SESSION IV

DIGITAL EQUIPMENT CORPORATION USERS' GROUP AND SYMPOSIUM

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The LNR laboratory

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A description of the LNR laboratory computing system is given, and issues related to building a laboratory around a central computing facility are discussed. The system provides a most hospitable and productive environment for the members of the laboratory. Fundamental to the creation of this environment are excellent communication facilities, numerous programming and word-processing tools, and an elegant and powerful operating system.

Based upon experiences in the Lindsay, Norman, and Rumelhart (LNR) laboratory at the University of California at San Diego (UCSD), we discuss a number of issues relating to the operation of a laboratory using a central medium-sized computer. First, a brief history of the laboratory is given; second, the hardware and software configuration of the LNR laboratory is described; third, the current uses of the equipment are briefly surveyed; and fourth, the virtues and problems that result from designing a laboratory around a central machine are discussed.

HISTORY

The LNR laboratory is a cognitive psychology laboratory. When it was first started, a primary interest was audition. At that time, the laboratory equipment included a patch panel housing various filters, noise generators, amplifiers, oscillators, and tone generators. These could be hooked up in the desired sequence by the experimenter with switchboard-like patch cables and directed into one or more of six soundproofed booths. The Digital Equipment Corporation (DEC) PDP-9 computer had the ability to control the frequency and amplitude of two programmable Wavetek tone generators, as well as to produce stimuli via D/A converters. The PDP-9 also had a millisecond clock and an interface to keyboards in the experimental booths,

which allowed the recoding of response latencies.

The PDP-9 hardware consisted of 16K words of 18-bit memory, 1 megabyte of fixed-head disk, and DECtapes (small magnetic tapes with a capacity of about .25 megabyte). The operating system was DEC's DOS, and software packages for controlling experiments were written in FORTRAN and assembly language. One of the chief drawbacks was the fact that this was a single-user system. The system had to be dedicated to the single user, whether he or she was running an experiment, analyzing data, or working on a program. Soon, the system was in use 24 h/day; experiments were run during the day when subjects were readily available, and program development went on during the remaining hours. The heavy demand resulted in an expansion with the purchase of an additional system, a PDP-15. The PDP-15 was upward compatible with the PDP-9, and software was developed so that programs written and compiled on the PDP-15 would run on the PDP-9. One problem with this configuration was that the peripherals that controlled experiments were only available on the PDP-9. Thus, experimental software could only be debugged on the PDP-9. However, at least the slowest procedure, the entering and editing of programs, could go on in parallel with experiments.

Another major drawback to the 9/15 system was the small amount of disk space, 1 megabyte on each system. Nearly half of the disk space was consumed by operating system files, such as the assembler and the FORTRAN compiler. The bulk of user storage was off-line on DECtapes. (DECtapes were also the only means of transporting files between the PDP-9 and the PDP-15.) Thus, if one wished to examine a colleague's programs, it was necessary to physically contact the person and borrow the appropriate DECtape in order to make a listing or put the file on-line to edit. The

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limited disk space was also a problem for experiments that collected large amounts of data. Often the experimenter was forced to save the files of other users, remove them, run an experiment and store the data on DECTape, and finally restore the other users' files.

Both of these \$100,000 systems have been replaced by a single \$100,000 system that provides a much more hospitable environment.

HARDWARE

The LNR laboratory has a DEC PDP-11/45 with 124K words of memory. Very little of the hardware is DEC supplied; rather, severe budgetary constraints made buying an all-DEC system impossible. An 11/45 class processor with the desired peripherals was out of the question. In order to afford a more powerful processor along with the desired peripherals, a "mixed-vendor" system was purchased. On the LNR system, only the CPU, cabinets, and a few interfaces, which were only available through DEC, are DEC products. Of the DEC products, several, including the CPU, were purchased as used items. All of the other peripherals are non-DEC, including two large disks, a magnetic tape unit, floppy disks, and most of memory. There are a large number of manufacturers who make PDP-11-compatible products. Often, these products cost less than the DEC parts they imitate, have better delivery times, and sometimes provide better performance.

The problem generally encountered with mixed-vendor systems, and the reason they are usually avoided, is maintenance. Each vendor will service only his equipment, and it can be difficult to persuade a representative of a vendor that a given fault is in his equipment and not in the equipment of another manufacturer. This often requires providing a "minimal" system with as few "foreign-vendor" peripherals as possible, which will still demonstrate the fault. This can be a painful, frustrating, and virtually impossible task for the user. The ideal solution is to find a good maintenance company that will service a mixed-vendor system; then many problems vanish. We have had reasonable success with an independent maintenance company and our mixed-vendor system.

Several custom interfaces provide connections to laboratory peripherals in six experimental booths. In each booth, it is possible to present auditory and visual stimuli (via terminals or scopes) and to record responses via keyboards. One custom interface provides both DMA A/D and D/A for the booths. In addition, there are TTL-compatible I/O buffers and a DMA point-plotting system that presents visual stimuli on oscilloscopes in the booths. Also, there are 32 serial lines that can be connected to terminals in the booths, in offices, or to external computers or terminals over dial-up telephone lines.

The other major peripherals include two 67-megabyte

"hard" disks, an industry-compatible magnetic tape, and a dual-drive floppy disk. The disk drives (a DIVA Computroller VI with Ampex 980 drives) are 3330 technology with moving heads and five platter-removable disk packs. However, because the software is disk based, the packs are, in fact, never removed during normal operation. The floppy disks (DEC compatible) are used for personal storage and archiving by users. They also occasionally provide a convenient transportable medium between our site and other installations. The magnetic tape serves two purposes: It is used to back up and archive the system as a whole, and it provides another, more system-independent, transportable medium. Table 1 summarizes the hardware configuration.

THE OPERATING SYSTEM

The UNIX operating system is run on the LNR computer. UNIX is, in many ways, the state of the art in computer operating systems, and many of the virtues associated with the LNR system derive directly from UNIX. It is an interactive system, designed at Bell Labs, which provides a most hospitable programming environment with facilities far too numerous to allow mention of all of them here. These facilities include a powerful command language interpreter, efficient file system with a convenient interface, excellent interuser communication facilities, powerful word-processing programs, and a variety of programming languages. In addition, numerous enhancements to UNIX are available in the university community. An overview of UNIX is presented in a paper by its originators, Ritchie and Thompson (1974).

USES OF THE SYSTEM

Due to the breadth of interests represented within the laboratory, the LNR system is required to support a wide variety of experimental and related work. The system serves the members of the laboratory in a number of ways. First, it is intended that virtually any experiment of interest to a cognitive psychologist can be readily run. The system is currently employed in studies ranging from speech perception to investigations of complex learning and tutoring situations. Second, the system makes possible efficient and convenient communication among the approximately 40 people associated with the laboratory. Third, the system provides a potent and convenient word-processing system for producing papers and reports. Finally, the system houses several artificial intelligence languages, including LNR's cognitive simulation language, Microsol.

In order to provide a flexible research environment, the software interfaces that control the various laboratory equipment were designed to be as general as possible. User-oriented packages were developed that

Table 1
LNR PDP-11/45 System Summary

CPU	DEC 11/45 DEC KT11-C DEC FP11-B	CPU with 16K core and expansion cabinet Memory management unit Floating-point unit
Memory	Fabri-Tek 1100	124K words
Serial Interfaces	DEC DL11-W DEC DH11 DEC DH11	Console interface 16-channel interface; DMA output 16-channel interface; DMA output
Custom Interface	LJE IOB11 LJE DCS11	Laboratory peripherals and keyboards DMA A/D; double buffered; scans multiple channels each sample cycle 14-bit D/A; DMA double buffered
Timers	LJE DCS11 DEC KW11-L DEC KW11-K	Clock used for timesharing Dual programmable clock for timing latencies, etc. Battery-powered clock and calendar
Disk	DP TCU-100 DIVA Comp V	RP04-compatible disks (2) 67 megabytes per drive
Floppy	CR FS-11	Charles River dual drive
Magnetic Tape	Cipher Mark IV	Nine-track tape
Graphics	LJE PGS-11	Custom DMA point-plotting system
Plotter	HP 7221a	Graphics plotter
Printer	HI 8210	Houston Instruments 2,400-line/min printer
Modems and Autodialer Terminals	ADM-3A H 1500 Diablo 1620	12 Lier Siegler CRT terminals 8 Hazeltine 1500 terminals 2 letter-quality terminals

provide a clean interface between specific user requirements and the very general operating system drivers. If a user requires a new use of a given laboratory peripheral, usually only a new user package is needed, rather than delicate modifications to the operating system.

A hypothetical snapshot of activity on the system might serve to convey the myriad of concurrent uses of the LNR system. Such a snapshot might reveal the following: One member of the group is working on a paper from his home and has escaped from the editing program to send a message over the ARPA net, another member is analyzing some experimental data, a third person is running a Microsol simulation program of the Flow Tutor and has another program running that will inform him when someone signs on the system, a fourth member of the group is plotting graphs for inclusion in a paper, another is sending a message, a student is working on a thesis, a researcher is running an experiment, and others are engaged in activities ranging from playing the game of adventure to preparing stimulus files for future experiments.

ADVANTAGES

The single greatest asset of the LNR system is undoubtedly the UNIX operating system. Software is, after all, the way in which users interact with the hardware, and it is what gives a system its most "visible" characteristics. UNIX has a very nice "feel" to it; indeed, it often feels as if there is a much more powerful CPU responding to one's requests. The user command interpreter, called the SHELL, has a simple but powerful

syntax that allows the user to do such things as "redirect" input to or from designated files or chain series of programs together with "pipes." A pipe is a buffering device that accepts the output of one program and passes it as input to another program. This facility permits one to write programs such as "sort," "pattern recognizer," or "pretty print." User programs can then be connected to these via pipes to produce sorted or multicolumn or paginated output without the author worrying about the details of quick-sort algorithms, and so on. Since the shell can be programmed (a series of shell commands written into a file as a script), a naive user can be productive after a very short time on the system.

Another side benefit of UNIX is its main programming language, C. Even though FORTRAN, BASIC, and assembler language are available under UNIX, the LNR laboratory has encouraged the use of C. The C constructs are designed in accordance with the principle of structured programming, and they can be employed to develop clear, concise, and efficient programs. This, again, is a virtue when dealing with non-computer-oriented users, because it allows them to share fairly equally in the general program pool. Also, the majority of software that comes with the distributed UNIX system is written in C, including about 90% of the operating system itself. This allows users to understand and modify for their own use many of the distributed programs.

A number of the virtues that users of the LNR laboratory experience derive directly or indirectly from the excellent communication facilities available with

UNIX. In a large laboratory, the value of such facilities cannot be overemphasized. The message system is one important aspect of these communication facilities. It makes possible a most convenient means of sending and reading mail. There are a number of distinct advantages to this form of communication. First, since any message can be automatically fanned out to any chosen set of recipients, it permits a group of people to be constantly informed about any matter of shared interest. One can set up message groups such as software or hardware with the recipients of the messages being those individuals responsible for the given area. This provides an excellent means of documenting problems and suggestions. Much of the communication within the laboratory, sometimes even between people in offices separated by only a few paces, involves the message system. A second advantage of this form of communication is that it allows one to peruse mail at his or her convenience and to maintain a greater mastery of time.

Another facility that users of the LNR system enjoy is a variety of word-processing programs. In addition to a number of text editors used in the preparation of programs and manuscripts, a very flexible text formatting program is available. The program allows a manuscript to be output according to various style specifications, including those suggested by the American Psychological Association. These facilities are further augmented by programs that check spelling and automatically create, drawing from a master reference file, the reference section of a paper based upon the citations in the text.

The convenient sharing of programs between users is another virtue of a laboratory based on a shared central computing facility. A number of different classes of programs are shared within the LNR laboratory. These include a variety of user-oriented packages to handle various pieces of laboratory equipment. For example, a plotting package is available that permits the presentation of visual stimuli on the oscilloscopes in the experimental booths with very precise control over stimulus onset, duration, and brightness. In addition, there are, of course, numerous packages to perform specific classes of experiments and to analyze data.

The large amount of available disk space plays an important role in the process of program sharing. Most user files can reside permanently on disk, and writing data files out to floppy disks when they are no longer being actively analyzed is encouraged. The uniform hierarchical structure of the UNIX file system makes it easy for one user to peruse another's files. Often the program for running an experiment requires only a minor modification to another user's program.

Another facility afforded the members of the LNR laboratory is a locally written simulation language, Microsol. Microsol is a language designed to allow the implementation of models based upon the concept of active semantic networks.

It should be apparent that the LNR system provides a most hospitable and productive environment for the members of the laboratory. Fundamental to the system are the excellent communication facilities, myriad programming and word-processing tools, and elegant and powerful operating system.

PROBLEMS

One problem that occasionally occurs results from the powerful feel of UNIX. Because a person becomes so accustomed to such facile response from the system, it is easy to forget the computational bounds of the system and make requests that require an inordinate amount of CPU time or number of disk accesses. For example, GREP, a very powerful program provided by UNIX, searches a file for lines that contain some specified expression. It is easy to forget how much processing is involved in multiple GREPS of a file and to initiate a process that makes very heavy demands on the system.

The major problem that has resulted from designing the LNR laboratory around a central computer stems from the difficulties of providing normal timesharing services on the system while, at the same time, meeting the real-time requirements of many experiments. The general philosophy of timesharing involves the sharing of the CPU and main memory between a number of processes. Usually, not all of the processes can reside in main memory at the same time and thus they must be swapped in and out of memory. It is probably obvious how this timesharing philosophy can conflict with real-time processing. There exist the related problems of being able to synchronize with external events and of having control of the processor at the appropriate times.

Many of these problem areas are addressed by real-time operating systems. However, the myriad advantages of UNIX encouraged us to modify it to do a limited amount of real-time processing. Since the bulk of the operating system is written in a high-level language, C, such modifications are greatly facilitated. The implementation of software drivers for our nonstandard laboratory peripherals was also facilitated by the fact that they could be written in C rather than in assembly language. In fact, other than drivers, very little modification to the UNIX kernel has been required. The majority of the LNR laboratory peripherals are DMA devices, and as such, do not require constant CPU attention. The non-DMA devices are interrupt driven and are serviced via the normal PDP-11 hardware interrupt mechanism.

ALTERNATIVES

The decreasing cost and increasing power of current and proposed microprocessors suggest a number of alternatives to building a laboratory around a single

central computing facility. While a complete specification of the range of options available is beyond the scope of this paper, the major alternative is to provide some form of distributed system.

One alternative is to make use of microprocessors in each of the experimental booths. The programs for running experiments would be written and compiled on the central machine, and then "down-line loaded" into the microprocessors. They would communicate with the central computer but locally handle the real-time requirements associated with experiments. Satellite processor systems such as we envision have been implemented (Lycklama & Christensen, 1978) and are in use in a number of projects at Bell Laboratories (e.g., Wonsiewicz, Strom, & Sieber, 1978). Such an organization provides the experimenter with a powerful

timesharing system, as well as the real-time response necessary for controlling experiments. A real-time process is free to use as much of the resources of the satellite processor as it requires. It could even be CPU bound without affecting the response to other users.

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