CARNEGIE-MELLON UNIVERSITY

HYBRID COMPUTATION LABORATORY

USER MANUAL

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USER MANUAL

INTRODUCTION

Carnegie-Mellon University
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1.0 HYBRID LAB

1.1 ORGANIZATION

The CMU Hybrid Computation Laboratory provides analog and hybrid (and, to a limited extent, digital) computation and simulation services to the university. Administratively, the hybrid laboratory is an integral part of the CMU Computation Center; all funds, employees, and user services are provided by the Computation Center. The director of the laboratory, Dr. J. C. Strauss, is Assistant Director for Hybrid Computation of the CMU Computation Center. Physically, the hybrid lab is located in Rooms 2 and 2A of Hamerschlag Hall (Level 3B, one floor below the parking lot level).

In addition to the administrative ties, the hybrid lab maintains a data phone connection to the computation center. This connection may be employed in a variety of ways; these include:

1) Use of the 1108 as a high-speed digital processor for hybrid operations.
2) Use of the 1108 for high-speed digital input/output and user file storage.
3) Use of the hybrid computer as an analog input/output device by the 1108.
4) Use of the DCT 2000 (data communications terminal) for printing, card reading and card punching by the hybrid computer.

1.2 PERSONNEL

In addition to Dr. Strauss, the personnel of the hybrid lab include:

Joseph A. Johnston - Assistant Hybrid Computer Engineer, Christopher L. Cross - Hybrid Computer Programmer,

and a part-time user consultant staff of undergraduate and graduate students.

A member of the hybrid lab staff will always be available when the hybrid lab is open to answer questions, assist with computer operations, and to be of general service to the user.

1.3 OPERATION

The hybrid lab is operated in an open shop mode; i.e., in addition to performing his own programming the user is also expected to operate the computer(s). A thorough understanding of this manual and the referenced manuals of the appropriate computers constitutes minimal preparation for using the equipment. The hybrid lab reserves the right to restrict usage of the hybrid computer to persons able to demonstrate a familiarity with this documentation. In addition, as usage patterns develop, it may become necessary to develop a user priority system for access to the equipment. This priority system will take into account the following factors:

1. Demand for the individual computers and/or the total system.
2. Appropriateness of the planned program for analog and/or hybrid solution.
3. Proficiency of the user in employing the equipment.
4. Importance of the problem solution.

For the present, computer time on the GPS Analog, EAI 680, PDP-9, or any combination is reserved in one-hour blocks by signing (with both user number and account number) the schedule sheets posted on the bulletin board outside the laboratory. The computers are available for student and faculty use from 9:30 a.m. to 5 p.m., Monday through Saturday. Other hours may be scheduled by experienced users by appointment. If demand warrants, a second shift operation (5 p.m. to 12 p.m.) will be initiated. Funded research projects will be given first choice of the scheduled hours. In all cases, scheduled time is subject to pre-emption for necessary hardware and/or software maintenance.

All necessary supplies with the exception of personal copies of the documentation, personal DECtapes, and private analog patch boards are provided cost free by the hybrid lab. Documentation and DECtapes may be purchased from the CMU bookstore. Private analog patch boards will be ordered (at cost) from EAI. Funded research projects are encouraged to purchase their own DECtape and analog patch boards if the projected computer usage warrants. Plans for long and short term leasing of analog patching equipment are under consideration.

1.4 DOCUMENTATION

This user manual constitutes the primary documentation facility for the CMU hybrid lab. It is organized in a loose leaf structure to facilitate corrections and additions. Corrections and additions, as they become available, will be announced in the data flag and may be picked up in the hybrid lab (at no cost).

In addition, the following equipment manufacturer publications will be very useful for hybrid lab users and are strongly recommended:

EAI 680 Reference Handbook, EAI publication #00800.2048-1, July, 1967.

Handbook of Analog Computation, EAI publication #00800.0001-3, July, 1967.

Fortran IV Manual, DEC-9A-AF4B-D, Digital Equipment Corporation, 1968.

Utility Program Manual, DEC-9A-GUAB-D, Digital Equipment Corporation, 1968.

The following are recommended as supplementary manuals:

Basics of Parallel Hybrid Computers, EAI publication #00800.3039-0, June, 1968.

Keyboard Monitor Guide, DEC-9A-NGBA-D, Digital Equipment Corporation, 1968.

PDP-9 User Handbook, F-95, Digital Equipment Corporation, January, 1968.

The following manuals are necessary for assembly language users:

MACRD-9 Manual, DEC-9A-AM9A-D, Digital Equipment Corporation, 1967.

Keyboard Monitor Manual, DEC-9A-MABO-D, Digital Equipment Corporation, 1968.

All of the above-listed manuals and the hybrid lab user's manual are for sale in the CMU bookstore and available for reference in the hybrid lab.

2.0 HYBRID COMPUTATION

A brief discussion of hybrid computation in general facilitates later presentation of the CMU hybrid computer. A hybrid computer is a combination of a high speed electronic analog computer and a small, fast, digital computer linked together through a communication interface system. The hybrid interface contains analog-to-digital and digital-to-analog converters, control functions, and interrupt lines. This combined system is used to solve problems amenable to a comtination of both analog and digital solution techniques.

An analog computer is a parallel computational device that is hardware expandable; i.e., problem size capability is increased by adding new hardware devices. Speed capability is increased by increasing the frequency bandwidth of each individual device. These devices include summers, integrators, multipliers, function generators, and logic elements. Once activated, the devices operate continuously and simultaneously in time until deactivated. Device precision is limited because all operations involve continuous signals (voltages); this precision decreases with increasing frequency of the signals, but in modern electronic analog computers it remains fairly high (> 99%) for signal frequencies in the kilohertz range. An analog computer program comprises a collection of devices interconnected to perform the operations necessary to solve algebraic and differential equations. In general, an analog computer is best suited for the solution of ordinary differential equations.

The digital computer is a serial computational device that is time expandable; i.e., problem size capability is increased by specifying a longer list of sequential instructions which take a correspondingly longer time to be executed. All computation is performed in a central set of registers on numerical representations of variables (or signals). A digital computer program comprises the set of instructions specifying the order in which various arithmetic and logical operations are to be performed in the registers. Through proper programming, problem size and accuracy of solutions may be made arbitrarily large, but only at the expense of increased solution time.

By making optimal use of the best features of the two types of computers (i.e., parallel and serial respectively), one can expect to solve certain classes of dynamic system optimization and simulation problems at anywhere from one to three orders of magnitude faster than is possible with either analog or digital computers alone. The hypothesis is advanced that for many significant problems of current research interest, speed of solution is tantamount to either solving or not solving the problem. The following examples illustrate this point.

Consider a space vehicle reentry simulation where the object is to study the human engineering and psychological factors involved in a particular control console design. In this simulation, a subject (pilot) flies the simulated vehicle through the simulated mission employing, perhaps, a dummy cockpit containing the control console under study. If it were not possible for the computer to update the simulation in real time the study would be completely impractical; i.e., a pilot responding to a situation developing at less than its normal speed would employ a completely different strategy than one operating in real time.

Consider the problem of determining the reaction rate coefficients in a dynamic model of a chemical reactor. The goal is an optimal match between the response of the model and the measured response of the actual system. By employing a steepest descent search technique with automatic adjustment for relative minima, it might be possible to determine a satisfactory set of coefficients in less than ten hours on a modern hybrid computer. For problems of this type it is entirely possible that the hybrid computer is three or more orders of magnitude faster than the fastest modern digital computer. Using a very conservative two orders of magnitude factor, such a problem might involve one thousand hours (more than one month) on a digital computer; it is very likely that the cost would prohibit the solving of this problem by all-digital techniques.

The principle problem in hybrid computer programming is the effective utilization of the combined computer complex. The basic idea is to place the high speed (scaled to 1 khertz or greater), low precision calculations on the analog computer and the low speed (1 khertz or less), high precision calculations on the digital computer.

The linkage system of the hybrid interface permits communication of data between analog and digital components at high speed (up to 30 thousand conversions/second) and reasonable precision (4 digits). The two computers are synchronized to realtime clocks contained in the digital and analog computers. The syncronization of the digital programs to events in the analog program is accomplished through an extensive priority interrupt system in the digital computer. All the control functions of the analog computer (i.e., mode control, potentiometer setup, device output readout, time scale changing, etc.) can be exercised from the digital computer under program control. The slow speed control communication is handled by a separate module of the interface system.

The features of the hybrid computer that distinguish it from the digital and make it particularly well suited for a wide class of simulation and computation problems are:

1. Speed - For certain problems, a several hundred thousand dollar hybrid will demonstrate a speed many orders of magnitude greater than a several million dollar digital computer.
2. Man-machine interaction - The user of a hybrid computer maintains an almost symbiotic relationship with the computer and his problem through the extensive display and control features afforded by the analog computer.
3. Analog Display - The analog computer affords excellent high speed (display scope and monitor scope) and low speed, hard copy (8 channel stripchart recorder and X-Y plotter) display capabilities.

3.0 PROGRAMMING

3.1 HYBRID COMPUTER PROGRAMMING

The hybrid lab maintains the following computers:

1) EAI 680 Analog Computer,
2) PDP-9 Digital Computer,
3) CMU Hybrid Computer (PDP-9 tied to EAI 680 through EAI 693 Interface),
4) GPS Repetitive Operation Analog Computer.

The analog and hybrid computers are highly specialized devices best suited for the solution of problems involving ordinary and/or partial differential equations. For many problems in this class, the proficient programmer will be able to obtain speed improvements of from one to three orders of magnitude as compared to all-digital solution. The hybrid computer also affords a much more usable interactive interface to the user. Appropriate combination of the potential speed and the interactive capabilities of the hybrid computer lead to the solution of problems that would be impractical, if not impossible, to solve by all-digital means.

The prospective user is cautioned however, that these solution speed and efficiency gains do not come easily. Efficient hybrid computer programming requires a good understanding of differential equation theory, sampling theory, analog computer operation and programming, and digital computer programming. In addition, the analog computer requirement that all problem variables be scaled between plus and minus one machine unit (10 volts on the EAI 680) and the limited precision of the analog computer and the hybrid interface means that the problem preparation time for hybrid computation is likely to far exceed that required for all-digital solution. For these reasons, the prospective user is urged to discuss his problem with a member of the hybrid lab staff prior to actual programming to ascertain its suitability for hybrid solution.

3.2 FORTRAN IV PROGRAMMING

The hybrid software system has been designed to facilitate an all-Fortran IV mode of operation. This approach implies certain inefficiencies:

1) The Fortran IV Compiler does not produce as efficient code (both from a core storage and execution time viewpoint) as that produced by an experienced assembly language programmer.
2) Fortran IV does not provide an efficient medium for dealing with single bits of information.
3) Fortran IV does not allow direct communication between the user program and the interface devices.

Considering the strong emphasis that has been placed on execution speed, the perspicacious reader might question the wisdom of the decision to encourage Fortran IV hybrid programming. This decision is based on the following observations:

1) In many hybrid applications, the speed of the digital computer will, within certain limits, have relatively little effect on the overall solution time. (The speed of the interface and sampling theory considerations often limit the overall solution speed.)
2) For those cases where the digital computer is the limiting factor, it is a relatively simple matter to scale down the speed of the analog to match that of

the digital. (The digital computer can set the solution speed of a previously programmed analog program to multiples of 1, 10, 10^3 and 10^4 times real time. Relatively simple scaling of the analog program gives all variations across this range)

3) The Fortran callable hybrid linkage routines have been carefully coded in assembly language to provide a rapid, yet thoroughly checked, transmission of data and control information between the analog and digital computers. These routines provide Fortran IV access to all the hardware features of the interface and yet protect the user from the details of the interface programming. The linkage routines are employed in all the higher level hybrid software and may be considered to be thoroughly debugged.

4) Hybrid programs written in Fortran IV are virtually transparent to the experienced consultant staff of the hybrid lab. Hence it is possible for the staff to provide valuable assistance in a minimal time without the necessity of becoming intimately familiar with the intricacies of the user program and/or problem.

5) Probably the most important reason for programming in Fortran IV where at all possible is the straight forward programming, readable documentation, and rapid debugging afforded by this medium. Programming in Fortran IV will also permit extensive all digital checkout of large portions of the hybrid program on the 1108. (It will be possible to transmit user

files from the 1108 to the PDP-9 via the data phone connection.)

By supporting Fortran IV as the standard hybrid programming language through the provision of useful programming aids and support software, the hybrid lab is encouraging the user to direct his efforts to the formulation and solution mathematics of the problem, not to the solution mechanics. The foregoing discussion does not mean to imply that the knowledgeable user with suitable justification will not be permitted to employ MACRO-9, the PDP-9 assembly language, where he deems it necessary. However, the majority of the users will be strongly advised to program completely in Fortran IV.