A HIGH PERFORMANCE GRAPHICS SYSTEM FOR THE CRAY-1

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ABSTRACT

This paper describes the design and implementation of a state-of-the-art interactive vector graphics system connected to the CRAY-1 supercomputer. The primary design goal for this graphics system is that it support large hydrodynamic computer programs used in weapons design calculations. The interactive use of these programs requires displays consisting of up to 20,000 vectors, extensive interaction tools, and high-bandwidth communication rates. The major system components selected for this project were an Evans and Sutherland Picture System 2 and a Digital Equipment Corporation (DEC) PDP-11/70 and PDP-11/34 running the UNIX operating system.

This paper presents the system design goals and performance criteria. The hardware/software systems chosen for this project are reviewed, and the integration of this system into the Los Alamos Scientific Laboratory's (LASL) Integrated Computer Network (ICN) is described. This implementation involved most areas of applied computing, including computer graphics, communications, distributed processing, and computer security. The level of effort required for this implementation is described, and the results and benefits are presented. Future plans for this system are also briefly described.

Key Words: Computer Graphics, High Performance Graphics System, Picture System 2, CRAY-1.

CR Categories: 8.2

INTRODUCTION

The Los Alamos Scientific Laboratory (LASL) is engaged in many areas of scientific research, including laser fusion, plasma physics, and weapons design. These applications perform extensive computer simulations that aid in understanding these topics. These simulations use approximately 90% of the LASL computer time. To aid researchers in running these computer programs, a refresh graphics system was developed (Sanders Graphics System) that allows users to interact with their large simulation programs [Gama-Lobo and Maas, 1975]. This interaction allows information to be graphically displayed and modified. The benefits derived from this system were, and continue to be, great.

The operating system that supports this graphics system will be replaced in October 1978. There was no question about the usefulness of the Sanders Graphics System, so when the decision was made to change operating systems, a decision was also made to replace the Sanders Graphics System. It was this decision that led to the acquisition of the High Performance Graphics System (HPGS). In this paper the goals of the HPGS, system selection, system components, integration, resulting system, and future plans for the HPGS will be discussed.

Goals of HPGS

When the decision was made to replace the Sanders Graphics System, it was decided that the new system should take advantage of new technology as well as new techniques, and would be a more general-purpose system to satisfy the needs of a greater portion of the work being done at LASL. This required a stand-alone capability with sizable calculational power. A major design goal was to provide for distributed processing to remove the small calculational tasks from the large machines and place them in a more suitable and hospitable environment. "Timely" responses from tasks in other worker computers, as well as a reasonable process-to-process communications path between computers, were recognized as necessities for efficient distributed processing.

Other goals included a relatively high bandwidth ($\geq$ 1 megabit/second) to other worker computers, a high level of local interaction, capability to display up to 20,000 0.5-inch connected vectors, and a graphics processor that would perform as many operations by hardware as possible.

System Selection

The selection of the major HPGS components was influenced by many factors. The final selection consisted of an Evans and Sutherland Picture System 2 graphics processor and associated peripherals, a Digital Equipment Corporation (DEC) PDP-11/70 computer, a DEC PDP-11/34 computer, and the UNIX [Ritchie and Thompson, 1974] operating system running on both computers. Figure 1 shows the HPGS configuration and system components.

The Picture System 2 was selected because of its ability to perform manipulative graphics operations quickly, its high-speed vector generator, and the hardware architecture.

The DEC PDP-11/70 was chosen as the general-purpose computer for several reasons. Included in these reasons are the calculational speed of the computer, the ease (and cost) of interfacing it to the Picture System 2, and the ease (and cost) of interfacing it to the ICN. When the system was designed, it appeared that a 32-bit computer architecture would be better suited to the applications that are to be run on the HPGS, but monetary and time constraints prevented the acquisition of that class of computer.

The DEC PDP-11/34 computer was required for economic, security, and expansion reasons. It will be located in the users' work area and will serve as a graphics concentrator.

The UNIX operating system was chosen because of ease of use, the time-sharing nature of the system, and the benefits derived from having software available from other UNIX systems in the ICN. These reasons were sufficient to override the fact that support software for the Picture System 2 would have to be written since Evans and Sutherland does not currently support UNIX.

INTEGRATION

The integration of the hardware and software is being accomplished in three phases. The first phase involved the direct connection of the PDP-11/70 to the CRAY-1. This link can operate at speeds up to 4 megabits/second and was used for the initial development of the communication protocol and task synchronization. Phase 2 of the project involves connecting the PDP-11/34 into the system and "remoting" the PDP-11/34 and Picture System 2 to the users' work area. Phase 3 (shown in Fig. 2) comprises connecting the HPGS PDP-11/70 to the LASL ICN as a worker machine. When this work is completed, the system will be able to communicate with any of the large worker computers in the LASL computing network.

The ICN provides computer services for a wide variety of Laboratory projects. The major worker computers are the CRAY-1, four CDC 7600s, two CDC 6600s, and a CDC Cyber 73. In addition, other computers support such things as a Common File System (CFS), File Transport (FT) between worker computers, and terminal access to the ICN. Currently, the ICN is supporting over 900 terminals throughout the Laboratory. These include

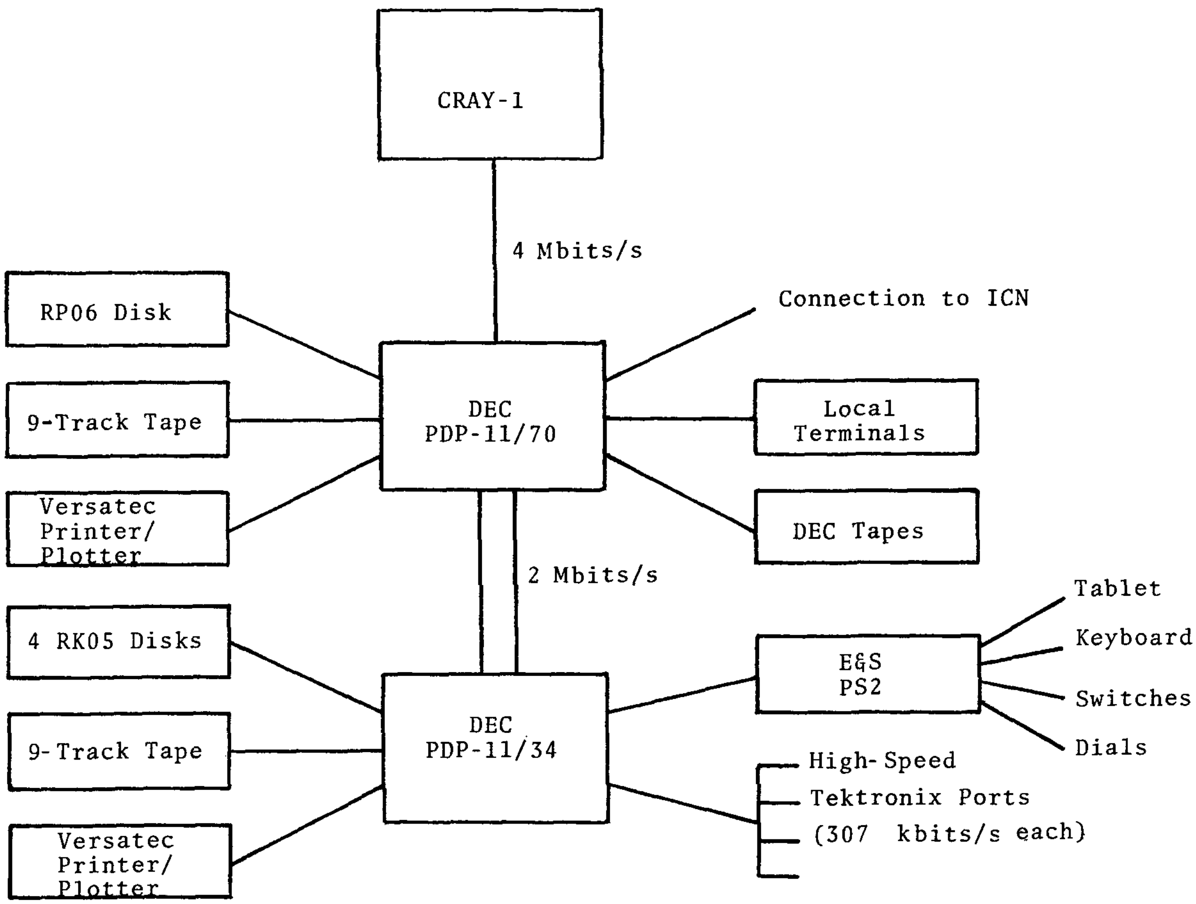

Fig. 1. HPGS Configuration.

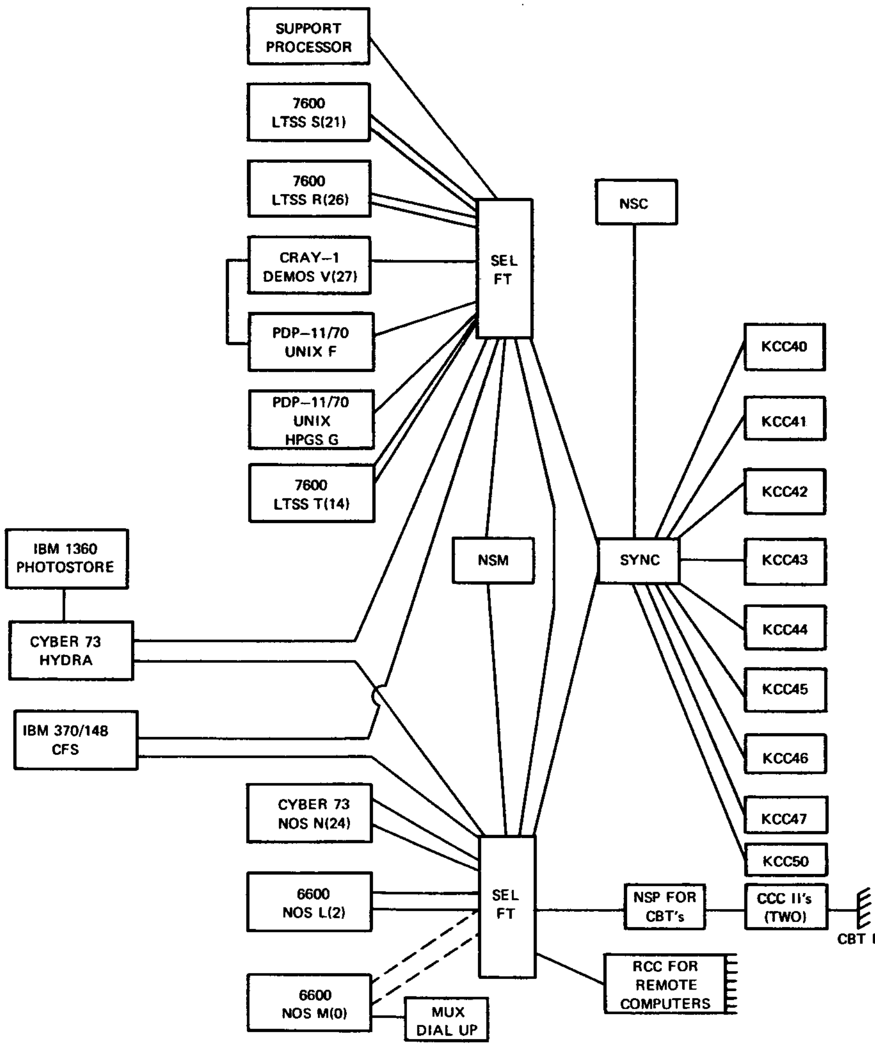

Fig. 2. Future ICN Configuration.

hard-copy, alphanumeric CRT, Tektronix graphics, and intelligent terminals.

Since it was decided to run UNIX on the PDP-11/70, it was necessary to develop software to drive the Picture System 2 under UNIX. Since most of the potential users of the system were very familiar with FORTRAN, a FORTRAN implementation was selected. A Picture System 2 UNIX I/O driver, written in the "C" language, was obtained from the University of California, San Francisco, [Ferrin, 1977].

It was determined that the standard UNIX FORTRAN would not provide the necessary support, so a FORTRAN compiler from Princeton University was obtained. Interface routines between the FORTRAN system and the I/O driver were developed in assembly language. After considerable deliberation, it was decided to provide a set of FORTRAN-callable routines with the same names and calling sequences as those normally provided by Evans and Sutherland [Evans and Sutherland, 1977]. These routines provide windowing, viewporting, transformation, matrix generation, vector generation, device control, and interaction facilities. This software package provides the same facilities and user interface as other Picture System 2 installations. A FORTRAN IV PLUS compiler [CULC, 1977] was obtained and all software was converted. When using the FORTRAN IV PLUS compiler, execution times were decreased about two times compared to the Princeton compiler.

LASL is developing an operating system called DEMOS for the CRAY-1 [Baskett, 1977], so the communication link with the CRAY-1 has proceeded in several steps. To enable HPGS development to proceed concurrently with DEMOS development, the HPGS was connected directly to the CRAY-1 using hardware built by LASL. A FORTRAN communications package was then developed on the HPGS that allowed the HPGS to send and receive files, set and read CRAY-1 sense switches, and set and read portions of CRAY-1 memory. These preliminary facilities enabled a FORTRAN program running on the CRAY-1 to communicate with a FORTRAN program running on the PDP-11/70.

A communication protocol between the two machines was developed using a reserved portion of CRAY-1 memory as a communication area. A large hydrodynamic code that runs on the CRAY-1 was modified to use the communication area, and monitor and display programs were developed on the HPGS. This initial system basically operated as follows:

1. The hydrodynamics code would start running on the CRAY-1, and the monitor code on HPGS.

2. The HPGS would poll the CRAY-1 communication area to determine the state of the program.

3. HPGS would request a data file when one was ready and would display it.

4. CRAY-1 would either continue or suspend execution until a continue signal was received from HPGS, depending on the display mode.

5. When an image was generated on the HPGS, the user could interact by modifying the data. That new data was then sent to the CRAY-1 for continued processing.

This initial system supported the operation of the HPGS and allowed development to continue on both the CRAY-1 application software and HPGS monitor and display programs. A sample hydrodynamic mesh generated by this system is shown in Fig. 3.

As DEMOS development continued, more process synchronization and communication tools became available. DEMOS allows a task (program) running on the CRAY-1 to communicate directly with another worker computer by sending variable length messages. This replaced the HPGS polling mechanism and enabled both machines to be used more efficiently.

Since the HPGS is intended to service several different graphical operations, drivers and software were also implemented to support Tektronix 4000-series terminals, FR-80 microfilm recorders, and a Versatec printer/plotter. The support of all of the different graphics devices will probably be unified under the LASL Common Graphics System [Kellner, 1978; Reed, 1978].

Because LASL does classified computing, security requirements (distinct from privacy requirements) had to be considered in every phase of HPGS development. These requirements necessitated

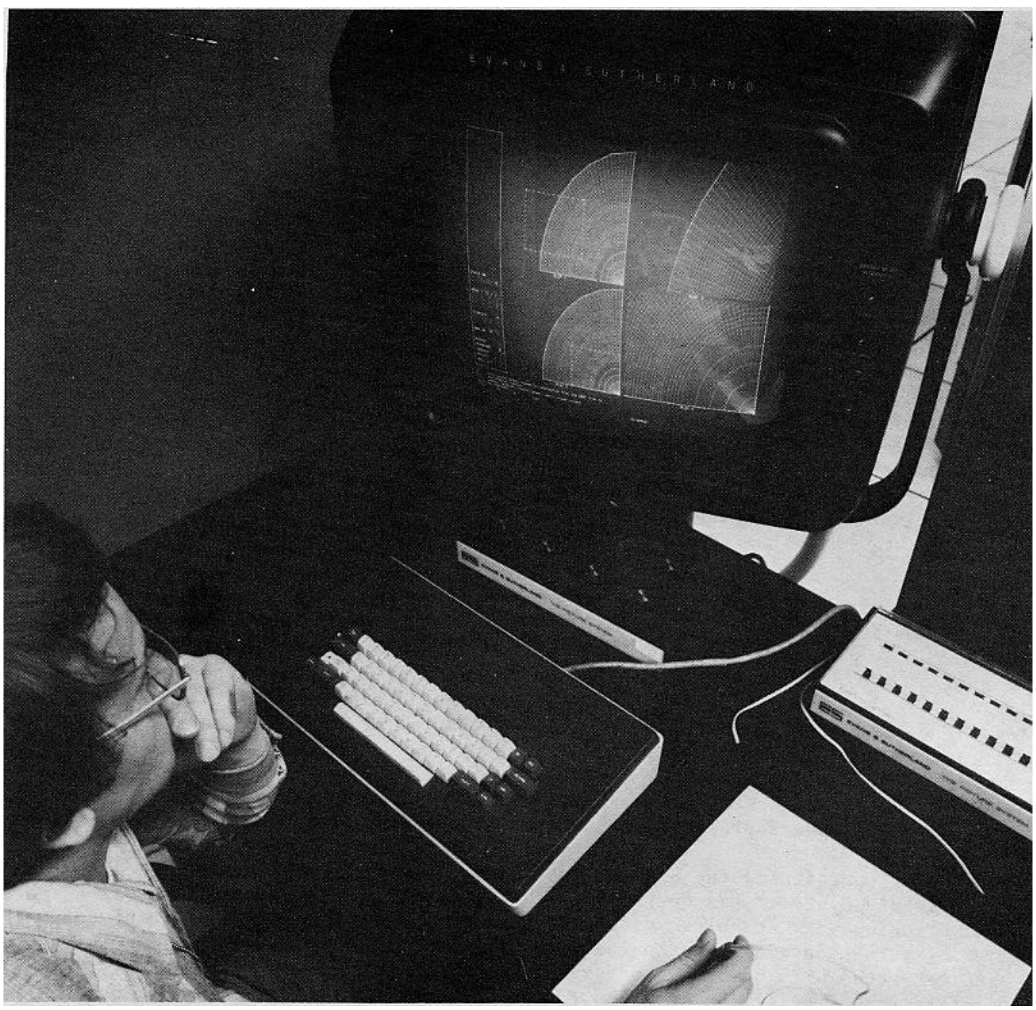

Fig. 3. Sample Hydrodynamics Mesh.

changes in UNIX, the I/O drivers, the graphics software, and system utilities.

The HPGS project has followed a phased development scheme, and the software, hardware, and communication links have been constantly upgraded. Table 1 gives a rough outline of the improvements in the HPGS system as certain hardware and software was installed or updated.

TABLE 1

RELATIVE EFFECTS OF IMPLEMENTATION STAGES

	Description	Performance*
1.	Initial system - no graphics software	0
2.	Mesh Application under Princeton FORTRAN	1
3.	Software segmentation added (objects)	1.2 - 1.5
4.	Graphics software converted to FORTRAN IV PLUS compiler	2
5.	Communication software converted to FORTRAN IV PLUS and RP06 disk installation	5

*Note: The numbers in the performance column indicate improvements in performance relative to item 2 (the first usable system).

The integration and development of the HPGS project has involved a large software development effort. Certain software was adopted from other development activities, and the effort involved in implementing this software cannot be accurately reported. However, the effort required to design, implement, and document certain parts of the HPGS is given in Table 2. This table is presented only in the interest of giving future system designers and implementors some idea of the time required for certain tasks.

RESULTING SYSTEM

A primary goal of the HPGS project is to provide an effective replacement for the Sanders graphics system. The Sanders is connected directly to a channel on a CDC 7600, which provides a very high bandwidth (3.2 megabits/second) link. All graphics processing is performed by the 7600, a comparatively powerful graphics processor.

The HPGS system is approaching the Sanders in capability. The Picture System 2 has operated in a stable fashion, allowing very complex displays to be generated. Pictures containing up to 14,000 vectors have been generated with no picture degradation. The interaction facilities are handled locally in the HPGS and provide facilities that are comparable to the Sanders.

TABLE 2

EFFORT FOR CERTAIN TASKS

	Task	Effort (Person-month)
1.	UNIX familiarization	1-2
2.	Picture System 2 Software	8
3.	FORTRAN-callable CRAY-1 communication package	3
4.	Security within UNIX	6
5.	HPGS Monitor Program	1
6.	HPGS Mesh Display Program	4
7.	System Documentation	2
8.	Consulting	2

It should be noted that the HPGS provides some additional benefits. The HPGS will be able to operate with any of the ICN worker machines, thus allowing more flexibility when a machine failure occurs. It can process graphical and problem data, relieving the large worker machines of these tasks, and allowing more efficient use of machines. The HPGS also provides a general-purpose, stand-alone graphics capability that can be used by other Laboratory projects.

FUTURE

The HPGS has just begun to be used in the production environment. As its production usage increases, several development projects continue. Among these projects are the completion of the network link to enable connection to any other network machine and to the file storage machines. As more graphics devices are supported on HPGS, the software support will be unified using the LASL Common Graphics System. In the hydrodynamics application, more work will be done in the distributed processing area to more efficiently use the HPGS and CRAY-1.

In the hardware area, it is envisioned that additional graphics terminals will be connected to the system. A high-speed Tektronix interface has been designed, and Tektronix terminals capable of running at 307 kilobits/second will be installed. Current planning indicates that additional Picture System 2 type terminals will be acquired.

CONCLUSION

The HPGS project has covered most areas of applied computing, including computer graphics, operating systems, telecommunications, distributed computing, security, and application programming. The resulting system can be used effectively in weapons design. The system provides a high-bandwidth communication link to the CRAY-1, allows complex images to be generated, and provides for user interaction.

The cost effectiveness of the system cannot be readily measured. The hardware for the entire HPGS project cost approximately $250,000, and about three person-years of effort have been expended. However, when the cost of a single underground test is considered, the cost of the HPGS project is less significant. The weapons designers who have used the system indicate that it is a necessity in their work. It has allowed them to speed the design process by as much as ten times and to do complex design calculations that otherwise could not have been attempted.

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