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EXPERIENCE IN NETWORKING - A CASE STUDY

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EXPERIENCE IN NETWORKING - A CASE STUDY

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Michael S. Sher

The Center for Advanced Computation is an interdisciplinary research center in the Graduate College of the University of Illinois at Urbana-Champaign. The Center's applied research and problem solving activities have been supported by the Department of Defense's Advanced Research Projects Agency (ARPA), the Ford Foundation, the National Science Foundation, and several other federal and state agencies. These activities include research and development in environmental information systems, economic modeling, energy studies, atmospheric modeling, image interpretation, transportation system modeling, statistical systems, graphics systems, computer network access systems, and numerical analysis. Since August 1972, over 90 percent of the computational resources required by Center staff has been obtained via the ARPA Network (ARPANET).

This paper reports on the following: (1) the Center's means of accessing the ARPANET; (2) the Center's reasons for choosing to rely upon networking (although there are a variety of computer systems available locally); (3) the Center's experience in using ARPANET resources; and (4) opinions regarding the future of networking in educational and research environments.

ARPANET and the Illinois Access Computer

The ARPANET is a wide ranging experiment in the remote access and sharing of computer resources. It was begun in the mid-1960's by Dr. Larry Roberts of ARPA [1,2,3,4,5]. Today, the network stretches from Hawaii to Norway and encompasses approximately forty connection nodes and over fifty computer and research installations (see figure 1).

The ARPANET is a full-duplex high-speed data transmission network developed by Bolt, Beranek and Newman, Cambridge, Massachusetts. It is a packet switched transmission network with each network node occupied by a mini-computer called the Interface Message Processor (IMP). The IMPs are interconnected by 50 kilobit per second leased communication lines and satellite links [6,7]. The IMP is responsible for such tasks as error control, message routing, and statistics gathering. Care has been taken in network design and implementation to insure an ultra-high level of reliability (no more than one single bit error per year should go undetected).

At any given network node, one or more HOST computers may be attached providing a service center or research project with access to the ARPANET community. A sending HOST directs messages to its IMP which breaks the messages into thousand-bit packets; these are sent to the destination IMP, which reassembles them into copies of the original message, which is then sent to the receiving HOST.

While many HOST computers are associated with ARPA sponsored projects, several locations serve as network service HOST sites. The earliest ARPANET service sites were the IBM 360/91 at the University of California at Los Angeles (UCLA) and the IBM 360/75 at the University of

California at Santa Barbara (UCSB). Others joined later to serve as service HOST sites providing capabilities and services particular to their installations and computer systems.

A second phase of ARPANET development has seen the addition of nodes which differ from the initial IMP. These new nodes provide for direct connection of terminal hardware and are called Terminal Interface Processors or TIPs [8, 9]. A TIP is a parasite node and provides no service capability. Interactive terminal users attached to a TIP must obtain all their processing and storage requirements from ARPANET HOSTS. Thus, the second phase of ARPANET development has seen the introduction of user oriented groups to compliment research and service HOSTS.

For expanded local capabilities, and as a compliment to the TIP, the University of Illinois has developed a "mini-HOST" computer system based on the configuration of a small mini-computer (Digital Equipment Corporation PDP-11) acting as a full capacity HOST (from the protocol standpoint) and attached to a standard IMP or TIP. The PDP-11 based system is called the ARPA Network Terminal System (ANTS). ANTS [10] provides facilities for attaching a wide variety of local input/output peripherals to any remote ARPANET HOST (see figure 2). Such peripherals include a variety of interactive terminals, card readers, line printers, plotters, magnetic tapes, disk storage, COM systems, graphics displays, etc. In addition, ANTS supports the attachment of integrated remote-job-entry systems whose components can be independently accessed from remote sites. ANTS may also serve as an intelligent network interface for larger computer systems.

Illinois Entry into Networking

For several years, the Center operated a dedicated, hands-on

research computer facility. In the summer of 1972, the Center decided to replace its Burroughs B6700 by remote use of the B6700 at the University of California at San Diego (UCSD). Center staff assisted UCSD in connecting their B6700 to the ARPANET. Even so, there was a great deal of skepticism among the Center's programmers regarding their ability to do systems development and sophisticated applications programming over a network. However, economics demanded an abrupt transfer to networking. Our B6700 was released on July 1, 1972, with an acceptable connection to the UCSD B6700 accomplished by mid-August.

Our experience in transferring from a dedicated facility to a network environment should be studied with the following facts in mind: (1) many of our initial computer users were experienced systems or applications programmers with demands for sophisticated computer services and (2) at the time of our transition, the ARPANET was in a rather transient state in terms of protocol development and the availability of computing services.

Illinois' Networking Requirements

UCSD has over three times more capacity than had our facility. It is operated in a service environment with good response to its customer's needs. Several large software systems which had been developed on our local B6700 were rapidly transferred to the UCSD B6700 with close cooperation of the UCSD staff. Initially, we principally accessed the the ARPANET to use the UCSD B6700. The major portion of our B6700 use involved use of the ILLIAC IV language compilers and simulator developed at the University of Illinois and the development of several systems, including a high-level language compiler and

operating system for a mini-computer, a large scale geographic information system for inexperienced users and a number of applications programs. Most of our programming had previously been done on the B6700 in ALGOL, for which the B6700 is particularly well suited. In two-to-three months, the reliability and level of service of the UCSD B6700 and its network connection had exceeded that which we had been able to provide with a smaller local system. Remote B6700 services were obtained at about 40 percent of the cost of our local operation.*

Soon after joining the ARPANET, we began experimenting with the use of PDP 10s and IBM 360s. Most of our programmers became conversant with several machines and several languages. The University of Illinois' Laboratory for Atmospheric Research (LAR) began to use the ARPANET for accessing the UCLA IBM 360/91 to perform large scale hydrodynamic and meterological simulations which exceeded the capacity of the University of Illinois' IBM 360/75. Center staff began experimenting with graphics display routines on various network PDP-10s. In performing the LAR meterological calculations, it soon became clear that there were advantages to using multiple machines. The PDP-10, in performance and cost, runs a poor second to the IBM 360/91 in large scale computational ability but is a much better interactive time-sharing machine.

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*We replaced a $40,000/month local operation with $10,000/month services from UCSD. Our network access computer (ANTS) with peripherals leased for about $4,000/month. The IMP leased for about $1,700/month. Our experience indicated that $10 of computing services leads to about one kilopacket (one million bits) transferred about the network. ARPA estimates communications costs of a moderately loaded network at 30 cents per kilopacket. Therefore, our communication costs have been about $300/month. Thus, a cost of $40,000/month was reduced to about $16,000/month.

We thus began experimenting with preparing batch programs for compilation on the UCLA IBM 360/91 by using the University of Southern California's Information Sciences Institute (USC-ISI) PDP-10 for file preparation and text editing. The prepared file was transferred from the PDP-10 to the IBM 360/91 for calculations requiring several hours and producing a large data base file.* This file was then transferred from UCLA to USC-ISI where graphical output was generated in the form of contour maps by PDP-10 subroutines. This graphics output was transferred over the ARPANET to Illinois where either a graphics scope or a plotter displayed the results for study by a meteorologist in order to prepare for his next run. (See figure 3).

Other large scale programs also can be separated into interactive and batch modules. These modules can most effectively and economically be performed either on medium scale interactive machines, such as the B6700 and PDP-10 or large scale computational machines, such as the IBM 360/91 and ILLIAC IV. Common subroutine libraries can be developed on one machine and then used for parts of calculations done primarily on another machine. This resource sharing is a quite powerful advantage for networking.

We then entered a phase where we began asking a new series of questions each time we approached a new programming problem or project. Which network machines are most appropriate for solving the problem in terms of the languages they provide, their file structure, their software

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*Machines may share files with one another through a file transfer protocol (FTP) which has recently been developed by the ARPA community. FTP compensates for the varying formats and word sizes of different machines.

libraries, and their special hardware capability? How do the machines compare in economy, reliability, security, and availability? Answering these questions helps us to implement the program, or its components, on the proper set of network systems.

The automation of resource sharing activities has recently generated a great deal of interest in the ARPA community. One example is the creation of the resource sharing executive, RSEXEC [11], by Bolt, Beranek and Newman. RSEXEC is intended to create one virtual system out of the several PDP-10s on the ARPANET.

Another example is the work being done at the Center [12] concerning a distributed information management system. This distributed system will isolate interpretive, file retrieval, and computational modules, selecting appropriate network HOSTS for each of these functions. The appropriate degree of replication will be studied in order to obtain specified levels of service.

Experience has led us to continuing research into the separation of the user interface portion of programming systems from the computational and information retrieval activities. We feel that interfacing users to networks is best done on mini-HOSTS, such as ANTS, while the more complex interactive and large computational and retrieval activities are best performed on larger network service HOSTS. The mini-HOST provides limited, but often necessary, local processing and storage capabilities.

Inter-University Collaboration

Aside from the technical and economical aspects of choosing the proper set of computational facilities for solving a particular problem, another aspect of networking is becoming quite important to our research. Joining a national network has broadened the communications opportunities

between our staff members and geographically remote colleagues with access to the ARPANET. New staff members or visiting staff generally have large programs residing on a machine used in their previous position. They generally have access to a comparable ARPANET machine and do not have to go through the normally laborious process of transferring their software to whatever machine is locally available.

The ARPANET also permits a much broader community of collaborative and interactive research in those applications areas which involve large scale computations. For instance, researchers studying similar phenomena often use different machines, different numerical techniques, and different data bases with varying degrees of accuracy and documentation. It is often very difficult to distinguish computational and methodological differences between investigations into similar phenomena. The ability to jointly develop a common data base and to use common numerical techniques with the same machine(s) permits investigators to concentrate on the merits of differing methodologies without worrying about other side effects.

The personal communications aspects of networking should not be underestimated. Geographically dispersed colleagues can use the network for rapid and effective communication. A mechanism referred to on the ARPANET as "mailbox" is actually a file in a chosen machine to which messages are sent by other network users. The person to whom the "mail" is sent is notified when he next attaches to the machine that there is a message waiting for him.

The ARPANET has provided a broader base for system developers to acquire user experience. We are able to select initial system users who will provide optimal feedback to further system development. We are

not restricted to users who have geographic proximity or a local machine similar to the one on which our system has been developed.

General Network Experience

The object of networking should be to provide a utility which represents a more reliable and economical computing resource than any single component with which it is constructed. Reliability is accomplished through redundancy within the homogeneous IMP sub-network and the duplication of service HOSTS. The most reliable part of the ARPANET by the summer of 1973 was the IMP subnetwork. Continued improvement was experienced over the last year. Network problems occurred only once or twice per week on the average. These normally resulted in unreliable access periods of about an hour or less in length.

Attached to the IMP subnetwork are network access computers, research facilities, and service sites. By the summer of 1973, our network access mechanism, ANTS, was experiencing an average software crash rate of less than two per day (downtime less than a few seconds) with continuous availability periods exceeding one hundred hours. We expect to significantly improve this by the end of 1973.

The reliability of the ARPANET service sites improved in the first half of 1973. Initially, most sites entered the ARPANET on an experimental basis. As techniques were tested and protocols were implemented, a number of sites elected to become service HOSTS offering guaranteed services and schedules on a contractual basis. Current network service HOSTS include the UCLA IBM 360/91, the MIT Honeywell Multics system, the UCSD Burroughs B6700, the UCSB IBM 360/75, and several DEC

PDP-10s. The Multics system and the UCLA IBM 360/91 appear to currently lead service HOSTS in terms of reliability and availability followed closely by the UCSD B6700 and the PDP-10s at Bolt, Beranek and Newman and Stanford Research Institute.

The least developed aspect of networking has proven to be the area of user services. Multics currently leads the service HOSTS in offering satisfactory documentation for remote usage. Other service HOSTS have successfully begun to experiment with providing on-line consultants and on-line documentation to be used in complimentary fashion for aiding remote network users.

An ARPA committee chaired by Dr. W. R. Sutherland is studying a unified network accounting system. Currently, billing is provided separately by each ARPANET service HOST. At the University of Illinois, all contracts with service HOSTS for external computer usage must be approved by the Computing Services Office (CSO). CSO is responsible for providing the campus with local computational services. The principal CSO resource is an IBM 360/75. Before approving requests for remote use, CSO reviews a written explanation of why such services cannot be obtained locally, either for technical or economic reasons. Reviewing such requests permits CSO to identify computational services which are not currently provided locally, but which CSO may want to provide and/or promote in the future.

Network Economics

As we indicated earlier, in the summer of 1972 the Center discontinued the lease and operation of its B6700, which was costing about $40,000 per month, and expanded our computer use to a variety of systems on the ARPANET. Service site costs have been about $20,000 per

month (half of which has been at UCSD), with an additional $6,000 per month in communications and network access costs. Our computational usage will continue to increase during the coming year with greater emphasis being given to the use of the MIT Multics systems, which has recently been shown to be extremely reliable and economical for large scale information retrieval systems.

We would be in an extremely awkward situation if we had to rely upon any single computer system at this time. The ability to identify the proper machine or set of machines for a particular set of computations, given a mix of computational tasks, can result in cost savings in programming labor and computer costs of 50 to 80 percent. Assuming moderate network usage, network costs should not increase service site costs by more than 15 to 25 percent.*

Overall, we estimate that to upgrade local University of Illinois research facilities to compete with currently used ARPANET service HOSTS (or establishing conventional, but comparable, remote links directly to uniqute remote service HOSTS) could only be accomplished at a cost exceeding 300 percent of the cost of services we now obtain over the ARPANET.

The Future of Networking

We believe that networking should provide a variety of specialized services operated independently and in competition using a healthy free market to provide the best services at the lowerst rates. Networks should be operated in a manner which prevents the formation of monopolies and encourages, whenever possible, the duplication of services. Development of service sites which support different philosophies for providing

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* We believe that communications costs will not exceed 10 percent of the computer resrouce costs and that a proper network access mechanisms will not exceed 15 percent of the computer resources costs.

very similar services should be encouraged. Examples are the BASIC services provided by PDP-10, various IBM systems, and Multics. Another example is the subsystem development environment supported by the PDP-10, Multics, and the B6700.

Homogeneous systems of PDP-10s or 360s on the ARPANET can support backup capabilities and load sharing facilities. However, the development of resource sharing protocols will permit a set of heterogeneous machines to be combined into a single "virtual" system. These unique resources can then be highly tuned to be cost effective on specific classes or subsets of problems.

Managing "complete" general purpose computing facilities generally combines the roles of the "wholesaler", who provides raw computational resources, and the "retailer", who molds these resources to meet the consumers needs. Universities are free to treat networks as wholesale outlets for computational resources while local staff play the retailer's role of molding the remote services and retaining the local facilities required to best meet the demands of their students, professors, and administrators [13, 14]. We believe that the economics of this approach will encourage solutions of the political and administrative problems involved in making the transition from local dedicated computation facilities to networking.

Biographical Sketch

Dr. Sher is Associate Director of the Center for Advanced Computation and Research Assistant Professor of Computer Science at the University of Illinois at Urbana-Champaign. He has a M.S. in meteorology from the University of Missouri and a Ph.D. in theoretical physics from Michigan State University. He joined the ILLIAC IV Project at the University of Illinois in 1969. His research interests have been in the application of parallel processing to the solution of equations in fluid dynamics and in the development of network access computer systems.

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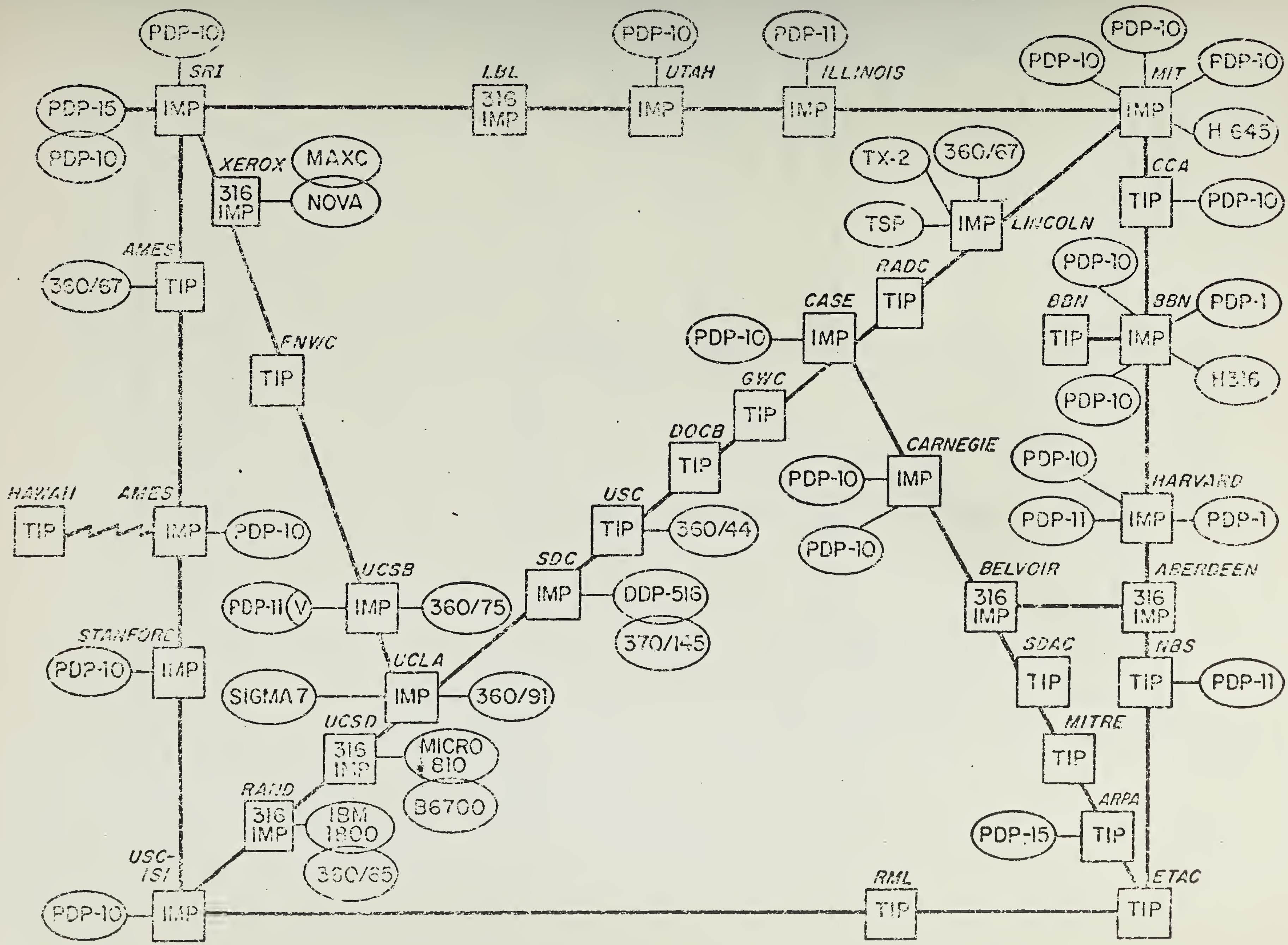
Figure 1 : ARPA NETWORK, LOGICAL MAP, MAY 1973



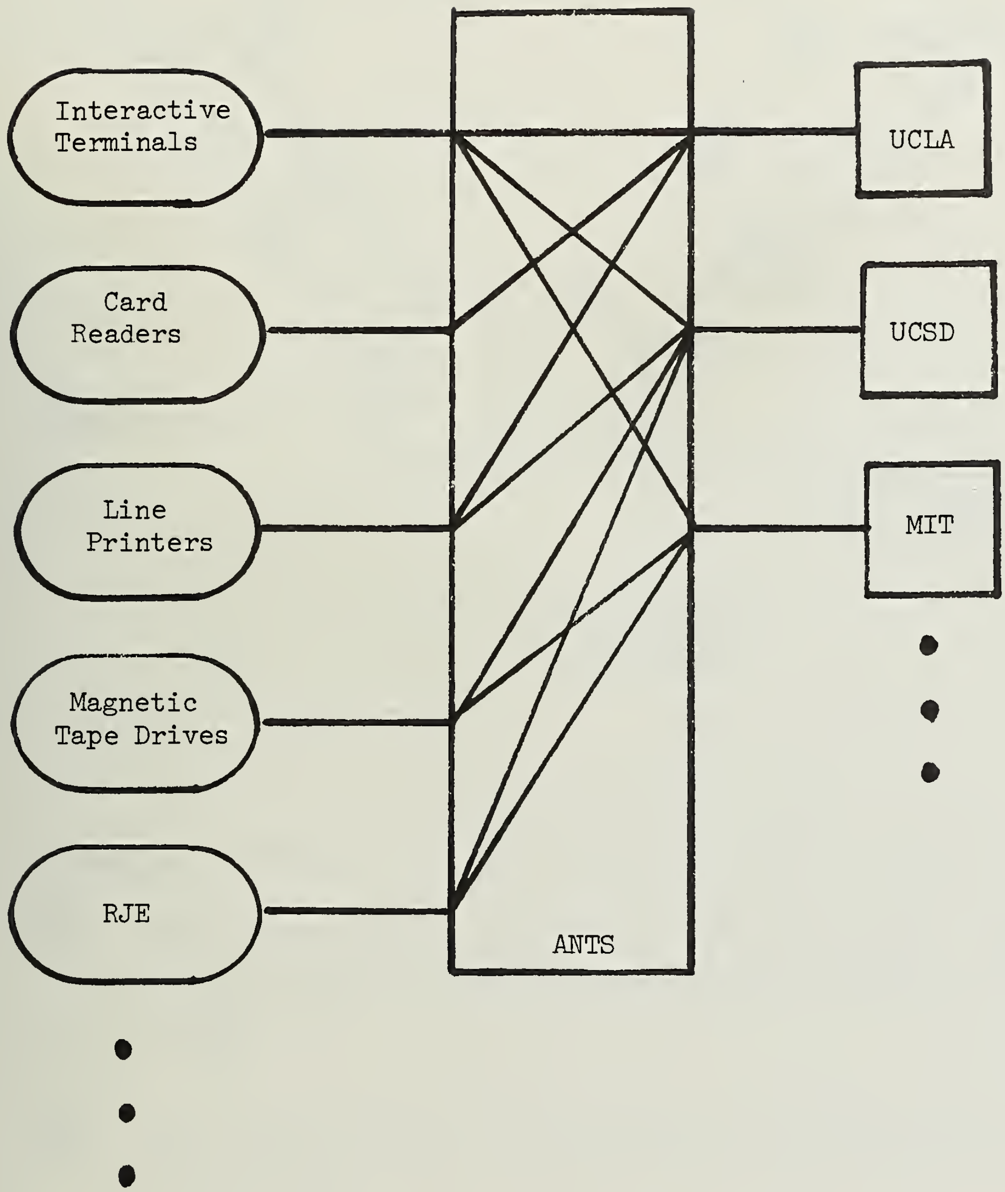


Figure 2

The ARPA Network Terminal System (ANTS), developed at the University of Illinois, is a mini-HOST which permits a variety of local peripherals to simultaneously attach to any ARPANET HOST(s) for input or output functions.

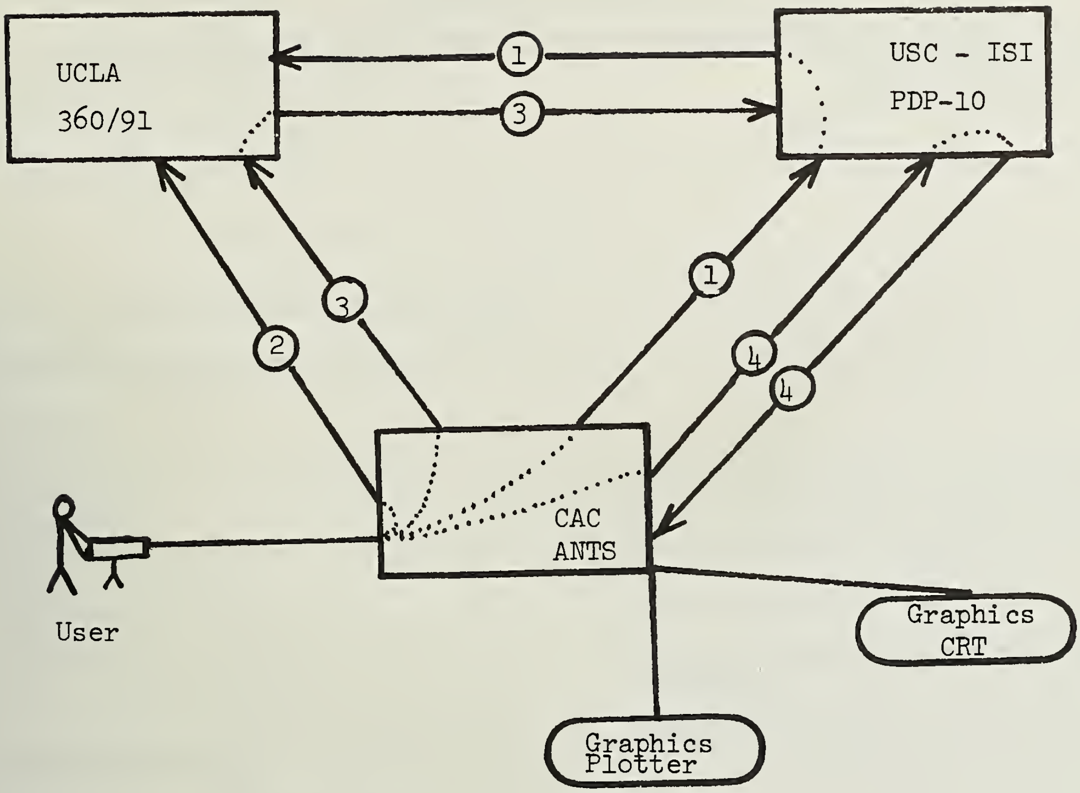


Figure 3 (details of ARPANET hardware have been omitted)

(1) : User interactively creates a file at USC-ISI which contains a 360/91 program and numerical data base. This file is transferred to UCLA.

(2) : User commands UCLA to execute program in batch mode and create a new data base.

(3) : After execution, user commands UCLA to transfer file containing newly calculated numerical data base to USC-ISI.

(4) : User executes graphics program to produce graphical output from numerical data base and transfers to CAC for display.

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13. ABSTRACT

The Center for Advanced Computation is an interdisciplinary research center in the Graduate College of the University of Illinois at Urbana-Champaign. Since August 1972, over 90 percent of the computational resources required by Center staff has been obtained via the ARPA Network (ARPANET). This paper reports on the following: (1) the Center's means of accessing the ARPANET; (2) the Center's reasons for choosing to rely upon networking (although there are a variety of computer systems available locally); (3) the Center's experience in using ARPANET resources; and (4) opinions regarding the future of networking in educational and research environments.

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