The paper concerns the extent of the application of large-scale calculating machinery. Presented diagrammatically are charts exhibiting the author's concept of a hierarchy of technical and mathematical steps leading one from a concrete problem to its final solution by fabrication or construction. A similar schematic is presented which is based on the author's classification of calculating machines and of mathematics. The central theme of the article is the effect of high-speed calculating machinery upon the systematic approach to problems requiring numerical solution.

Dr. A. T. WATERMAN began his discussion, "New vistas in mathematics," with a description of the role of the Office of Naval Research in the program of development of high-speed computation—with particular reference to automatically-sequenced, high-speed digital computers. In the early planning stages of this program, ONR suggested to the NBS that a computing center be established to serve the combined interests of industry and government agencies. Dr. Waterman mentioned plans of the NBS to establish such computing facilities on the East and West Coasts, preferably in connection with a university. The speaker emphasized the importance of a training program in the new computer techniques.

The expediency demanded by World War II precluded an extensive program of scientific research under the Office of Scientific Research and Development; however, it is hoped that, in the future, the establishment of a National Science Foundation will encourage and support research. At present support to science comes largely from the Armed Services. Because of the wisdom and judgment of these groups in administering this support, Dr. Waterman believes there is no danger of military control of science.

Emphasis was placed on the important relationship between pure and applied mathematics—specifically as applied to the formulation of a wise program of support of mathematics. To quote Dr. Waterman: "History has provided us with repeated examples of mathematical disciplines, which studied only for their intrinsic interest and dealing apparently with purely formal truths, have reached results of profound importance for our description of the physical universe." It is important to remember that the high-speed computing machine is the servant of human endeavor; the Harvard group under Prof. Aiken has kept this in mind in the solution of problems where sheer magnitude of work would have prevented solution by other devices. Heretofore scientists were able only to prove the possibility of solution of certain problems; now, with the advantageous speeds promised by these new computers, there can be greater emphasis on actually solving the problem and in turn opening up new vistas on unsolved questions and encouraging development of new and penetrating theories.

The review of the contents of the talks presented at the Harvard Symposium, even though only a very brief abstract of each talk has been given, has been an extended one. It is believed that this fact should occasion no disquietude of reviewers and editors since in this case the length of the review can be interpreted as a measure of the importance of the material reviewed. The symposium was very well organized and the caliber of the participants beyond reproach. The high stature of the speakers is evidenced by the agreement between their prognostications concerning future developments in the field of high-speed calculating machinery and the direction this development has followed since the symposium. In view of the fact that the ENIAC remains the only operating large-scale electronic digital computing machine, one might tend to deplore mildly the optimism of certain speakers concerning the time required for the consummation of the developments under way in the field. However, no one would insist that their "batting average" on estimating the duration of engineering-development programs was an unusually low one.

This volume is recommended reading for everyone interested in the development and application of large-scale computing machinery.

MDL

¹ For details, see F. L. ALT, "A Bell Telephone Laboratories' Computing Machine," *MTAC*, v. 3, p. 1-13, 69-84.

² This machine has since been completed and is now in successful operation at the Naval Proving Ground, Dahlgren, Va.

³ In our program as published we had here the name of Dr. K. G. MACLEISH.

5. INSTITUTE FOR ADVANCED STUDY, Princeton, N. J. *Second Interim Progress Report on the Physical Realization of an Electronic Computing Instrument*, by JULIAN H. BIGELOW, THEODORE W. HILDEBRANDT, JAMES H. POMERENE, RICHARD L. SNYDER, RALPH J. SLUTZ & WILLIS H. WARE. 1 July 1947, 48 leaves, 52 figs., 12 drawings, 3 tables. 21.6 × 27.9 cm.

This report covers conditions sufficiently far in the past that it is of little value in indicating the present status of computer development at the Institute for Advanced Study. Approximately half of the report concerns details of magnetic wire drive and performance. The bulk of the remainder of the report covers experimental results on various circuit components planned for the IAS Computer, such as "flip-flops," "registers," "accumulators," and "pulse drivers."

Since the report deals almost exclusively with the special features pertinent to the particular computer visualized at the Institute for Advanced Study, it will be of interest chiefly to those connected with this project or to those who are interested in the design and construction of similar components. A large portion of the detail on magnetic wire performance, for example, will not be of great value to one who is primarily interested in the use of magnetic tape rather than wire. The report is probably of more general interest in its treatment of the methods of approach to the problems encountered. Some of these methods will doubtless suggest new viewpoints to the reader faced with analogous problems.

MDL

6. JOHN B. IRWIN, "The expected performance of the EDVAC on some astronomical problems," *Astron. Soc. Pacific, Publs.*, v. 60, 1948, p. 235-244. 15.2 × 22.8 cm.

The EDVAC (Electronic Discrete Variable Computer) is a comparatively small, extremely fast electronic digital computer now being tested at the Moore School of Electrical Engineering, University of Pennsylvania. Because of its great speed, it is valuable in solving astronomical problems heretofore considered too difficult or laborious to attempt. This article briefly describes the essential design features of the machine and its application to some of the above-mentioned problems. In most of the examples discussed here, over one-half of

the estimated time of solution is spent in input-output time, and therefore these problems could be handled by slower computers, leaving the EDVAC free to tackle the more time-consuming problems. The successful application of these machines to astronomical problems, the report concludes, will depend on the availability of these machines to astronomers, the quality of mathematical personnel, and the efficiency of programming.

MDL

7. G. A. KORN, "Elements of d-c analog computers," *Electronics*, v. 21, 1948, p. 122-127, bibl. 20.3×27.9 cm.

"Design criteria of simple circuits for adding, multiplying, integrating and differentiating are presented with their limits of accuracy. Operating principles and types of applications of direct-current electrical analog computers are summarized."

MDL

8. K. G. MACLEISH, R. D. O'NEAL, & A. W. TYLER, *High-Speed Digital Electronic Computer*. Eastman Kodak Co., Rochester, N. Y. 22 Feb. 1946, 24 leaves. 21.6×27.9 cm.

Early in 1946, the Eastman Kodak Company issued a proposal for designing and constructing a computer that would embody several significant advances over the designs proposed up to that time. Among these are: 1) the use of photographic film as an input-output medium, capable of storing from one hundred to five hundred 30-binary-digit words per inch, 2) methods for scanning a two to three foot loop of film at rates up to a million words per second, 3) a multiplying unit capable of obtaining the product of two 30-binary-digit numbers in 50 μ sec. (microseconds), 4) graphical output on a cathode-ray tube screen, 5) automatic execution of floating binary-point operations.

The report first lists the fundamental desiderata for a computing machine, namely: reliability, speed, ease of computation, and flexibility. It then describes ways in which each of these may be achieved. Reasons are given why the Eastman Kodak Company prefers the binary to the decimal number system, parallel to sequential operation, and photographic film to magnetic tape as an input-output medium.

A suitable memory device, according to the report, would have an access time of only 10 μ sec. per word, in which the word would not be erased when transferred. Such storage must be achieved, however, without an unreasonable amount of gadgetry. No definite decision had been made, at the time of writing, on the type of memory device; but a detailed discussion covers the pros and cons of storing numbers by: (1) a charge in capacitors in electron tubes; (2) current in gas tubes; (3) position in special beam tubes; (4) circulating pulses in delay lines; and (5) stable states in trigger pairs.

The proposed machine would handle numbers in the normal form, $N = q2^p$, where q consists of 30 binary digits and the exponent p has a maximum of six binary digits. 36 trunk lines would transfer such numbers within the computer. The control is based on a three-address system so that a program word would contain, besides the operation, a Source (address of word stored in the High-Speed Memory), a Destination (address of the Computing Unit), and a Next Command (address of word stored in the High-Speed Memory). In addition to the High-Speed Memory, the principal parts of the computer would be

a) a Film Preparation Unit, containing provisions for introducing decimal data (representing numbers or orders), either from a key board or punched-card reader, for translating information into binary codes and for photographing these data on 35-mm film;

b) Film Readers, capable of introducing information into the High-Speed Memory at five hundred to one thousand words per second;

c) Computing Units, capable of carrying out floating-point addition and subtraction in about 20 μ sec, multiplication in 50-250 μ sec, division and extraction of square root in 100-250 μ sec;

d) a Cyclic Program Unit, containing a high-speed film reader capable of scanning a

short loop of tape at speeds of up to a million words per second, this loop carrying either a cyclic series of program data or a function table with appropriate coefficients for interpolation, so that a "look-up" may be achieved in from .1 to 10 milliseconds;

e) the Control, receiving program data either from the Cyclic Program Unit or from the High-Speed Memory, and interpreting this information for the computing units;

f) Output Units, containing a graphical device yielding about 1 percent accuracy; a binary-to-decimal translator, as well as decimal printer yielding up to nine significant figure accuracy at the rate of some 15 numbers per second; and a recorder of binary output on photographic film at the rate of about 1000 words per second.

MDL

9. MOORE SCHOOL OF ELECTRICAL ENGINEERING, Univ. of Pennsylvania, *Theory and Techniques for Design of Electronic Digital Computers*. Lectures delivered 8 July–31 August 1946. V. 3–4, mimeographed, Philadelphia, 30 June 1948. A., v. 3, 157 leaves, Lectures 22, 23–24 (abstracts), 25, 27–29, 31, 33; B. v. 4, 158 leaves, Lectures 34, 35, 37, 39, 43–45, 46 (abstracts) 47. 21.5 × 28 cm., \$10. V. 1–2 were reviewed *MTAC*, v. 3, p. 128–132.

A. At the time the lectures were delivered there was little general knowledge concerning automatic digital computing machinery. Unfortunately, however, in a field progressing as rapidly as is that of electronic computers today, a delay of two years in publication substantially vitiates the usefulness of a report. This delay coupled with the incompleteness of several of the lectures has now made this report primarily of historical interest.

Lecture 22. *Sorting and collating* by J. W. MAUCHLY. After showing that comparison operations are essential to an automatic machine design for handling large computational problems, the author shows how these facilities may be used to change an initially random sequence of variables into an ordered one. Two cases are considered: (1) that in which the desired ordered sequence is monotonic throughout; and (2) that in which the variables are to be ordered only by classes.

On modern electronic machines the operating speed is much higher for operations involving only the internal high-speed memory than it is for operations involving the transfer of data to or from an external memory, such as magnetic storage. Under these conditions the time of sorting for a number of data much larger than the internal memory can accommodate becomes largely the time necessary for external memory transfers. On this basis the author analyzes the comparative times of different procedures. Considerable attention is paid to performing decimal sorting on a machine having a minimum of input and output tapes.

Lecture 25. *Conversion between binary and decimal number systems* by J. W. MAUCHLY. In many of the standard algebraic treatments of the conversion from one number system to another, no attention is paid to carrying out all of the operations in only one of the two number systems. In the design of an automatic computer to work in any system other than the decimal, it would be highly inefficient to build arithmetic circuits working in both systems. The author shows how the arithmetic operations can be carried out completely within the machine's number system, both for conversion from decimal to binary and for conversion from binary to decimal. He also points out that, provided the numbers entered into the machine are either wholly integral or wholly fractional, one of these conversions will involve only a particularly simple multiplication while the other will involve division. He goes on to show that by including an extra multiplication in one of the conversions the remaining operations become entirely simplified multiplication. This analysis is of particular interest if it is desired either to perform a conversion in minimum time with the regular arithmetic facilities of the machine, or if it is desired to build special conversion equipment of minimum complexity.

Lecture 27. *Magnetic recording* by CHUAN CHU. Equations are derived to describe the

recording and reproducing processes on a magnetic medium. For the recording processes, the author points out that the non-linearity of the magnetic medium invalidates the linear analyses customarily applied in analyzing acoustic recordings. He then continues, however, to derive equations for the recording processes which would be useful for analyzing pulse recording only if a linear substitution were to be applied. For reproduction, however, the magnetic fluxes generated in the reproducing head are in general so low that a linear analysis is well warranted. For this case the author makes an excellent analysis of the effect of gap width in degrading the reproduced signal.

Lecture 28. *Tapelypers and printing mechanisms* by J. P. ECKERT, JR. This lecture gives a discussion of the author's preferences concerning typing and printing mechanisms, with a description of possible methods of using gang printers to obtain high-speed output from a machine.

Lecture 29. *A review of government requirements and activities in the field of automatic digital computing machinery* by J. H. CURTISS. This lecture gives an excellent and apparently comprehensive survey reviewing the history of automatic digital machines, describing those which were constructed up to the time of the lecture, discussing those which were then planned, and giving considerable attention to the need for such equipment in governmental operations.

Lecture 31. *Numerical mathematical methods—VIII* by ARTHUR W. BURKS. This lecture reviews the method of "closed-cycle" integration of total differential equations in which at each stage only the values of the variables for the next preceding stage are used, with no reference to earlier stages. Approximation formulae of the first through the fourth order are discussed, covering the Heun method and the Runge-Kutta method. The author points out that in the Runge-Kutta method one is actually generating intermediate values of the variable, making this method appear at first to be no improvement in machine capacity over open-cycle integration of the same order. He shows, however, that the work can be so arranged that the intermediate values can be computed and used one by one, without the need for storing them simultaneously in the machine's memory.

Lecture 33. *Continuous variable input and output devices* by J. P. ECKERT, JR. The author states that there are four fields of primary utility for the application of digital computing in conjunction with continuous variable input and output devices. These are: gun directors, guided missiles, industrial control, and real time simulators ("trainers"). In addition to a general discussion of the utility of these operations he describes some rather interesting ideas for carrying out the conversion. One particular idea is a means for controlling a cathode-ray tube so that the position of the spot depends upon the previous history of the signals applied to the equipment. This is accomplished by enclosing appropriately perforated plates in the cathode-ray tube and using a feedback system to give the plates partial control of the spot position. If such a scheme were proved to be feasible it could be used to provide discrete indications within the cathode-ray tube for many possible values other than the two-condition storage carried out in the customary flip-flop, and in addition other variations of this scheme could be used to carry out addition or other computations compactly and at high rates of speed. A slightly different application of the method would provide an absolute positioning scheme for locating the spot in the tube; this would be useful in some types of memory tube applications. At the present time this lecture probably holds the most interest of any in the volume, since through the pressure of other work little has been done in the field described here. It holds promise for significant developments in the future.

NBS

RALPH J. SLUTZ

B. Lecture 34. *Reliability and checking in digital computing systems* by S. B. WILLIAMS. This is a discussion of reliability in checking mainly applicable to the Bell Relay Machine. This machine has a very complete low-level checking system based on its property of having only one relay closing in a given set. It also has the feature of step-by-step operation wherein each sequence operation must be checked before the next operation can proceed. The reading of the paper tape is checked by a redundant coding, now common practice. The chief con-

clusion is that a machine failure should give an alarm and hold the results for diagnosis and resumption of calculation.

Lecture 35. *Reliability and checking* by J. P. ECKERT, JR. This gives only general considerations on checking, such as the truism that no amount of checking will increase machine reliability, and that checking is a second line of defense. It is pointed out that reproducible errors are easy to find by means of test runs. Intermittent errors cause more difficulty, but a fundamental advantage of serial machines is that all digits are affected so that intermittent errors are apt to be easily detected in a smoothness test. This test is characteristic of so-called high-level checking as opposed to the low-level checks of the relay machine.

Lecture 37. *Code and control—II. Machine design and instruction codes* by J. W. MAUCHLY. Here is a discussion of the concept of a general purpose machine and the problem of the optimum number of orders. Too few orders make for difficult and lengthy programs, while, on the other hand, too many orders make the programing difficult, since too many things must be remembered and the machine then becomes very complex and therefore less reliable. General types of orders are discussed, and some comments are offered on the relative length of other words and number words from the standpoint of efficient storage.

Lecture 39. *Code and control—IV. Examples of a three-address code and the use of 'stop order tags'* by CALVIN N. MOOERS. There is a discussion of Tags for terminating sub-sequences, as, for example, when a nonanalytic boundary of a region of integration is reached. Two problems are coded in full for illustration.

Lecture 43. *The Selectron* by JAN RAJCHMAN. This presents physical principles and problems of the Selectron memory tube together with an analysis of the combinational system of element selection used.

Lecture 44. *Discussion of ideas for the Naval Ordnance Laboratory computing machine* by C. N. MOOERS. This is a discussion of some design proposals of an EDVAC-type machine.

Lecture 45. *A parallel-channel computing machine* by J. P. ECKERT, JR. This discusses the speed advantages and calculation disadvantages of a parallel-channel type computer as compared with single-channel serial operation.

Lecture 46. *A four-channel, coded-decimal electrostatic machine* by C. B. SHEPPARD. There is a summary of a lecture on some design considerations for a machine using four memory tubes containing 12,000 storage elements each.

Lecture 47. *Description of serial acoustic binary EDVAC* by T. K. SHARPLESS. Block diagrams of the EDVAC are presented and its operations illustrated by coding the iterative method of finding a reciprocal and tracing the operations through the machine.

CHESTER H. PAGE

NBS

10. R. D. O'NEAL & A. W. TYLER, *Progress Report no. 1, Photographic Digital Reader-Recorder*. Eastman Kodak Co., Rochester, N. Y. 7 June 1948, 23 leaves. (Contract N6ori-205 with Office of Naval Research, Special Devices Center). 21.6×27.9 cm.

This report discusses the objectives and techniques in designing and constructing a photographic input-output device to insert and receive information on the M.I.T. Servo-mechanism Laboratory's PROJECT WHIRLWIND Computer. Among the input-output requirements discussed are

1) the necessity that the film must be handled at a variety of speeds; 2) the storage of both a number and its complement on film in binary form, a 1 being represented by a clear spot and a 0 by an opaque spot; 3) the necessity that the machine be able to move tape in either direction to search efficiently for information.

The same piece of equipment will read and record. Recording, or exposure of the film, is accomplished by a masked cathode-ray tube, while reading is done with a phototube and light source. A detailed description of these operations is illustrated with block diagrams. Four possible arrangements of data on film are presented together with a method of recording without complements. "Breadboard" experimental results and problems are discussed, as

well as results of tests on various components, such as magnetic clutches, phototubes, cathode-ray tubes, and r-f power supplies and suitable film drives.

The summary includes the following information: 1) Reading and recording will take place at a peak rate of 2000 25-binary-digit words and complements per second. 2) One hundred 25-binary-digit words and complements will be stored on one inch of 35-mm un-perforated film stock. 3) All information recorded or read will be automatically checked against the original. 4) A minimum of optical and electronic adjustments will be necessary, and all panels will be readily removable for servicing. 5) Since film will be in daylight-loading magazines, short lengths may be removed without exposing film in the main part of the drive. 6) Commercially available automatic film processing machines will be used with the above equipment. The film must be removed from the reader-recorder and placed in the processor for development.

MDL

11. F. C. WILLIAMS & T. KILBURN, "Electronic digital computers," *Nature*, v. 162, 25 Sept. 1948, p. 487. 17.8 × 25.4 cm.

Presented here is a very brief description of a small electronic digital computing machine built to test the soundness of a storage principle. The computer is now in successful operation at the Royal Society Computing Laboratory, Electrical Engineering Laboratories, University, Manchester 13.

MDL

12. U. S. AIR FORCE, Planning Research Div., *Scientific Planning Techniques, Project SCOOP* [Scientific Computation of Optimum Programs]. *Discussion Paper*, no. 1-DU, 5 Aug. 1948, 29 p., 9 charts. 20.3 × 26.7 cm.

The scope, policies, and administration of Project SCOOP are set forth in AIR FORCE, *Letter* 170-3, dated 13 Oct. 1948. The following is a quotation from this *Letter*: "The primary objective of Project SCOOP is the development of an advanced design for an integrated and comprehensive system for the planning and control of all Air Force activities. The recent development of high-speed digital electronic computers presages an extensive application of mathematics to large-scale management problems of the quantitative type. Project SCOOP is designed to prepare the Air Force to take maximum advantage of these developments. The basic principle of SCOOP is the simulation of Air Force operations by large sets of simultaneous equations."

MDL

NEWS

Association for Computing Machinery.—The ballot for election of President, Vice-President, Section Officers, and Members-at-large for the period ending May 31, 1949, under the provisional Constitution and Bylaws, has been submitted to the membership with the Secretary's October 21st report. Because the nominee for the Section Officer from New York, Dr. SAMUEL LUBKIN, has moved to Washington, and is now with the NBSAML, the nominating committee has made a substitute nomination: Mr. E. G. ANDREWS (BTL, now on the ACM Council).

It was suggested that the Association issue a more regular bulletin than the present irregular series of reports. The Council has invited the views of the members on this question and volunteers for the work it will involve, but the Secretary has received no comments on this suggestion. This would seem to indicate that there is no substantial demand for such a bulletin and that possibly *MTOAC* largely fills this need for the Association.

A copy of a mimeographed summary of any one of the reports will be sent to any member who has not already received a copy, upon written request to the Secretary, Mr. Edmund C. Berkeley, 36 West 11 Street, New York. The summaries prepared are as follows: The Pilot Model of EDVAC, by T. K. SHARPLESS, 2 pp., 9/22/47. Optimum Size of Automatic

Computers, by G. R. STIBITZ, 2 pp., 12/24/47. Operating Characteristics of the Aberdeen Machines, by F. L. ALT, 2 pp., 12/29/47. Reduction of Doppler Observations, by DORRIT HOFFLEIT, 1 p., 1/11/48 (see MTAC, v. 3, p. 373-377) General Principles of Coding with Applications to the ENIAC, by J. VON NEUMANN, 1 p., 1/17/48. Adaptation of the ENIAC to von Neumann's Coding Technique, by R. F. CLIPPINGER, 2 pp., 3/15/48. Census Applications for High-Speed Computing Machines, by J. L. MCPHERSON, 1 p., 3/30/48 (see MTAC, v. 3, p. 121-126). The Raytheon Computer, by R. V. D. Campbell, 2 pp., 4/6/48.

Naval Research Lab., Washington D. C.—On 17 Nov. 1948, Prof. H. H. Aiken, of the Harvard University Computation Laboratory, discussed design features and operational characteristics of the Mark I, II, and III relay computers. The discussion was supplemented with slides.

The first two computers were developed at Harvard University under the leadership of Prof. Aiken and have been placed in service—the Mark I at Harvard and the Mark II at the Naval Proving Ground, Dahlgren, Va. Up to the present time they have performed with excellent reliability (the Mark I has averaged 60 to 75% successful operation and in some cases as high as 95%, and the Mark II has averaged about 85%). A comparison of the operation speeds of the two machines was given as follows:

	Mark I (23 dig. nos.)	Mark II (10 dig. nos.)
Multiplication	5 seconds	750 milliseconds
Addition	300 milliseconds	200 milliseconds

In addition it was pointed out that the Mark II machine could be mathematically cut in half (a valuable facility in the case where trajectories, arising so frequently in the work at Dahlgren, are to be handled).

The talk was highlighted by a discussion of the Mark III calculator, now being developed by Professor Aiken's group. It is expected that this machine will also be available for operation at Dahlgren, by June 1949. The fundamental components of the machine, like those of the Mark II, are the latch, the 2-coil, and the 3-coil relays. It will use a magnetic drum memory and will have a memory capacity of approximately 4000 16-digit-numbers. Magnetic tape is to be used in the eight input-output tape mechanisms. The addition and multiplication times quoted for the Mark III were 4 milliseconds and 12.5 milliseconds, respectively.

Although the machine operation speeds mentioned are comparatively small, Prof. Aiken believes that they are sufficiently fast until more is learned about numerical methods to be used in problem programing. In the opinion of the speaker, one should strive for more expedient problem preparation techniques rather than for increased speed in the machine.

Office of Naval Res., Washington, D. C.—On 15 Dec. 1948, an interesting and informative lecture (with slides) on the Mark II Calculator was given by Dr. C. C. BRAMBLE, director of Computation and Ballistics, NPG, Dahlgren, Va. The speech paralleled that of Prof. AIKEN, although Dr. Bramble presented a more detailed description of many of the machine design features and a step-by-step explanation of a particular coding routine which had been used on the machine.

Errata.—MTAC, v. 3, p. 216, l. 8, for both of King's College, read respectively of Birbeck College Res. Labs., and The British Rubber Producers' Res. Labs.

OTHER AIDS TO COMPUTATION

BIBLIOGRAPHY Z-VII

1. J. R. BOTHEL, "Slide Rule easily made for converting ram to sample pressures," *Chem. Engin.*, v. 55, Sept. 1948, p. 125-126. 21 × 28.5 cm.

In the use of hydraulic presses for different materials or under various pressure conditions, it is necessary to convert the pressure on the rams to pressure on the sample.