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April 1, 1972 - September 30, 1972

Center for Advanced Computation
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REPORT SUMMARY

This document reports progress on ARPA contract DAHC04-72-C-0001 entitled "ILLIAC IV Applications Research at the Center for Advanced Computation, University of Illinois at Urbana-Champaign." The principal objective of this program is the development and testing of numerical techniques and software systems for use of ILLIAC IV over the ARPA Network. This is being accomplished through activities in the following areas:

1. Development of numerical techniques suitable for parallel processing in the areas of:
   a) Linear systems of equations
   b) Algebraic eigenvalue problems
   c) Linear programming
   d) Graph algorithms
   e) Approximation of functions
   f) Determination of real roots of polynomials
2. Development of an ILLIAC IV multispectral image processing system
3. Development of ILLIAC IV language for the phase II system
4. Development of programs in large scale calculations such as input-output economic modeling, quadratic assignment algorithms for various classes of spacial allocation problems, and atmospheric dynamics.

In addition, education of segments of the ILLIAC IV user community was accomplished through seminars, classes, and the development and dissemination of tutorial materials.

1. ALGORITHM DEVELOPMENT GROUP

1.1 Introduction

During this period the Center's B6700 computer was disconnected (June 30th) and at least three weeks elapsed before we had reliable access to the simulator on the B6700 at UCSD. This has resulted in some delay in completing some of the ILLIAC IV codes.

1.2 Computational Methods in Linear Algebra

1.2.1 Solution of Systems of Linear Equations

The conjugate gradient method for solving the linear system of equations $Ax = b$ [1], has been coded in GLYPNIR and fully debugged, and a document is forthcoming. This algorithm is especially designed for large sparse matrices A with regular structure. It requires as an input a routine to compute Ay and $A^t y$ for a given y rather than storing the matrix A. To this end a high level language for matrix specification is being developed together with assembly language routines for handling such sparse matrices on the ILLIAC IV.

1.2.2 The Algebraic Eigenvalue Problem

A study of an algorithm for finding the eigenvalues of tridiagonal matrices on the ILLIAC IV using a generalization of the bisection method [1, 2] has been completed. The results compared favorably with the QL algorithm [1] on serial machines. The results of this study will be published soon. Work has also continued on finding suitable parallel algorithms for finding the eigenvalues and eigenvectors of large sparse matrices that arise from the numerical solution of elliptic differential equations (using the finite element methods for example). A comparison between Householder's method [1, 2] and Lanczos' method [2-4] to reduce such matrices to the tridiagonal form on the ILLIAC IV is almost completed.

We also obtained the eigensystem subroutine package (Eispack) from the NATS project at Argonne National Laboratories and had it installed on the University of Illinois' IBM 360/75 to provide an excellent set of routines that would enhance the development and testing of new algorithms. We are now in the process of adding this package to the library of the SPEAKEASY system [5] on the UCLA 360/91 for interactive usage. Hopefully this will also be used by the ARPA network community.

1.3 Linear Programming

The revised simplex code, described briefly in the previous semi-annual report, is largely written; however, it has not yet been debugged en masse (or with large data bases). This is mainly due to lack of complete documentation of the ILLIAC IV I/O. Since this I/O dependence will, most probably, be a stumbling block during the early months of ILLIAC IV availability, it was decided to consider instead for the next six months a new algorithm for linear programming developed by Gill and Murray [6] and Saunders [7]. This replaces the usual product form of the inverse of the basic matrix by a factorization into a lower triangular and an orthogonal matrix, with only the lower triangular matrix being stored. This method seems superior in both numerical accuracy and the greater sparseness of the lower triangular matrix compared with the product form of the inverse. This algorithm has already been implemented in ALGOL on the UCSD B6700, and is being implemented in GLYPNIR for the ILLIAC IV. The package is being coded so as to need little or no I/O and might therefore be executable under the earliest operating system. If the sparse matrix is of a given structure, the implicit generation of Ay and $A^t y$ mentioned in (1.2.1) could greatly enhance the number of rows that can be handled in core.

1.4 Graph Algorithms

The ALGOL and ASK programs for reducing a matrix A to the block triangular form $B = PAP^t$ where P is a permutation matrix, were modified in several ways thus delaying documentation of the algorithm. The ILLIAC IV performance exceeded our wildest dreams. An operation count on the ASK code for Warshall's algorithm [8] for an n x n matrix showed that for $n < 2000$ the ILLIAC is 29,000 times as fast as a B5500 on the same problem. The largest boolean matrix which will fit in core requires only eight seconds of processor time. This ASK program is many times faster than the one mentioned in the last semi-annual report. A report is forthcoming.

We also considered the problem of clique detection in graphs. A highly parallel algorithm was developed and was compared favorably with two algorithms tested at the University of Toronto [9]. An ASK program is partially written for a 64 node graph. Clique detection has applications in information retrieval.

1.5 Approximation of Functions

A recent effort has been started in the area of uniform approximation of vector-valued functions. An algorithm has been developed [10] and is being implemented. This will be followed by implementation of an algorithm for simultaneous best approximation of sets of experimentally-determined exponential decay curves. Results of the latter will be incorporated into a revised version of [11].

Both of these algorithms are based on the solution of linear inequalities to obtain improved approximations, since a Remez-type algorithm does not seem feasible. In the case of single-function linear approximation, the inequality approach, although applicable, has been studied very little and probably never automated. If the tests for simultaneous approximation work out well, it may be worthwhile to examine the method as an alternative to the Remez algorithms.

The applicability of the inequality approach to various types of single-function nonlinear approximation will also be investigated. For example, curve fitting by sums of exponentials (a program of considerable importance in analyzing chemical reaction data) presents serious difficulties when carried out by a Remez-type method [12].

Finally, a survey will be made of algorithms currently available for the solution of integral equations. An effort will be made to determine which algorithms are "best" (depending upon the particular problem to be solved), as well as to identify ways in which existing algorithms may be improved and problems for which new algorithms must be constructed.

1.6 Finding Real Roots of Polynomials

An ASK program has been fully debugged and tested for finding real roots of polynomials with real coefficients using a generalized bisection method. A document is forthcoming.

2. ILLIAC IV MULTISPECTRAL IMAGE PROCESSING

2.1 Introduction

In support of the earth resources observation and monitoring objectives of the ERTS/ERGS programs of USGS/DI and NASA, the Center, in collaboration with the Laboratory for Applications of Remote Sensing (LARS) of Purdue University, has proposed to design, implement, and assist in the evaluation of an advanced multispectral digital imagery processing system for automatic interpretation of high-altitude aircraft- and satellite-gathered data and detection of land-use and resource boundary changes. Such a system would also be applicable to problems in aerial reconnaissance.

2.2 Research Findings

CAC investigations during the last six months, conducted in collaboration with LARS which is supported by NASA, have led to the following conclusions.

First, the ILLIAC IV should be quite efficient in executing the large scale calculations required for digital processing of multispectral images. An early examination of input/output data transmission rates with respect to central core processing speeds has shown that the full capacity of the ILLIAC IV could be exploited by such an image processing system.

Second, the archival laser store associated with the ILLIAC IV would seem an adequate device for storage and retrieval of the large quantities of data associated with multispectral images and the interpreted resource information processed from these images.

Third, an appropriate portion of the software package LARSYS, developed at LARS for research in remote sensing, could easily be implemented in parallel fashion on the ILLIAC IV. Together with CAC-developed data and information management software, this would provide immediately a powerful capability for multispectral image interpretation

and a sound foundation for future ILLIAC IV image processing and pattern recognition experiments.

Fourth, the ARPA Network seems a practical means for interfacing numerous, geographically-dispersed national management and planning agencies. ILLIAC IV image processing and pattern recognition research by other members of the ARPA community should also be facilitated.

2.3 Proposed ILLIAC IV Implementation

As presently proposed to USGS/DI and NASA, the system would include, at a minimum, parallel software for raw data management, multispectral cluster analysis, classification of image elements into aggregate categories, digital registration of multiple images, automatic change detection capabilities, and basic information management services necessary for tabular report generation and automated mapping procedures. Also included would be the development of remote-inquiry, serial software to allow decentralized access to the ILLIAC IV processing system and peripheral storage devices.

Through this project (and in accordance with the objectives and spirit of the ARPA Network), discussion has resulted between CAC and the Image Processing Laboratory of USC concerning picture-processing systems sharing. CAC has discussed with NBS possible connections of D.C. area Federal agencies to the ARPA Network via the NBS ANTS facility. Communication with NASA-Ames ILLIAC IV users has been increased.

A preliminary proposal was submitted to USGS/DI and NASA by CAC and LARS in July. Contractual arrangements are still being negotiated. The Center is hopeful that some FY-73 support from USGS/DI and/or NASA will be available for a continuation of efforts in the area.

3. ILLIAC IV LANGUAGE DEVELOPMENT FOR THE PHASE II SYSTEM

3.1 Introduction

A six month study, described in preliminary terms in the last progress report, culminated with a report on the IDOL (ILLIAC Data Oriented Language). That language is designed to make flow of control and working set information readily available to the compiler. The information would be used to produce programs which interact smoothly with the memory hierarchy to provide a steady flow of data to and from ILLIAC IV with a minimum of "page faulting."

3.2 IDOL

IDOL (ILLIAC Data Oriented Language) is designed to facilitate program construction for the entire ILLIAC system. It has two portions--a data language in which to express data movement between the phase II memory hierarchy and ILLIAC, and an algorithmic language to be used for ILLIAC processing. In this report, we shall emphasize the data language, for although languages for ILLIAC have often been studied, the problem of data management for a memory hierarchy has received relatively little attention.

In handling data management for ILLIAC IV, one quickly realizes that it is really a virtual machine, since the data required for an ILLIAC problem typically exceeds the capacity of the core memory (PEM). As in other virtual memory systems, the fundamental problem is efficient use of the memory hierarchy so that CPU usage is maximized while minimizing channel traffic. The problem is aggravated on ILLIAC IV for several reasons.

First of all, on other virtual systems multiprogramming is possible, so that one program may run while the others wait. On ILLIAC IV, multiprogramming is impractical because of the extremely small core memory in comparison to the processing power. Also, ILLIAC IV is so fast compared to the rotation time of its disk that

even fast transmissions from the disk, if not timed exactly right, can cause serious loss of efficiency, while the time lost by waiting for data from lower levels of the hierarchy is particularly disastrous. Finally, unlike other useful virtual systems, ILLIAC IV has no special paging or even memory protection hardware, which imposes a greater software overhead than in other systems if page faulting is to be relied upon.

In the past, attempts to have the proper data present when needed have centered on various ways to determine the current working set for a program in terms of what had been accessed in the recent past. The efficiency of such schemes varies with different programs, but is always well below optimum.

The primary focus in the design of IDOL is that working set determination and sequencing are a function of the compiler; i.e., IDOL is designed to make the appropriate working set for each segment of an algorithm, and also the flow of control between these segments, apparent to the compiler. As a consequence, the compiler can generate a set of programs which will make maximal use of the available ILLIAC resources. The compiled programs will execute on the ILLIAC IV--PDP-10 multiprocessor with appropriate PDP-10 companion processes formulated in response to one unified source program. Moreover, the programs produced will run under the standard ILLIAC operating system and will, therefore, serve to augment the basic system.

3.3 Types of Problems

IDOL is designed for efficient movement of data through the phase II hierarchy, even under changing allocations of space on the various devices, and is primarily for problems in which ILLIAC execution proceeds in an orderly manner through a large data base, processing (and possibly updating) a well defined part of the data base in each step, with many passes possible through the data base. In reading papers on problems proposed for ILLIAC IV and in discussions

with probable ILLIAC users, we have determined that, for the problems we have seen, the majority of the input/output fits the pattern for which IDOL was designed. For the few cases in which the sequence of (data dependent) I/O requests cannot be determined in advance, explicit I/O statements will be allowed in the ILLIAC language portion of IDOL.

4. ECONOMIC RESEARCH GROUP

4.1 STEP I

During this period, the Economic Research Group estimated all the component models of STEP I and worked toward completing the interconnection of these models. Initial planning and design for enlarging STEP I from 218 economic activities and 86 industries to 400 activities and 376 industries has been completed and a proposal for support of this work has been submitted to NSF RANN. Work under ARPA support on STEP I should be completed by the end of December, 1972.

4.2 STEP II

Planning and design for STEP II has begun. Support for this work will be sought from NSF RANN and the Department of Transportation and will involve no cost to ARPA.

4.3 MEASURE

MEASURE, a user-oriented operating system involving network computers (PDP-10, B6700, and 360/91), has been substantially expanded to provide a wide range of library maintenance, editing, mathematical, and statistical routines. The first experiments in using the PDP-10 to establish a communications link to the 360/91 has been written. An efficient matrix computations package for the 360/91 has been written and a statistical package is being written. The first experiments in computer initiated transfer to computations from the B6700 to the 360/91 will be carried out in November. Initial benchmark calculations suggest that interactive jobs on the B6700 cost about one-fifth as much on the B6700 as in TSO 360/91 and large matrix computations on the 360/91 will cost between one-half and one-fourth as much as the B6700. The use of MEASURE with the 360/91 being used invisibly for large computations can be expected to realize substantial cost savings over either the B6700 or the 360/91 used alone. When fully implemented,

MEASURE will permit naive users to use STEP I for forecasting over the network and MONICA for general numerical and statistical computations at minimum computational cost.

5. NETWORK SYSTEMS GROUP

5.1 Introduction

The Network Systems Group has research responsibility in the area of development of local basic computer systems and services to serve the need of the Center staff and user community, and for the development of hardware and software systems for Network utilization and implementation. There are four project areas to be reported on at this time:

a. Project to Interface the Burroughs B6700 to the ARPA Network
b. ARPA Network Terminal System (ANTS)
c. Center Graphics Support
d. Network Graphics Effort

5.2 Project to Interface the B6700 to the ARPA Network

During the period, a re-evaluation of the software effort needed to bring the UCSD (University of California at San Diego) Burroughs B6700 system onto the Network indicated that in order to provide Network access in the shortest amount of time, the NCP effort previously accomplished by the Center would be used. Additional effort was therefore applied and the NCP project re-instituted.

The first version of the NCP was completed, debugged, and installed in the UCSD system utilizing a temporary connection to the Network, via a 3600-baud line direct to the UCLA Network IMP. This enabled the San Diego system to come on the Network around August 1, 1972.

The Center staff member associated with this area of research left the Center and is now employed by the UCSD Computer Center. Therefore, all further work on interfacing Burroughs B6700's to the Network will be accomplished at UCSD with no further support from the Center.

5.3 ARPA Network Activities

5.3.1 ARPA Network Terminal System (ANTS) Development

During the reporting period, development of ANTS continued to be affected by the performance of the in-house Burroughs B6700 system. With the advent of the B6700 system at UCSD becoming a full Network site, the in-house B6700 was removed from service on June 30, 1972.

Further development efforts on ANTS were directed at stabilizing the current system, now known as MARK I, with capability at the minimum TELNET level and including remote job entry service to the UCLA 360/91.

In addition, several "Kludge" software patches were added which allow the transmission, for experimental purposes, of graphics images back from UCSD, Rand Corporation's TENEX system, and 360/91, to both the Gould graphics plotter and the Computek storage scopes.

Remaining efforts of the group during this period were to complete software necessary to operate with the UCSD Computer Center via the Network and provide the development group with PEESPOL support for developing MARK II ANTS in the next reporting period.

The MARK II system will implement all available Network protocols such as low level graphics protocol, file transfer protocol, full TELNET protocol, and remote job entry service protocol. In addition, all of the peripheral devices such as DECtapes, mag tapes, Gould printers, card readers, disks and graphics displays will be fully incorporated and the system brought to a completed status.

5.3.2 ARPA Network Usage

During the reporting period, usage of the Network continued at an increasing rate. TSO was added at the 360/91 and access to it was gained by Center members.

As of August 1, 1972, the UCSD B6700 system was available as a Network Host and the Center programming efforts on the machine were transferred to that site. The B6700 at San Diego was brought to full status of operations with such Center provided systems as MONICA, NARIS, the PEESPOL compiler and ANTS development software packages, and the use of the ILLIAC IV software packages maintained there by Ames.

5.3.3 Further Installations of ANTS Systems on the Network

During the reporting period, further contacts were made with additional sites desiring information as to the availability of an ANTS system to provide those sites with access to the Network. An investigation is under way regarding the feasibility of establishing a number of sites on the Network for the Army Materiel Command and providing the various sites with access to Network for such service sites as UCLA 360/91, ILLIAC IV, and several AMC service sites such as the CDC-6600 installation at Ft. Belvoir, Virginia.

In addition, the system utilization measurement group at the Lawrence Radiation Laboratories, Livermore, California, has elected to procure an ANTS system to facilitate their gaining access to the Network and to non-Network service sites in order to study the utility of access to those systems and to evaluate the services those systems supply.

Negotiations have been under way with Digital Equipment Corporation for the procurement of additional hardware at the Center, based on the advanced concepts PDP-11 model 45 processor and memory system, to provide Center research personnel with an advanced design access system to the ARPA Network. During the next reporting period, a basic design of the system will be undertaken and an implementation schedule for its production will be developed. This enlarged advanced system will provide the Center with a mechanism for studying Network operations in the area of process-to-process communications, software resource sharing, processor service sharing, etc.

5.4 Graphics Support for Center Projects on the Burroughs B6700

With the advent of the UCSD B6700 system as a service site on the Network, effort originally terminated on the Center's B6700 system for providing graphics support software packages to Center personnel was reinstituted. Initial efforts were directed at bringing previously developed in-house systems up to full operational status to be used remotely between San Diego and the local ANTS system. The extent and conclusion of this effort will be documented in the next reporting period.

5.5 Network Graphics Efforts

5.5.1 Network Graphics Protocol

During the reporting period, the first level graphics protocol was agreed to by members of the Network Working Group. No further meetings have transpired during this time to enlarge upon or elucidate experiences in the production of this protocol.

Efforts in the Center have been directed at developing the capability of sending Network graphics protocol from UCSD, Rand TENEX, and the Model 360/91 at UCLA. Initial experiments in the use of this protocol were moderately successful, due mainly to the problems in returning images directly to ANTS supported graphics peripherals.

5.5.2 Laboratory for Atmospheric Research Support

Support of the University's Laboratory for Atmospheric Research, under the direction of Professor Ogura, was limited during the period to the study, specification, and acceptance of bids by graphical plotter vendors for the purchase of a drum plotting device to be attached to the Center's ANTS system. This proposed device would provide high-quality incremented graphics plotting capability for both Laboratory and Center personnel. During the next reporting

period, it is proposed that this device be procured, installed, and software for the generation of graphical images be developed at UCSD, Rand and on the UCLA model 360/91.

6. ADMINISTRATION

6.1 Introduction

Due to a last minute budget reduction of $100,000 by ARPA, significant changes were made at the Center, resulting in a decrease of personnel.

6.2 Fiscal Status

Actual expenditures through 31 March 1972:		$723,965
Estimated expenditures and obligations for the 6-month period covered by this report (1 April - 30 September 1972):		
April	139,045	
May	121,430	
June	165,399	
July	109,965	
August	153,025	
September (estimated)	94,200	
	783,064	783,064
Total estimated expenditures and obligations through 30 September 1972:		$1,507,029

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