UNIVERSITY OF ILLINOIS
GRADUATE COLLEGE
DIGITAL COMPUTER LABORATORY

TECHNICAL PROGRESS REPORT

Teaching and graduate research are
not, in general, reported herein.

- PART I: HIGH-SPEED COMPUTER PROGRAM
- PART II: SWITCHING CIRCUIT THEORY
- PART III: MATHEMATICAL METHODS
- PART IV: GENERAL RESEARCH
- PART V: ILLIAC USE AND OPERATION -
GENERAL LABORATORY INFORMATION

December, 1957

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PART I

HIGH-SPEED COMPUTER PROGRAM

This work is supported in part through Contract No. AT(11-1)-415 of the Atomic Energy Commission. The contract is supported jointly by the Atomic Energy Commission and the Office of Naval Research. In addition, this work is supported through Contracts N6ori-07130 and Nonr-1834(15), both from the Office of Naval Research.

The University of Toronto is participating in this work through staff members of its Computation Centre.

1. Transistor Circuits

In order to compare the speeds of circuits wired in bread-board fashion and plug-in units, the operation times of two racing registers using the Eccles-Jordan flipflops given in the November Report were measured. For a four flipflop register the times for both were 28 ± 2 μ s/operation; the plug-in units having a slight edge. It should be mentioned, however, that by varying the supply voltages by the allowed amount ($\pm 3\%$) the operation times can change by as much as 10%.

A 4-digit shifting register was built using 8 of the above mentioned plug-in units. Experiments with a four-phase logical oscillator of the type used in Illiac (two phases of which controlled the drivers for the up-gates and the down-gates) showed that the transmission of information takes less than 100 μ s. This encouraged us to design a two-phase logical oscillator and improve the drivers according to Figure 1 and Figure 2. In this fashion, gate-pulses of less than 50 μ s length were obtained and error-free shifting was observed for many hours. A life test will be started soon. Figure 3 shows some timing diagrams.

Figure 1

50-m μ s Logical Oscillator
(circuit values of FF, AND and NOT--see November report)

Figure 2

50-m μ s Driver

Figure 3

Timing Diagram for the 50 μ s Shifting Register--Pattern 0001.

The methods indicated in the November Report have resulted in the design of a flow-gating flipflop which satisfies our usual tolerance conditions (2% resistors, 3% power supplies) with the difference that transistors must have $\alpha > .98$ instead of the usual $\alpha > .95$. The analytical program mentioned last month is now completed and has been used to check the flow-gating flipflop circuit values. This program calculates the voltages and currents under the "worst case" conditions. The input values are the nominal values of resistors,

power-supply voltages, alphas, diode and base-emitter drops as a function of current and finally the tolerances on all these parameters. The circuit values are given in Figure 4. Note that a bumping diode has been added in the output collector.

Figure 4

Circuit Values for a Flow-Gating Flipflop
(resistor tolerances $\pm 2\%$, power supply tolerances $\pm 3\%$, $\alpha > 0.98$)

2. Control Studies

Storage Requirement Studies

A study has been made of the problem of solving a three-dimensional hyperbolic differential equation (one time variable) by finite difference means on the new proposed computer. This problem makes severe demands on the core memory, drum, and magnetic tapes, since a very large amount of temporary storage

is required. The problem is to rearrange the order of calculation so as to advance the time variable by a number of step intervals for each pass of the data and to store large numbers of data on the drum, to be used frequently, and a smaller amount in the core memory, to be used even more frequently.

For a given size of drum memory and core memory, and given speeds for reading data to and from the drum and magnetic tapes, a system of 5 inequalities must be satisfied in order that the memory time not exceed the time for calculation. The parameter in those equalities is the number of mesh points in any one dimension. By allowing other quantities to vary, this can be used to obtain estimates (at least for this problem) of the relative sizes of the memories and the way in which magnetic tape speeds influence these sizes.

Floating Point Studies

Three versions of the 1.7 precision floating binary interpretive routine (69-bit fractional part and 10-bit exponent) have been used. These are:

- (a) Standardize the accumulator after every arithmetic operation.
- (b) Standardize the accumulator only before storing its contents, or if it would otherwise overflow.
- (c) A modification of the Metropolis system of significance indicated by leading zeros or leading ones, in which a product is shifted left one place, if this does not cause overflow, and a quotient has the same number of significant bits as the least significant of the divisor and dividend..

Preliminary experiments indicated that (a) was not detectably better than (b), and since it requires more complex circuitry and is slower, it was not extensively tested.

The floating binary experimental routines were used during the month on two classes of problems--matrix inversion by the elimination method, and proper values of symmetric matrices by Givens method.

The matrices inverted so far have been:

(a) Hilbert matrices $\|a_{ij}\|$ when $a_{ij} = \frac{1}{1+j-1}$, $i, j = 1, 2, \dots, n$,

for $n = 3, \dots, 15$ for standardize on store

and $n = 3, \dots, 13$ for modified Metropolis

(b) Power matrices $a_{ij} = i^j$, $i = 1, 2, \dots, n$

$j = 0, 1, \dots, n-1$

for $n = 3, \dots, 15$ by both methods

These matrices have inverses which can be computed directly (for the inverse of the Hilbert matrix see the NBS monograph on Matrices and Linear Equations). For the power matrix, the inverse may be found as follows:

Let $\|b_{ij}\|$ be the adjoint matrix.

Then $\sum_i i^j b_{jk} = 0$ when $i \neq k$.

Hence b_{jk} , for fixed k , are the coefficients of the polynomial

of degree $n-1$ where zeros are $1, 2, \dots, k-1, k+1, \dots, n$.

The inverses of both classes of matrices consist entirely of non-zero elements.

If c_{ij}^* is an element in the exact inverse, and c_{ij} is its computed approximation, then the relative error γ_{ij} is defined by

$$\gamma_{ij} = \frac{c_{ij} - c_{ij}^*}{c_{ij}^*}$$

The following measures of error have been computed for the above matrices:

$$\begin{aligned} & \frac{1}{n^2} \sum |\gamma_{ij}|, \\ & \sqrt{\frac{1}{n^2} \sum \gamma_{ij}^2}, \\ & \max_{i,j} |\gamma_{ij}|, \\ & \frac{1}{n^2} \sum \gamma_{ij}. \end{aligned}$$

The errors have not yet been analyzed.

As a further test of methods for floating point arithmetic and to relate loss of precision during matrix inversion to the ratio of the largest to smallest proper value, Givens method has been used to obtain proper values of both the Hilbert matrices and the inverse of the Hilbert matrices of orders 3 through 13. As n tends toward infinity, the ratio of the largest to smallest proper values for the Hilbert matrix tends toward e^{-3n} , so numerical inversion rapidly becomes inaccurate as n increases.

PART II

SWITCHING CIRCUIT THEORY

(This work is supported in part by the Office
of Naval Research under Contract N6ori-07130.)

1. Combinational Circuits

A study was made of combinational switching circuits formed from AND, OR, and NOT elements. A method was found for generating a combinational circuit yielding a given set of switching functions which contains no more NOT elements than any other combinational circuit producing the same switching functions. It was also shown that no circuit having n inputs requires more than k NOT elements, where $k =$ the least integer no smaller than $\log_2 (n+1)$. A 2^r-1 digit adder having r NOT elements has been designed by this method, and has been proved to have a minimum number of NOT elements.

2. Distributive Circuits

Several new results have been obtained in the theory of distributive circuits having cyclic behavior. A theorem stronger than (8:D) of Report 78 was found to apply to distributive circuits. The stronger theorem states that in a circuit which is distributive with respect to some initial state u if A and B are two equivalence classes of states such that $A \nabla B$, then any cycling vector $w(i)$ in $W[A]$ is also in $W[B]$.

A second result is also concerned with such a cycling vector $w(i)$. If A is an equivalence class which is minimal with respect to $w(i)$, then for each non-zero component $w_j(i)$ there is a C-signal (α, j) in the corresponding change chart corresponding to a join-irreducible element $\underline{a}$ such that $\underline{a} + w(i)$ is join irreducible and corresponds to $[\alpha + w_j(i), j]$.

This latter result indicates that the set of such changes $(\mathcal{A}, j)$ represent a better way of characterizing cyclic behavior of distributive circuits than the equivalence sets which were used with semi-modular circuits.

PART III

MATHEMATICAL METHODS

1. Determination of Interval Size in Numerical Integration of Differential Equations (Supported in part by the National Science Foundation under Grant G2794.)

A method is being sought for automatically determining the interval to be used for numerically integrating a system of ordinary differential equations by the Runge-Kutta method. The requirement is that the solution should have a specified accuracy, and from this specification, the interval size is to be adjusted automatically so that it is never smaller than necessary. Professor A. T. Nordsieck of the Physics Department is investigating a method for achieving this result different from that described below.

If the quantities $\bar{y}_i$ are the values given by the Runge-Kutta method for the solution of the differential equation

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

at the points $x_i = x_0 + ih$ where i is an integer,

then $y(x_i) = \bar{y}_i + h^5 T_i$ where T_i is the truncation error due to the approximate integration.

$$\text{We define } \bar{z}_{i+1}^h = \bar{y}_{i-1} + \frac{h}{3} [f(x_{i-1}, \bar{y}_{i-1}) + 4f(x_i, \bar{y}_i) + f(x_{i+1}, \bar{y}_{i+1})]$$

$$\text{and } \bar{z}_{i+1}^{2h} = \bar{y}_{i-3} + \frac{2h}{3} [f(x_{i-3}, \bar{y}_{i-3}) + 4f(x_{i-1}, \bar{y}_{i-1}) + f(x_{i+1}, \bar{y}_{i+1})]$$

If the $\bar{y}$'s appearing on the right-hand side were replaced by $\bar{z}$'s, we would have the equations defining the Simpson's rule approximation for the solution of the

differential equation and it would be true that

$$\bar{z}_i^h = y(x_i) - \frac{h^5}{90} y^{(5)}(\bar{v})(\xi) \quad x_{i-1} < \xi < x_{i+1}$$

$$\bar{z}_i^{2h} = y(x_i) - \frac{32h^5}{90} y^{(5)}(\bar{v})(\eta) \quad x_{i-3} < \eta < x_{i+1}$$

These equations hold only approximately in view of the definitions of the $\bar{z}_i^h$ and $\bar{z}_i^{2h}$. Nevertheless, it may be shown that a difference equation for the quantities $E_i = \bar{y}_i - y(x_i)$ may be obtained which involves the numbers $A_i = \frac{1}{31}[32(\bar{z}_i^h - \bar{y}_i) - (\bar{z}_i^{2h} - \bar{y}_i)]$. This difference equation is being studied with the following question in mind. How must the A_i 's and h be restricted so that E_n , the total error after n steps of Runge-Kutta integration is less than a prescribed amount?

2. Monte Carlo Method for Studying Crystals

A program, known as Monte Crysto, to compute the ordering statistics for a binary alloy with face-centered cubic structure and composition A_3B was written last summer for an IBM 704 computing machine. This work is an extension of work done earlier on the ILLIAC where the ordering statistics of a two-dimensional Ising lattice were computed by a Monte Carlo scheme. Results of this early work were reported last spring at the Washington meeting of the American Physical Society and also at the meeting of the Association for Computing Machinery in Houston, Texas. The computational method employed in this work follows very closely that of Metropolis and others in the equation of state calculations for a gas [N. Metropolis, A. Rosenbluth, M. Rosenbluth, A. Teller,

E. Teller, J. Chem. Phys. 21, 1087 (1953)]. Briefly, the Monte Carlo game is arranged to generate a set of configurations which will in the limit, as more and more configurations are generated, produce an ensemble distributed according to Boltzmann statistics [i.e., the probability $p(E_i)$ of generating a configuration, i , with energy E_i at temperature T is proportional to $e^{-E_i/kT}$]. Once the ensemble is generated, the desired physical properties may be obtained by averaging over the members of the ensemble. The Monte Crysto program permits as input parameters: (a) the dimensions of the lattice--maximum is 15 unit cells (4 atoms per cell) on a side; (b) $\frac{V}{kT}$, the ratio of next-neighbor interaction energy to temperature; (c) λ , the ratio of second-neighbor interaction energy to next-neighbor interaction energy. Monte Crysto will compute averages of: (a) the long-range order; (b) The next-neighbor order parameter; (c) the second-neighbor order parameter; (d) standard deviations of these three quantities. Convergence to the Boltzmann distribution is assumed to occur when results from a lattice with an initial configuration of perfect order "agree" with those from a lattice with an initially random configuration. Monte Crysto calculations have continued this semester by remote control on the 704's located at Argonne and MURA.

Recent calculations with the Monte Crysto program have produced good results for the order parameters at temperatures above the order-disorder transition temperature (the Curie temperature, above which long-range order vanishes). However, at lower temperatures convergence of the Monte Carlo process has not been achieved. The reason for this appears to be due to the inability of the lattice, initially started with a random configuration, to establish a consistent pattern of order-- the tendency being to establish only

small regions of local order but almost no long-range order. Alternate schemes for accelerating the convergence by partial ordering were tried but seemed unsuccessful. This consisted of establishing a small, perfectly ordered, region in the lattice with the initially random configuration to serve as a nucleus for the growth of a pattern of order. Different sizes for the ordered region were tried without success.

3. Logical Programming (Supported in part by the Office of Naval Research under Contract N6ori-07130)

A study in programming has been undertaken in which a program will be written for testing equivalence of a pair of given programs. Thus, program A will be used to determine whether given programs B and C perform the same transformation upon given data. It is hoped that program A may then be used to perform transformations upon a program A¹ which is identical to A. The former use of program A may be regarded as equivalent to the execution of mathematical proofs concerning the system described by B and C, and the latter use as equivalent to the execution of metamathematical proofs which may affect the handling of systems B and C.

In order to carry out this study, it is helpful to use a system of machine instructions which admits a simple description. The tentative system chosen consists of two four-address instructions: one for sensing individual binary digits in the memory, and one for altering the memory contents. Program A, referred to above, tests equivalence by breaking down any program into a canonical form which is unique for a given transformation upon a set of data. Such canonical forms are then compared directly.

PART IV
GENERAL RESEARCH

Satellite Data Reduction

A final program to analyze the satellite interferometer data was prepared and placed in production. The method of machine minimization developed by Dr. D. B. Gillies was incorporated in the program. This was concluded to be close to optimum within the limitations imposed by running time, memory space and register length. It is contemplated that this investigation should lead to a library program and possibly to a survey-type paper.

PART V

ILLIAC USE AND OPERATION - GENERAL LABORATORY INFORMATION

Machine Use

During December specifications were presented for 6 new problems.

This list does not indicate how the Illiac was used because large amounts of machine time may have been consumed by problems with numbers less than 1084.

1084 Psychology. Attenuation in Factor Analysis. This is a preliminary investigation into the effects of attenuated tests on the obtained factor loadings.

1085 V. A. Research Hospital (Psychiatry). The Relationship Between Psychiatric Diagnostic Information and Therapist Conceptualization of the Patient. The aim of the study is to evaluate the relative utility of the various types of psychiatric diagnostic information for the therapists conceptualization of the psychiatric patient. The study will attempt to discover how, in what ways, and to what extent standard psychiatric and psychological information is utilized by therapists in altering their original views of patients. A Q sort instrument was administered to 18 psychiatrists three times under varying amounts and kinds of information. Three separate correlational matrices (18 x 18) are needed, one for each experimental condition. Three independent factor analyses and rotational solutions will then be carried out--the aim being in each case to determine the dimensions of therapists conceptualization under each condition.

1086 Physics. Superconducting Phase Transition. In order to calculate an energy gap in the theory of superconductivity from the phase diagram, one must know the relation between the critical field H_c and temperature T very accurately. Measurements have been completed of these values which are accurate enough to differentiate and obtain an energy gap. It is proposed to fit these data to the expansion

$$H_c = H_o + \sum_{n=2}^n a_n T^n$$

by a least squares method.

1087 Computer. Flow-Gating Flipflop Analysis. This program analyzes the output voltages and currents to establish the holding conditions, saturation conditions, etc., for the "flow-gating" type flipflop given nominal values of the resistors, power supply voltages, transistor parameters, diode parameters and their tolerance limits.

1088 Electrical Engineering. Crystal Lattice Filter Design. For a given set of design requirements, such as the cut-off frequencies of the pass band, the frequencies of infinite attenuation, and the characteristic impedance of the filter, the parameters of the filter are computed. The equations for this wide band, crystal lattice filter were developed by Dr. W. P. Mason, of Bell Telephone Laboratories, and require repeated calculations to obtain a suitable design.

1089 Electrical Engineering. High Pass Filter Design. The problem involves calculation of transfer loss of a filter network with variation in cut-off and resonant frequencies as well as coil Q 's and number of sections.

Table I shows the distribution of machine time for the month of
December.

Table I

	Hrs:Min
Regular Maintenance	36:00
Unscheduled Maintenance	2:15
Drum Engineering	40:34
R.A.R.	4:47
Leapfrog	33:37
Wasted	:03

Use by Departments

Computer	74:42
Physics	21:50
Control Systems Lab.	75:44
Struct. Res.	57:09
Struct. Res. (AF 24994)	9:45
Psychology	21:11
Psychology (PH M1733)	4:29
College of Medicine	7:12
Electrical Engineering	11:18
Chemistry	21:43
Agriculture	11:55
Theor. and Appl. Mech. (ORD 593 IC)	:06
Theor. and Appl. Mech. (CONVAIR)	1:20
State Water Survey	7:39
Inst. of Communications Research	6:45
U.S. Navy	1:04
Veteran's Administration (Psychiatry)	:54
Classes	21:26
Demonstrations	:57
Miscellaneous	16:08
	490:33

Error Frequency and Analysis

The machine is normally used for "engineering" and maintenance between 7:00 A.M. and 11:00 A.M., and for a check of its performance between 5:30 and 6:00 P.M. of each weekday. Since the periods between 7:00 and 11:00 A.M., together with certain irregular periods like Saturdays and Sundays, are devoted to a heterogeneous group of functions, it is more instructive from an error standpoint to look at the periods between 11:00 A.M. and 7:00 A.M. of the next day in order to make an observation of the error frequency in the machine. This is the actual period when the machine is designated for use. With this in mind, a summary table has been prepared using the period between 11:00 A.M. and 7:00 A.M. of the next day. This table lists the running time when the machine was operating, the amount of time devoted to repairs because of breakdowns, and a number of failures while the machine was listed as running. During the 5:30-6:30 period (when the machine is checked) if no errors are found, the time is given to the "running" column. Each failure was considered to have terminated a running period and was followed by a repair period in preparing this table. Since the leapfrog code is our most significant machine test, the length of time which it has been used on the machine is listed separately together with the number of errors associated with that particular code. This information for the month is presented in Table II.

It is important to notice that any interruption of machine time that was not planned for is considered a failure in this table. In rare cases where the failure is not known until a later time, it is possible that no repair period is associated with the failure. This over-all system has been adopted because it makes it possible for a machine user to estimate directly the

probability that the machine will be "running" at any instant of time and the probability of a failure during any given interval of running time.

Table III presents a summary of errors or interruptions for December.

TABLE III

Punch Errors	8
Arithmetic Error	1
Drum Errors	4
Unknown Errors	<u>3</u>
	16

T A B L E II

DATE	RUNNING OK TIME	REPAIR TIME	INTERRUP- TIONS OR FAILURES STOPPING OK TIME	TYPES OF INTERRUPTIONS OR FAILURES CAUSING REPAIR TIME	WASTED	LEAPFROG	FAILURES STOPPING LEAPFROG
12/2/57	19:58	:02	2	(1) Punch No. 4 error extra 2 hole (2) Punch No. 4 error extra 2 hole	:00	:40	0
12/3/57	19:40	:20	2	(1) Punch No. 4 not punching 1 hole (2) Drum failure	:00	:39	0
12/4/57	19:58	:02	1	(1) Punch No. 3 error	:00	:42	0
12/5/57	20:00	:00	0		:00	:41	0
12/6/57	19:34	:26	2	(1) Unknown (2) Unknown	:00	:39	0
12/9/57	20:00	:00	0		:00	:42	0
12/10/57	20:00	:00	0		:00	:51	0
12/11/57	20:00	:00	0		:00	:44	0
12/12/57	19:06	:45	1	(1) Arithmetic error	:00	1:20	0
12/13/57	19:43	:17	1	(1) Drum failure	:00	:40	0
12/16/57	20:00	:00	0		:00	1:16	0
12/17/57	19:59	:01	1	(1) Punch No. 1 failed to punch "8" hole	:00	:39	0
12/18/57	19:59	:01	1	(1) Punch No. 1 failed to punch "4" hole	:00	1:01	0
12/19/57	19:25	:35	2	(1) Drum failure (2) Punch No. 3 jammed	:03	2:08	0
12/20/57	20:00	:00	0		:00	:51	0
12/23/57*	16:00	:01	1	(1) Possibly a line failure at 4:01 A.M. caused trouble	:00	:40	0
12/26/57	20:00	:00	0		:00	:40	0
12/27/57	20:00	:00	0		:00	1:08	0
12/30/57	19:11	:12	1	(1) Drum Failure	:00	1:57	0
12/31/57**	7:36	:01	1	(1) Punch No. 4 error	:00	:00	0
TOTALS	380:09	3:26	16		:03	17:58	0

* Computer shut down at 4:01 A.M.

** Computer Shut down at 7:37 P.M.

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Reports and Seminars

Seminars

"The Word Arrangement Core Memory Proposed for the New Computer", by K. C. Smith, December 3, 1957.

"Proposed Core Memory II", by Christopher Pottle, December 10, 1957.

"Cryotron Circuits", by Gene Leichner, December 17, 1957.

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