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.)

August, 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.

Comments on Relative Memory Sizes

One estimate of the minimum time necessary for carrying out most computations is given by the product

$$m F M$$

where

m = number of multiplications in the problem

M = time for one multiplication

F = a factor varying between 2.5 and 7.5 for most problems.

For some problems the total number of multiplications satisfies the inequalities:

$$10^7 \leq m \leq 10^{11}$$

Such problems may require the use of 50,000 to 100,000 words of data. However, only small amounts of data are needed at any one stage of the computation. The question arises as to whether all these words need to be in the memory with access time a or whether some may be stored in "back-up" memories. We shall try to evaluate the time lost in using a back-up memory.

Suppose our problem is such that if N words of data are in the highest speed memory we may then calculate $N-k$ new words which replace the same number of words previously held. Thus in one sweep through the memory $N-k$ words are calculated and these may be stored in positions previously occupied by other words. If $N-k$ is as large as required by the problem, this process is repeated many times and the total time for the calculation is

$$(N-k) \times n \times F \times M \times T = \tau_1 T$$

where

n = the number of multiplications for each of the $(N-k)$ words
 T = the number of times the memory is swept through.

If however $N-k$ is not as large as required we must add to this the time necessary to load and unload the memory. Let us say that the time necessary to unload the high-speed memory is made up of two parts: (a) a time to get access to another memory, α and (b) a time to read $N-k$ words into this memory, $(N-k)\beta$.

Thus unloading time is

$$\alpha + (N-k)\beta.$$

Assuming that reading and writing in the latter memory take equal times and that we have to read N words from it in order to properly load the high-speed memory we have as our loading time

$$\alpha + N\beta.$$

Hence the total loading and unloading time is

$$2(\alpha + (N-k)\beta) + k\beta.$$

The ratio of this time to the computation time per load in the memory is

$$R = \frac{2(\alpha + (N-k)\beta) + k\beta}{(N-k)n F M}$$

$$R = \frac{2}{n F M} \left(\frac{\alpha + \frac{\beta k}{2}}{N - k} + \beta \right)$$

The total computation time is now

$$(1 + R) \tau_1 T.$$

Hence the ratio R is a measure of the cost of using a pair of memories instead of a single memory. We may write

$$\alpha/M = \alpha_1$$

$$\beta/M = \beta_1$$

Then

$$R = \frac{2}{n \cdot F} \left(\frac{\alpha_1 + \frac{\beta_1^k}{2}}{N - k} + \beta_1 \right) = \frac{2}{n \cdot F} \left(\beta_1 + \frac{\alpha_1/k + \beta_1/2}{N/k - 1} \right)$$

In this formula n , N , and k depend on the problem being solved and α_1 and β_1 depend on the equipment being used. For a given problem we may estimate the size of high-speed memory N so that R is the order of 10%. The important thing to note is that the rate of change of R with N is a slowly varying function beyond the value of 10%.

Goldstine, in a private communication, has shown that a problem in hydrodynamics in which time and two spatial variables enter where 50,000 words of storage are needed an inner memory with room for 1750 words of data involves less than 10% of computing time for consulting the secondary memory, when

$$\alpha_1 = 1700 \text{ or less}$$

$$\beta_1 = .8 \text{ or less}$$

$$k = 500$$

$$n = 10$$

$$F = 5.$$

However Goldstine did not consider the complications ensuing when slip-streams occur in the computations.

Suppose now we examine the question as to whether a random access memory of 30,000 word capacity is needed.

In two and three dimensional hydrodynamics problems in which the quantities are time dependent, the amount of data which has to be processed in one time step will exceed this capacity by a factor which is at least between one and two and may be five. Therefore a back-up memory will be needed in any case. We are thus dealing with the factor R and the question is what is the value of R for $N \approx 30,000$ and say $N \approx 2,000$.

Suppose we have a drum in which

$$\alpha = 17000 \text{ } \mu\text{sec} = \text{access time to a word.}$$

$$\beta = 8 \text{ } \mu\text{sec} = \text{read time for a word.}$$

If then our multiplication time is assumed to be 5 μsec

$$\alpha_1 = 3400$$

$$\beta_1 = 1.6$$

$$R = \frac{2}{nF} \left(1.6 + \frac{3400/k + .8}{N/k - 1} \right)$$

For $k = 500$

$$R = \frac{2}{nF} \left(1.6 + \frac{7.6}{N/500 - 1} \right)$$

$$R_{30000} = \frac{2}{nF} (1.7) = .068$$

$$R_{2000} = \frac{2}{nF} (3.6) = .144$$

when $2/nF = .04$, ($F = 5$, $n = 10$).

Hence the ratio of the times to do the same problem with a memory of 32,768 words and one with 4768 words (2768 words of code being used) is

$$\frac{1.14}{1.07} = 1.07$$

A seven percent increase in time is gained by an almost eight-fold increase in size of memory.

For $k = 1000$ we have

$$R = \frac{2}{nF} \left(1.6 + \frac{4.2}{N/1000 - 1} \right)$$

$$R_{30000} = \frac{2}{nF} \left(1.6 + \frac{4.2}{3} \right) = \frac{2}{nF} (1.74) = .07$$

$$R_{2000} = \frac{2}{nF} (1.6 + \frac{4.2}{1}) = \frac{2}{nF} (5.8) = .23$$

Here then we have a similar phenomenon. The ratio in times being

$$\frac{1.23}{1.07} = 1.15,$$

a fifteen percent loss in time being paid for by an almost eight-fold increase in size of memory. The doubling of the factor k, the amount of dead-weight data being carried in the transfers is responsible for the change in loss of time.

PART II

MATHEMATICAL RESEARCH AND PROGRAMMING

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

The basic method of handling time in speed independent circuit theory has been changed so as to simplify all the initial development. This new treatment has removed all the difficulties mentioned in previous reports, and the complete theory is now in condition to be written up. A verbal description of the new theory was given in August at the Los Angeles meeting of the Association for Computing Machinery.

The theory in its abstract form deals with n dimensional vectors $a = (a(1), a(2), \dots, a(n))$ whose components are zeros and ones (these vectors are called states) and with a set of n Boolean functions $z(i)' = f_i(z(1), z(2), \dots, z(2))$ (which are called the circuit). We discuss "allowed" sequences of states $a_1, a_2, \dots$ which satisfy two conditions:

1. For any consecutive pair of states a_j, a_{j+1} in an allowed sequence we have $a_j \neq a_{j+1}$ and $a_j' \oplus a_j \supset a_{j+1}' \oplus a_{j+1}$.
2. There is no pair of integers i and j such that $a_k(i)' \neq a_k(i) = a_j(i)$ for all $k \geq j$.

Allowed sequences may be finite or infinite and are intended to represent the sequences of states through which an asynchronous circuit may pass when started in state a_1 . The first important result is that at least one allowed sequence exists having any initial state a_1 . Speed independence is now most conveniently defined with reference to allowed sequences as follows.

A circuit is speed independent with respect to an initial state a_1 if there exists a maximal set of states M (as defined in previous reports) such that at least one state in M is present in every allowed sequence starting with a_1 .

This definition can be shown to be equivalent to the previous definition, and using the new theory we can show more easily that semi-modular circuits are speed independent. No previous results are invalidated by the new theory.

PART III

ILLIAC USE AND OPERATION - GENERAL LABORATORY INFORMATION

Machine Use

There are several combinations of function digits used for stop instructions on the Illiac, the combination FF being used for stops caused by programmed checks. Addresses have been assigned to all FF orders in programs, and a list is maintained so that the operator can readily determine the cause of a stop. For example, if the computer is stopped by FF 015, the data tape for Library Routine K-8 has the wrong number of variables. A stop by FF 013 signifies a drum transfer failure in Library Routine K-12. The list now has about 25 addresses.

During August specifications were presented for 12 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 856. Numbers followed by T are for theses.

856T Physics. Release of Stored Energy in Cold-Worked Metal Crystals. This problem uses the same program as that for problem number 750. In the present series of experiments the samples used are single crystals of pure copper, rather than polycrystals which were used previously.

857 Structural Research. Natural Frequencies of a Beam Simply Supported at Both Ends, with a Spring Support at a Distance. This is a variation of problem number 740 in which Library Routine H-1 for inverse interpolation is used to search for the natural frequency of a simply supported beam with a spring support at a distance from one end.

858 Physics. Probability of Counting Gamma Rays from the Decay of Pi^0 Mesons. This problem is for the purpose of determining the efficiency with which a counter will detect mesons by counting its decay gamma rays. The principal part of the computation is concerned with the evaluation of a double integral, the results being printed in tabulated form.

859T Physics. Release of Stored Energy in Cold-Worked Cu Crystals. This is an entirely new program designed to do a more complete and efficient job of the work formerly done with problem 856T.

860 Chemistry. Random Walk of Polymers. The work on this problem is in connection with the determination of the equilibrium statistics of dilute polymer solutions. Monte Carlo methods are used to study the special distribution of such polymers.

861 Chemistry. Calculation of Vibrational Frequency of Three Centered Body. This problem is concerned with the development of a mathematical model to describe certain experimental results.

862 Michigan State University. Cam Dynamics. The problem to be solved here is, given the acceleration characteristics of a cam, to calculate a table of values specified on the cam contour. A table will also be calculated to specify the residual dynamic stresses in the follower system after one cam stroke. The basic computations consist of the evaluation of a definite integral by means of Simpson's rule.

863T Theoretical and Applied Mechanics. Buckling of Shell under Internal Pressure and Axial Compression. The problem is to determine the post-buckling, equilibrium configurations of a long cylindrical shell subjected to internal pressure and axial compression. The equilibrium configurations are obtained by minimizing the potential energy of the shell, the potential energy being described by a fourth degree polynomial in three displacement parameters and four other parameters involving thickness and wave length.

864 Structural Research. Stiffness of Carry-Over Factors for Orthotropic Plates. This investigation is concerned with the analysis of orthotropic plates simply supported along two opposite edges and continuous in other directions over a series of rigid or flexible supports transverse to the simply supported edges. The present program evaluates expressions for stiffness, carry-over factors and the product of these quantities, for values of the relative stiffness parameter less than one.

865T Chemical Engineering. Calculation of Average Interaction Energies. The evaluation of multiple integrals for the calculation of average interaction energies will be done either by Simpson's rule or by a Monte Carlo method.

866 Mechanical Engineering. Axially Symmetric Supersonic Flow. Various types of initial and boundary conditions will be studied in a solution of systems of self-iterating difference equations derived from a quasi-linear second order partial differential equation of hyperbolic type.

867 Structural Research. Analyses of Rectangular Orthotropic Plates. Ritz's approximate method is used to study the analysis of rectangular orthotropic plates fixed along the boundaries and subjected to a load uniform in one direction and linearly varying in the other. The program computes the coefficients in the systems of equations and uses a modified version of Library Routine L-2 for the solution.

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

TABLE I

Regular Maintenance and Illiac Engineering	40:49
Unscheduled Maintenance	5:11
Drum Engineering	32:32
R.A.R.	5:41
Leapfrog	45:36
Wasted	:05

TABLE I (Cont.)

Use by Departments

Computer Group	15:11
Physics	33:38
Control Systems Laboratory	32:52
Structural Research	4:15
Struct. Res. (AF 24994)	5:46
Electrical Engineering	9:02
Elec. Eng. (Nobs 64723)	1:29
Elec. Eng. (Nobsr 1834(02))	:27
Psychology	10:04
Psychology (MD 620)	3:34
Chemistry	13:17
Agriculture	24:30
MURA	274:12
Ill. Dept. of Public Welfare (Coan)	4:54
Ill. Dept. of Public Welfare (Hurley)	1:33
Michigan State University	4:20
Demonstrations	:00
Miscellaneous	36:45
	<hr/> 605:43

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 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 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 August.

TABLE III

Reader Errors	2
Punch Errors	2
Memory Errors	1
Drum Errors	6
Unknown	1
Film jammed in camera	<u>1</u>
TOTAL INTERRUPTIONS AND ERRORS	13

Personnel

The personnel associated with the group and hence the contributors to this report are:

TABLE II

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
8/1/56	19:59	:01	1	(1) 5th hole failed to punch on 5	00	1:15	0
8/2/56	19:59	:01	1	(1) Drum out of synch.	00	:41	0
8/3/56	20:00	:00	0		00	:43	0
8/6/56	19:31	:29	1	(1) Memory pos 2 ²⁴	00	1:29	1
8/7/56	20:00	:00	0		00	1:06	0
8/8/56	19:57	:01	1	(1) Unknown error	02	1:14	0
8/9/56	19:44	:14	2	(1) Drum Failure (2) Drum Failure	02	:48	0
8/10/56	19:59	:01	1	(1) Reader "B" error	00	1:10	0
8/13/56	19:49	:11	2	(1) Drum Failed (2) Film jammed in camera	00	:55	0
8/14/56	20:00	:00	0		00	:52	0
8/15/56	20:00	:00	0		00	:42	0
8/16/56	19:59	:01	1	(1) Punch No. 5 jammed.	00	:39	0
8/17/56	20:00	:00	0		00	:48	0
8/20/56	20:00	:00	0		00	1:03	0
8/21/56	20:00	:00	0		00	1:15	0
8/22/56	19:25	:35	1	(1) Drum and white switch trouble	00	1:06	0
8/23/56	20:00	:00	0		00	:40	0
8/24/56	20:00	:00	0		00	:48	0
8/27/56	20:00	:00	0		00	:43	0
8/28/56	20:00	:00	0		00	:56	0
8/29/56	20:00	:00	0		00	:28	0
8/30/56	19:59	:01	1	(1) Drum error	00	1:30	0
8/31/56	19:59	:01	1	(1) Reader "B" error	00	1:16	0
TOTALS	458:20	1:36	13		04	22:07	1

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