UNIVERSITY OF ILLINOIS
GRADUATE COLLEGE
DIGITAL COMPUTER LABORATORY

TECHNICAL PROGRESS REPORT

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

- Part I: Study Program on High Speed Computer
- Part II: Mathematical Research and Programming
- Part III: Illiac Use and Operation -
General Laboratory Information .

(Most vacations in the Digital Computer
Laboratory are being taken during the
months of July and August.)

July, 1956

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PART I

STUDY PROGRAM ON HIGH SPEED COMPUTER

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 N6ori-07124, both from the Office of Naval Research.

The University of Toronto is participating in this work through staff members of its Computing Centre and Department of Physics.

Speed-Independent Circuits

In the last few months, work has been carried out in the Laboratory on the theory of speed-independence or asynchronous logic. This work has resulted in Laboratory Reports No. 66, "Theory of Asynchronous Circuits" by David E. Muller, and No. 71, "Speed-Independent Counting Circuits" by James C. Nelson, and Illiac Library Routine Q-3, "Complete Circuit Analyzer" by W. S. Bartky.

These reports indicated that some truly speed-independent circuits which were fairly simple were possible, provided that one or more special circuit elements could be devised. One of these circuit elements was called the C-element in Report No. 66. A physical electronic circuit with the properties of the complement of the C-element ($\bar{C}$ -element) has been devised. This circuit is shown in Figure 1 and uses a single input-single output kind of flipflop which has been used here before on the transistor test computer with an adapter circuit. The element is shown in Figure 1. The $\bar{C}$ -element is one such that if both inputs are "1" the output is "0"; if both inputs are "0" the output is "1". If the inputs differ, then the output agrees with the output of the previous state of the element.

The $\bar{C}$ -element has been experimentally used in a three-phase speed-independent logical oscillator. The logical diagram for this circuit was first shown in Report No. 71 and has now been built and made to work. The circuit provides a logical oscillator which is truly speed-independent. It is possible to slow up the output of any point of the circuit for example by a capacitor, without interfering with the operation of the oscillator.

FIGURE 1
Circuit of a $\bar{C}$ -Element

Figure 2

Logical Layout of a Three-Phase Speed-Independent Logical Oscillator

Transistor Test Computer

The transistor test computer was put into operation during the month. There was one error-free run of 55 hours which was terminated by a flipflop failure when one transistor had an α -drop to about .85. Some additional changes will be made, which, it is hoped, will provide very long error-free runs. As reported earlier, the transistor test computer is a computer which uses asynchronous circuits constructed of one megacycle transistors.

PART II

MATHEMATICAL RESEARCH AND PROGRAMMING

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

Logical Design

We may conceive of a modification of the Illiac by adding additional S-registers in the arithmetic unit. An S-register may be connected when desirable to the adder in place of R^3 and may be connected to the accumulator in place of the memory.

A partial order code for a proposed automatic computer (PAC) which employs the use of additional S registers was designed and applied to several Illiac programs. The logic and current features of Illiac were maintained as far as possible in PAC, the major changes initiated being:

- (1) addition of S registers
- (2) circulation of the Q register
- (3) addition of 3 B-boxes.

Three models of PAC are being considered: PAC-1, PAC-2 and PAC-3, the digits indicating the number of S registers assigned. A program was taken from the Illiac library, programmed for PAC-1-2-3 and these four programs were then compared on the basis of words, order accesses, instruction accesses and temporary storage. This was repeated for several programs, and it is planned to do this for a total of 8 or 10 programs. The qualities looked for in the programs selected are length, which must be reasonably moderate, frequency of use, and the loops and operations employed, which should be those most commonly used in programming. In some cases parts of programs, rather than entire programs were used. Although this does not offer a fair basis for comparison of computers, it is valuable in that those parts, which might otherwise be ignored because they are imbedded in lengthy programs, suggest new instructions which might be desirable in PAC.

Some results of this work follow. The columns are headed: words (W), order accesses (OA), instruction accesses (IA) and temporary storage (TS). Here an order access is defined as the time required to transfer a word from the store to the arithmetic unit or vice-versa while an instruction access is defined as the time required to transfer a word from the store to the order register.

1. Square Root: R-1 (Newton's Method)

	W	OA	IA	TS
Illiac	9	$4 + 6n$	$4 + 5n$	3
PAC-1	9	$3 + 2n$	$4 + 5n$	2
PAC-2	8	$1 + n$	$3 + 5n$	1
PAC-3	8	1	$3 + 5n$	0

(1) n = number of iterations.

2. Scalar Multiplication with Overflow Check (from M-6)

	W	OA	IA	TS
Illiac	$11-1/2$	$10k$	$9k$	2
PAC-1	9	$2k$	$(5 \text{ to } 7)k$	0
PAC-2 } PAC-3 }	not needed			

(1) k is defined by $c_{ij} = \sum_k a_{ik} b_{kj}$

(2) This is the $11-1/2$ word loop which actually performs the scalar multiplication in M-6.

3. Exponential: S-2 (Polynomial Evaluation)

	W	OA	IA	TS
Illiac	17 programs 16 constants	$19 + (5) \cdot 8$	$15 + (5) \cdot 5$	2
PAC-1	12 programs 15 constants	$10 + (5) \cdot 1$	$10 + (5) \cdot 2$	1
PAC-2	12 programs 14 constants	$8 + (4) \cdot 1$	$10 + (4) \cdot 2$	1
PAC-3	12 programs 14 constants	$6 + (4) \cdot 1$	$10 + (4) \cdot 2$	0

(1) The number in parentheses under OA and IA is the number of passes through the polynomial loop used to evaluate an exponential.

(2) The Illiac program uses the old method of setting the link (i.e. does not use K-5) which necessitates a waste order. Therefore the number of program words should really be 16 instead of 17.

The problem of code-checking becomes much greater when B-registers are used because less information is stored. A study is being made of this problem to help decide what instructions might be useful in checking and what hardware might be desirable to make code-checking easier.

Program Library

The following routine, prepared by Judith Blankfield for the Department of Electrical Engineering, was added to the Auxiliary Library.

V-18 (219)

Ordinary Bessel Functions. 257 Words. This is a routine for calculating Bessel functions J_n and Y_n of the first and second kinds. An input parameter is used to specify which kind or kinds shall be calculated and whether the order is to be first or second or a combination. For example, one may compute J_0 alone or J_0 and J_1 or J_0 and Y_0 , etc. The accuracy is about 4 decimal places and the time at most 100 milliseconds.

PART III
ILLIAC USE AND OPERATION -
GENERAL LABORATORY INFORMATION

Machine Use

During July a new procedure was introduced for the running of small standard problems. Problem specifications and code checks are no longer required for running any of the problems listed below provided that

- (a) the time required is 15 minutes or less,
- (b) parameters and data are furnished on a single tape,
- (c) use is made of the operator's copy of the program.

A minimum of formality is thus required to solve short problems using the following programs:

- J-2 Roots of a Polynomial
- K-2 Product Moment Correlations
- K-8 Product Moments (Drum)
- K-9 Product Moments (Log Scale)
- K-12 Multiple Regression
- K-13 Analysis of Variance
- L-2 Simultaneous Equations
- M-12 Matrix Triangularization
- M-13 Equation Solver and Inversion
- M-18 Eigenvalues and Eigenvectors

During July specifications were presented for 28 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 828. Numbers followed by T are for theses.

828 MURA. Partial Differential Equation. The Illiac will be used for solution of the Dirichlet problem for a second-order elliptic partial differential equation in two variables by an iterative method. The problem will be solved for many different domains and boundary values.

829 Psychology. Factor Structure of Anxiety Responses. Three 90 by 90 correlation matrices will be calculated and analyzed by the centroid method of factor analysis. A simple structure will be sought by use of the oblimax method and plotting with the cathode ray tube output.

830 Illinois State Geological Survey. Mixed-Layer Effects in Rhombohedral Carbonates. The problem is concerned with the computation of predicted X-ray diffraction diagrams for crystals made up of two kinds of atomic layers present in varying proportions and with varying probabilities of alternating with each other. Intensity from a single layer is computed from an exponential expression and the result from a succession of layers is obtained from a Markov chain model.

831 College of Medicine. Attitudes Toward Neurotic Children. Standard factor analysis routines from the Illiac and Psychology Program Libraries will be used to study the types of children that develop psychosomatic illnesses.

832 Computer. Frequency Analysis of Instructions and References to Store. This will be a study of the relative frequency of occurrence of different instructions and the frequency of references to storage locations for programs in the Illiac Library.

833 Electrical Engineering. Pattern of an Antenna in Front of a Conducting Screen. The relation for the pattern will be evaluated for a wide range of values of the three parameters giving azimuth, elevation and wavelength.

834 T University of Michigan Psychology Department. Factorization of Psychological Variables. The Psychology program for estimation of communalities will be used to factor analyze a 75-variable correlation matrix. The purpose of the study is to identify the underlying dimensions of a number of tests among which are personality tests, social perception tests, vocational interest tests, economic interest tests, political interest tests, and humor preference tests.

835 Computer. Quotient of Two Polynomials. This program will evaluate the quotient $P(j\omega)/Q(j\omega)$ where P and Q are complex polynomials of degree 63 or less.

836 Civil Engineering. Simultaneous Equations. This is a check program, using the Illiac routine, for solving a set of 140 simultaneous linear algebraic equations.

837 T Economics. Molasses Demand Study. This is a statistical analysis of the demand for industrial molasses using the single equation least squares approach and the limited information system of equations approach.

838 Washington State College. Fruit Demand Study. Library Routine K-12 will be used to make a study of the demand of consumers for fruit as the season progresses. Data were taken on prices and quantities as well as quality and appearance for a number of fruits.

839 T Civil Engineering. Non-uniform Torsion of Bow Girders. Finite difference methods will be used to reduce the governing differential equations to sets of simultaneous linear algebraic equations which will be solved by one of the Illiac library programs.

840 Psychology. Analyses of Biological Correlations. This study is concerned with the applications of factor analysis to biology. A comparative study will be made with a series of correlation matrices ranging from size 10 by 10 to size 18 by 18 and dealing with characteristics of flies, aphids and bees.

841 University High School. Analysis of Mathematics Project Data. Standard library routines will be used to calculate product moments and to carry out some computations involving a covariance matrix. Data are scores on tests of various mathematical abilities collected from 500 high school students participating in the University of Illinois School Mathematics project.

842 T Physical Education. Relationship Between Body Structure and Weight Lifting Activities. The object of this study is to obtain prediction equations which will make it possible to predict performance from body measures. Twenty-seven body measurements and ten performance measures have been obtained on 241 subjects.

843 Electrical Engineering. Ladder Network Analysis. The problem is, given a ladder network, to calculate the impedance. The analysis is to be carried out in floating arithmetic and will consist of calculating the coefficients of two polynomials and then finding the roots of the polynomials.

844 T Physical Education. Study of the Primary Components of Cardiovascular Tests. The study is directed at determining the relationship between cardiovascular tests in young boys seven to fifteen years of age and of determining the primary factors involved in the relationship. The analysis will make use of library routines.

845 Chemistry. Data Fitting. An empirical equation is to be determined from data consisting of molar extinction coefficients of a solution in which several first-order chemical reactions are taking place.

846 T Electrical Engineering. Network Analysis. The problem is concerned with the determination of the poles and zeros of an equation which is given as a function of five parameters.

847 T Dairy Science. Effects of Weather on Daily Milk Production. Observations on daily milk and fat production were collected in a dairy herd at ten-day intervals during the summer months for the past five years. Also recorded were the maximum and minimum temperatures, relative humidity, and wind velocity for each of the sample days and for the three days preceding the sample day. The effect of each of the factors and of combinations of them will be studied.

848 University of Michigan Psychology Department. Study of Marital History Variables. This is a factor analysis problem in which data were obtained from a study of 300 engaged couples assessed on about 400 variables. The study began 20 years ago and the subsequent marital history has been followed, most of the original subjects being re-tested after 20 years of marriage.

849 T Psychology. Dimensionalization of Difficulty. Messick's technique is used to obtain scalar distances between pairs of words on data obtained when a list of 14 words was given to each of two groups of 40 subjects.

850 T Dairy Science. Seminal Characteristics of Dairy Cattle. Thirteen characteristics were observed twice weekly over a period of one year. Library Routine K-2 will be used to analyze the data.

851 T Agricultural Economics. Supply and Demand for Milk. Library Routine K-12 will be used to solve a 3-variable multiple correlation problem to show the influence of income and price upon the per capita milk consumption. A simple correlation of milk prices and milk production will also be carried out.

852 Economics. Optimal Partition of Discrete Points. The original economic problem is to divide a population into groups or categories such that members within the same group are homogeneous in the sense of having numerical measures nearly the same. The problem differs from analysis of variance and other classification problems in statistics in that the groups are not defined in advance but are defined as a result of solving the problem. The method of solution is to have the Illiac systematically identify, list and compute values for certain relevant partitions, reducing the number by application of several basic principles.

853 Physics. Processing of Superconduction Transition Data. Experimental data consist of a sequence of 31 numbers which must be summed and normalized and then plotted. The Illiac will be used to carry out the computations with the results being plotted and photographed on the cathode ray tube output.

854 T Civil Engineering. Natural Frequency with Rotational Restraint. The problem is an extension of structural frequency analysis which generally has a determinantal equation of n^{th} order corresponding to n degrees of freedom. Inclusion of rotational restraint at the base requires a system having $n+1$ degrees of freedom.

855 T Electrical Engineering. Calculation of Network Function. From the topological relations of a network it is possible to write an expression for the driving point function, to pick all possible combinations of $v-1$ elements (where v is the number of vertices in the network), and determine whether or not they represent a tree of the network.

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

TABLE I

Regular Maintenance and Illiac Engineering	38:11
Unscheduled Maintenance	8:56
Drum Engineering	30:06
R.A.R.	6:15
Leapfrog	40:32
Wasted	:06

Use by Departments

Computer Group	17:50
Physics	37:00
Control Systems Lab.	87:27
Structural Research	3:08
Struct. Res. (AF 24994)	13:46
T.A.M. (Task 53)	:25
Psychology	22:21
Psychology (MD 620)	4:32
Electrical Engineering	12:39
Elec. Eng. (AF 3220)	:05
Elec. Eng. (Nobs 1934(03))	1:40
Chemistry	28:07
Agriculture	23:16
MURA	114:14
Ill. Dept. of Pub. Welfare (Coan)	10:27
Ill. Dept. of Pub. Welfare (Hurley)	:39
Washington State College	6:17
University of Michigan	4:50
Demonstrations	1:06
Miscellaneous	31:17
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	545:12

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 the number of failures while the machine was listed as running. During the 5:30-6:00 P.M. 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 July.

TABLE III

Reader Errors	7	White Switch Error	1
Punch Errors	7	Scope Output Errors	2
Drum Errors	3	Control Error	1
Power Supply	1	Power Line Failure	1
		Memory Error	1
TOTAL INTERRUPTIONS AND ERRORS			24

TABLE II

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DATE	RUNNING OK TIME	REPAIR TIME	INTERRUPTIONS OR FAILURES STOPPING OK TIME	TYPES OF INTERRUPTIONS OR FAILURES CAUSING REPAIR TIME	WASTED	LEAPFROG	FAILURES STOPPING LEAPFROG
7/2/56	19:59	:01	1	(1) Possibly reader "B" error	:00	:47	0
7/3/56	19:58	:02	2	(1) Reader "B", failed to read a "1" (2) Reader "B" error	:00	:43	0
7/5/56	20:00	:00	0		:00	:54	0
7/6/56	19:59	:01	1	(1) Drum error	:00	1:01	0
7/9/56	19:37	:23	1	(1) Bad photo cell in reader "B"	:02	1:13	0
7/10/56	19:56	:02	2	(1) White switch trouble (2) Drum failed	:02	1:41	0
7/11/56	19:26	:34	2	(1) Operator jammed punch (2) Leapfrog failed, punch "3" error	:00	1:47	1
7/12/56	19:58	:00	0		:02	:28	0
7/13/56	20:00	:00	0		:00	:50	0
7/16/56	19:57	:01	1	(1) Punch "5" error	:02	:41	0
7/17/56	19:13	:43	2	(1) Pos. C.R.T. output pulser fil. out (2) Control error. A 2C51 tube in even address gate chassis caused failure. This was not found, partly because of its intermittent nature, until July 24.	:04	:59	0
7/18/56	19:48	:10	0		:02	2:00	0
7/19/56	19:22	:38	2	(1) Punch "5" punched extra 4 holes (2) " " " " " 4 "	:00	:56	1
7/20/56	20:00	:00	0		:00	:40	0
7/23/56	18:12	1:48	0		:00	1:04	0
7/24/56	19:37	:23	2	(1) Film jammed in cassette (2) 38 should have been 34 - C.R.T. Pos. 2 ⁻²⁴	:00	4:41	0
7/25/56	19:59	:01	1	(1) Drum failure	:00	:47	0
7/26/56	19:49	:11	2	(1) Drum power supply failed. Control rectifier filament burned out (2) Reader "B" coupling came loose	:00	:50	0

TABLE II, Continued

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DATE	RUNNING OK TIME	REPAIR TIME	INTERRUPTIONS OR FAILURES STOPPING OK TIME	TYPES OF INTERRUPTIONS OR FAILURES CAUSING REPAIR TIME	WASTED	LEAPFROG	FAILURES STOPPING LEAPFROG
7/27/56	19:49	:11	3	(1) Power line failure (2) Reader "B" light out (3) Reader "K" error	:06	1:29	0
7/30/56	19:59	:01	1	(1) "A" gate on punch "5" burned out	:00	1:00	0
7/31/56	19:59	:01	1	(1) Operator error, jammed punch "5"	:00	:49	0
				Note: The control error listed on July 17 as error number 2 was not diagnosed and repaired until July 24. There were 9 more interruptions of work due to this one tube failure before the trouble was diagnosed. These nine interruptions are not listed as separate errors in this table.			
TOTALS	414:37	5:11	24		:12	22:20	2

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Reports and Seminars

Laboratory Report No. 71, "Speed-Independent Counting Circuits,"
by James C. Nelson, July 1, 1956.

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