# COMPUTER GRAPHICS SYSTEMS

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## ABSTRACT

Three-part presentation dealing with different classes of computer graphics systems are included in this article. The first part is about a supercomputer graphics system, the second part is about mini-supercomputer graphics systems and the last one about computer graphics workstations. System architecture, operations and system evaluations of these computer graphics systems are surveyed.

In the concluding part of this article, a system engineering approach is proposed for designing and constructing a meteorological data visualization system. The following topics are discussed: graphics system operation requirements, system architecture, individual system selection guidelines, system integration and implementation, and system operation and maintenance.

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# 1 A SUPERCOMPUTER GRAPHICS SYSTEM

## 1.1 INTRODUCTION

This is an overview of a computer graphics system using a supercomputer Cray XMP, in operation at Digital Productions (DP), Los Angeles, California, U.S.A. from 1983 to 1987. This computer graphics system was very unique in that a scientific supercomputer was used solely for computer graphics applications. The DP computer graphics system was used for producing movie special effects, TV commercials and videos.

Before the advent of today's mini-supercomputer graphics systems and high speed computer graphics workstations, the Digital Productions system at that time was considered avant-garde in the field of computer graphics system design. It also made computer graphics history for its phenomenal capital expenditure and number of people involved in system development and applications. This system no longer exists today; however, it might very well have inspired the design of contemporary computer graphics systems. Today, some people who have previously worked on the DP computer graphics system are actively engaged in developing mini-supercomputer graphics systems and workstations.

This article is intended to be used as a historical review paper of a supercomputer graphics system or, for its content, as a reference for computer graphics system design.

The brand names, company names, and trademarks used herein are for demonstration purpose only. The author does not endorse products or services rendered by the named companies. For brevity's sake, no bibliographic references, footnotes to brand names, company names or trademarks are provided.

## 1.2 SYSTEM ARCHITECTURE

Digital Productions had a computer graphics system installation, as shown in Figure 1, with a supercomputer, two front-end main frame mini-computers, a host of graphics equipment and communication networks. A user could be logged on to a user terminal and execute application programs for generating computer graphics products.

### 1.2.1 HARDWARE

#### 1.2.1.1 Computers

##### 1.2.2.1.1 Supercomputer

Cray: DP started with a Cray 1S machine that was upgraded to an XMP in less than a year. The Cray XMP was a model 22300. It had two central processors, two million words (16 Mega Bytes, MB) of central memory and an I/O sub-system with an additional 8 million words (64 MB) of buffer memory and three high-speed (850 Mega bits per second, Mbps) channels. The XMP ran the Cray Operating System (COS), version 1.14 and 1.15, and could reach speeds of 400 Mega FLOPs (MFLOPs). The Cray could be logged onto from three operating consoles and operated independently of other computer systems.

##### 1.2.1.1.2 Front-End Main Frame Mini-Computers

Digital Equipment Corporation (DEC) VAX: The DEC VAX 11/782 with DEC VT100 Terminals provided user access to the VAX and Cray XMP. The VAX supported two paths to the Cray XMP via front-end interface (FEI) devices attached to two DEC DR-70 interfaces. Each FEI was supported by a software station program that controlled access to the device by users on the VAX. One FEI ran the Cray Research, Inc. VMS station product providing both interactive and batch access to the Cray via the VAX and any DECNET modes, and the other ran a DP developed station that supported high-speed transfer of graphics data to the VAX from the Cray XMP.

International Business Machines (IBM) VM: The IBM 4331-2 VM/SP with IBM VM Terminals was attached to the CRAY XMP via an FEI and ran the Cray VM/SP station product, which also supported both batch and interactive access to the Cray XMP from the IBM VM Terminals. Stand-alone communications processors on the 4331-2 provided remote telephone line access to batch and interactive Cray work via the IBM.

1.2.1.1.3 Data Storage Device

High Speed Disc Drives: The Control Data Corporation (CDC) high speed disc drives were used for Cray XMP operations. The DEC and third party disc drives were used for VAX operations. The data on two types of storage devices could not be transferred without going through one provided FEI.

Magnetic Tape Drives: The Cray provided tape drives which were used for reading/writing Cray originated or related tapes. The drives could accept Cray 64 bit per word format and other tape formats. The VAX tape drives were used for reading/writing tapes originated or destined for the VAX. The drives could accept 32 bit per word data tapes and other VAX compatible tapes.

1.2.1.2 Graphics Equipment

1.2.1.2.1 Digitizing Workstations

Three Evans and Sutherland Digitizers (Model PS200) were used for digitizing construction blue prints for making three-dimensional wire frame objects. A three-dimensional object digitizer was also used. This device could digitize a three-dimensional solid object into a wire frame object.

1.2.1.2.2 Animation Devices

Two Interactive Machines, Inc (IMI) Animation Workstations were used to animate the wire frame objects created by PS200.

1.2.1.2.3 Display Devices

Ramtek 9400 and 9460 color graphics terminals were used for displaying color images. There were 1280 by 1024 pixels, and each pixel consisted of three color planes with 8-bit-depth (24 bits total) resolutions. These pixel and color resolutions were provided by the Ramtek 9400 and 9460 Frame Buffers. Ramtek frame buffers also provided a multi-frame, low-resolution animation capability.

1.2.1.2.4 Scanning Devices

A Digital Film Scanner originally designed at Information International, Inc. (III) and refined at DP, was used for digitizing film based images. The scanner was capable of digitizing film with dimensions up to vistavision size and with maximum 2560 x 2480 pixels and 36 bits color resolutions. This film scanner was capable of digitizing image data from film and transferring them to the Cray in under 12 seconds. There was a backup scanning device developed by Data Product, and it was used for low resolution scanning.

1.2.1.2.5 Recording Devices

High-Resolution Film Recorder: A Digital Film Printer (DFP), originally designed at III and refined at DP, was a major film recording device used for film productions. This device was attached to the XMP via one of the 850 Mbps channels on the I/O subsystem. This film printer was capable of accepting graphic image data from the Cray and recording it on film in under 7.5 seconds per frame. It was capable of recording the most commercially available films, in size up to 70 mm and resolution up to 4K x 6K pixel per frame with 12 color bits each for the three principal colors: red, green and blue.

Slow-Speed Film Recorder: The Matrix MX3000 Film Recorder was a backup film recording device for low-resolution film productions. The recorder accepted image data from RAMTEK frame buffers. Thus the pixel and color resolutions were confined by the frame buffers. The maximum pixel resolution was 1280 x 1024 and maximum color resolution was 8 bits for each of three principal colors. The Matrix MX3000 had a very poor performance record. It's down-time exceeded its up-time. A Dunn Instrument film recorder was tested for replacing the MX3000, and it was certain that the Dunn Instrument recorder would outperform the MX3000.

Video Recorder: Video productions were not a major activity at DP. However, the video recorders were available for accepting digital image data and recorded encode format in video. A video encoder manufactured by Lyon-Lamb with a Sony U-matic Video Tape Recorder (VTR) was used for recording low resolution videos. The device received red, green and blue data from Ramtek frame buffers and converted them to analog signals which were subsequently recorded on U-Matic video tape. There was a high-speed, high-resolution Abbekas video recorder. The recorder received data from the Cray I/O subsystem hyper-channel and recorded on its own recorder. This recorder also provided storage and replay capabilities and it was about ten times faster than the Lyon-Lamb recorder.

### 1.2.2 SOFTWARE

The software system accommodated different operating systems and languages. The two dominant operating systems were Cray COS and VAX VMS. UNIX was used for IMI animation workstations, and VM was used for IBM workstation. The major language was Fortran, specifically vectorized Cray Fortran was used as a graphic system development language. Cray Assembly Language (CAL) was used to replace particular, computationally deficient FORTRAN code segments. Fortran, Pascal and C languages were also used for developing software tools for VAX. The C language was also used for developing software for IMI animation workstations; Fortran and Pascal were used for developing software for the PS200 digitizer.

#### 1.2.2.1 General Utility

##### 1.2.2.1.1 Vax

Text Editors (EDIT, EDT, EDI), Compilers (Fortran 77, Pascal, C), and System Utility (DECNET) and Operating System (VAX VMS; Command Languages)

##### 1.2.2.1.2 Cray

Text Editor (TEDI), Compilers (Fortran, Pascal, C), System Utility (DP Station, UK Station), and Operating System (COS 1.14 & 1.15; Command Languages).

##### 1.2.2.1.3 IBM

Text Editor (VM editor), Compilers (Fortran 77, Pascal, C), System Utility (Communication Protocols), and Operating System (VM; Command Languages).

#### 1.2.2.2 Computer Graphics

##### 1.2.2.2.1 Input Data Processing Software for PS200:

Data Formatting: Converting to Movie BYU compatible format; Object Manipulations: Viewing, Scaling, Docking, Grouping, De-Grouping.

##### 1.2.2.2.2 Preprocessing Software for Making Animation Sequence

Command Syntax Generating preprocessor languages Trac and Fifth.

1.2.2.2.3 Animation Control Software

Command Syntax Generator for animation workstation. The software translates joystick and knob motions into command syntax to be used for computing object motions in different frames.

1.2.2.2.4 Data Scanning Processing Software

Data from the digital film scanner were processed by this software. The frame size and bit resolutions would be determined by the user through available interactive viewing/modifying tools. Image compositing, e.g. combining fore-ground objects and back-ground scenes could be accomplished.

1.2.2.2.5 Scene and Object Processing Software

Major software component. Initially adopted codes from Movie BYU software package. It was greatly overhauled and restructured. The finalized software package was developed into two separate software entities:

DP3D -- a Polygon Based Object-Oriented Processing Software.

DPART -- a Ray Tracing Based Object-Oriented Processing Software.

The software would accept output from (1), (2), (3) and (4), and it would generate a sequence of image data which were ready for image data postprocessing before filming or video taping. The software provided a low-resolution animation tool. A user could use the tool to preview an animated sequence.

1.2.2.2.6 Image Data Postprocessing Software for Recording

This software did:

Image Destination: send data to High-Resolution Film Recorder, Low-Resolution Film Recorder, Low- Resolution Video Recorder, or High-Resolution Recorder.

Image Data Formatting: process data for Film or Video Formats.

Image Resolution: process data for different pixel resolutions (e.g. 1280 x 1024, 2560 x 2048, 5120 x 3840, etc.).

Cray Resource Control: use one or two processors.

1.2.2.2.7 Archiving and Retrieving Software

Image Data Compression or Decompression.

Object Data Library.

## 1.3 OPERATIONS

### 1.3.1 UTILITY REQUIREMENTS

A special power supply unit was required for the Cray, VAX and IBM computer complex. The Freon cooling circulating system, room humidity controller, and voltage regulator were mandatory for Cray operations. The air conditioning room temperature control was demanded by Cray, VAX, IBM and other devices. The digitizing, color graphic terminals, film recorders, scanners, and other peripherals required air conditioning but were not critically demanding.

### 1.3.2 MATERIALS

Magnetic tapes were used for backups of different computer systems. The Cray and VAX were scheduled for a weekly full backup and daily incremental backups. The workstations used floppy discs and VAX files for backups.

Film materials were stock-piled. The film supply maintained was sufficient for 3 months' use. There were nominal amounts of video tapes available for video productions.

### 1.3.3 MAINTENANCE

There was a weekly preventive maintenance (PM) conducted by the on-site Cray computer engineers (CEs). The maintenance downtime was scheduled for 4 hours. Parts replacement, diagnostic and system tests were conducted in the PM. The other systems, such as VAX, would do concurrent PM. The display devices and other peripherals were checked periodically. The DP staff maintained all the systems except the Cray.

### 1.3.4 PERSONNEL

At its peak production and optimal operation period (1985), Digital Productions had about 100 employees. There were approximately 7 hardware and 9 software engineers, 10 designer encoders, 12 technical directors and 5 systems operation staff. Those DP people as well as the 4 on-site Cray CEs had direct and daily involvement with the computer graphics system.

### 1.3.5 SYSTEM UTILIZATION

The DP staff made full use of the Cray and other subsystems. The computer graphics system as a whole was in use all the time, except for the night time which was scheduled for daily film recording activities. The latter engendered some production problems for the staff. The VAX with its slow buses became a source of traffic jams at the daily peak in the active period. The number of frame buffers were limited. This limiting factor made the application users often wait for his/her turn to display his/her animate/rendering results.

## 1.4 SYSTEM EVALUATION

### 1.4.1 PROCESSING POWER

In the early 1980s, most computer graphics systems were designed with mini-computers. Digital Productions chose the Cray XMP as the major computing machine for computer graphics applications to shorten the waiting period between animation ideas and their visualization. This unprecedented use of a high-power computer set a trend for future system design. A future system that would surpass the computing power of the mini-computer and realtime animation was a system design goal.

### 1.4.2 NETWORKING

It might not have been included in the original plan, but the DP computer graphics system became a prototype for networking different computers and graphic systems. There were basically two independent graphic systems: VAX and RAMTEK computer graphics system and Cray and Digital Film Recorder/Scanner computer graphics system. These two graphic systems could work independently. However, since the DP computer graphics system was configured with human-interactive input/output devices for VAX only, without the VAX, the Cray and Digital Film Recorder/Scanner System could solely have worked on batch jobs.

The FEI provided a somewhat weak linkage between the VAX and Cray systems. One of the shortcomings of the DP computer graphics system was that the VAX became overloaded with too many tasks, and the performance of the whole system was thus severed. This kind of bottleneck problem has been solved efficiently by the new mini-supercomputer graphics systems. The new mini-supercomputer is a self-contained system whose computer power surpasses the VAX. Moreover, it provides human-interface and fast internal buses to transfer data within the system.

### 1.4.3 EQUIPMENT AND DEVICES

Two propriety devices were used in the DP computer graphics system: the Digital Film Printer and Digital Film Scanner. Those two devices were the salient feature of the system. At that time, the recording speed was fastest and pixel resolutions were the best. However, due to their uniqueness, the recorder and scanner required constant care and numerous engineering modifications. The cost of maintaining these devices was high. For comparison, today a recorder/scanner can be purchased off-the-shelf for a fraction of the previous cost.

### 1.4.4 SYSTEM ENGINEERING

#### 1.4.4.1 Software Engineering

The biggest software engineering effort at Digital Productions went into developing and maintaining the DP3D software package. The DP3D had more than 60,000 lines of codes, and it was developed in a year and a half with about 6 full-time software developers working on it almost around the clock. After completion of the DP3D software implementation, it had been used for graphic productions every day. It had been upgraded almost weekly, and new interactive tools had been added to it constantly.

At its inception stage, the DP3D software was developed in the specific COS environment with little regard for portability to other operating environments. Some program segments did run on other Cray sites with COS environment, and DP did sell a copy of DP3D to Cray Research, Inc. However, due to a subsequent company merger and change-over, most of the software products were lost. Today there remains no visible legacy of Digital Productions' software in the computer graphics industry.

#### 1.4.4.2 Hardware Engineering

DP's major hardware engineering efforts were applied to installing and maintaining the high-speed digital film recorders and scanners. These devices, which were inherited from III, were prototypes that required constant care and modification. Most production jobs required only videos, but DP would produce very high quality film products that would later be transferred to video products. Price-wise, this practice made DP less competitive in the computer graphics industry. This could be a lesson for future system developers: to use a less expensive approach to hardware procurement and implementation.

## 1.5 CONCLUSION

Digital Productions became computer graphics history in April 1987. The installation was dismantled in June 1987. The software and hardware were in the custody of a financial bank, and the Cray computer was reclaimed by the Cray Research, Inc. During that period, hundreds of people lost their jobs.

The bitter DP experience proved to be beneficial to the future development of computer graphics. The hardware systems now available to the users, and which were designed after DP computer graphics system, are less massive, more portable, as well as operationally economically-minded. The recently developed software systems are usually targeted for the UNIX operating system environment and can be implemented in most UNIX based machines.

## 2 MINI-SUPERCOMPUTER GRAPHICS SYSTEMS

### 2.1 INTRODUCTION

In the early 1980s, many computer graphics workstations and mini-supercomputers were developed. The workstations were designed after graphics terminals and relatively inexpensive. Due to lower prices, the workstations were used by computer graphics users much sooner than the mini-supercomputers. Computer graphics users, who were also on the lookout for faster processing machines than a graphics workstation, were aware of mini-supercomputers by about 1983. However, commercialized minicomputers did not reach the consumers until about 1985.

One of the main reasons a user might opt for a mini-supercomputer graphics system could be the affordable price and the system's data processing power. A computer graphics user can appreciate near realtime animation, response and graphics capability of the machine. The very same reasons also accounted for the design goals of the mini-supercomputer graphics system developer. While the system will have the processing power of a fraction of a supercomputer (e.g. Cray XMP), it would nevertheless cost a lot less than a supercomputer.

Today, a few mini-supercomputers are available to computer graphics users at a competitive price. The performance rates about equal, and the operating environment (e.g. UNIX/OS and window interface) is gradually becoming standardized. It is anticipated that the software also will be standardized. The main features of mini-supercomputer graphics systems are to be reviewed henceforth.

This article could be used as a review paper of a mini-supercomputer graphics systems or, for its contents, a reference for computer graphics system design.

### 2.2 SYSTEM ARCHITECTURE

A mini-supercomputer graphics system consists of two major parts: a data processing and a graphics subsystem. Some systems are designed with these two clearly separated, while in others, the two subsystems are combined. The architecture of a typical mini-supercomputer system is shown in Figure 2.

#### 2.2.1 HARDWARE

#### <u>2.2.2.1 Data Processing Subsystem</u>

##### <u>2.2.1.1.1 Processors</u>

More than one and typically 2, 4 or up to 8 processors are used for central processing function. Some parallel processing can be achieved. A CPU processor is often a Reduced Instruction Set Chip (RISC). It has vector, integer and cache units. Each CPU is connected by buses to other CPUs, memory, I/O subsystem, and graphic subsystem.

##### <u>2.2.1.1.2 Memory</u>

Internal memory typically consists of multi-board memory units. Each board has a performance of more than a few hundred Mega Bytes per second.

##### <u>2.2.1.1.3 I/O Subsystem</u>

It typically consists of disc channels, keyboard for operating console, serial and parallel ports.

2.2.1.2 Graphics Subsystem

2.2.1.2.1 Display Unit Input Devices

Keyboard, Mouse, Digitizing Tablet, Knob box and other viewing device (e.g. stereo viewer) are typical for most minicomputer graphics systems.

2.2.1.2.2 Display Monitor

A color graphics monitor has at least 1280 by 1024 pixels, and each pixel consists of three color planes with 8-bit-depth (24 bits total) resolutions.

2.2.1.2.3 Scanning Devices

External and Optional.

2.2.1.2.4 Recording Devices

Film Recorder: External and optional device. For high end film productions, it is typical to have a film recorder capable of recording the most commercially available film formats, high pixel and color resolutions. Some desk top recorders which provide lower color and pixel resolutions are adequate for ordinary science and engineering computer graphics applications.

Video Recorder: External and optional device. Video recorders are available for accepting digital image data and for recording in video encode format (e.g. NTSC or PAL). A high-speed and high-resolution video recorder (e.g. Abbekas) is available for producing high-definition TV. This type of recorder receives data from an I/O subsystem and stores its data locally for replaying and recording.

2.2.2 SOFTWARE

The UNIX operating system is currently the most widely used operating system for mini-supercomputer graphics systems. The major languages are C and Fortran, since these two languages are currently being vectorized efficiently by mini-supercomputers.

2.2.2.1 General Utility

Includes: Text Editors (VI, EMACS and others), Compilers (C, Fortran and others), System Utility (NFS, and software tools).

2.2.2.2.1 Input Data Processing Software

Object Building: Graphics primitives are available for building an object. The building process is highly interactive and easy to build. An object can also be built by digitizing.

Object Manipulations: Viewing, Scaling, Docking, Grouping and De-Grouping can be done with interactive tools.

Data Formatting: External graphics data can be converted to a system software compatible data format.

2.2.2.2.2 Preprocessing Software for Constructing Animation Sequences

Command Syntax Generating preprocessors, and Interactive tools for animation control.

2.2.2.2.3 Animation Control Software

Direct user-controllable animation tools.

2.2.2.2.4 Image Processing Software

Image data can be manipulated. The frame size and bit resolutions can be determined by the user through available interactive viewing/modifying tools. The image compositing, e.g. combining foreground objects and background scene, can be accomplished.

2.2.2.2.5 Scene and Object Rendering Software

Major software component for the graphics subsystems. Scene and objects can be rendered with interactive tools.

2.2.2.2.6 Archiving and Retrieving Software

Data compression and decompression.

## 2.3 OPERATIONS

### 2.3.1 UTILITY REQUIREMENTS

The mini-supercomputer and external devices such as film and video recorders as well as other peripherals require some air conditioning; however, they are not critically demanding.

### 2.3.2 MATERIALS

Magnetic tapes and discs are needed to backup a mini-supercomputer graphics system. Film stocks and video tapes are needed for continuing productions.

### 2.3.3 MAINTENANCE

A weekly preventive maintenance (PM) is recommended. The maintenance downtime needs to be scheduled. Parts replacement, diagnostic and system tests should be conducted in the PM. The display and recording devices as well as other peripherals need to be checked periodically.

### 2.3.4 PERSONNEL

A system manager, a system analyst, a computer graphics specialist, programmers and visualization analysts are recommended staff members.

### 2.3.5 SYSTEM UTILIZATION

For visualization purposes, a mini-supercomputer graphics system is expected to be used during daytime. Recording activities can be scheduled for the night hours.

## 2.4 SYSTEM EVALUATIONS

### 2.4.1 PROCESSING POWER

In the early 1980s, most computer graphics systems were designed with mini-computers; animation and rendering of objects were never done in realtime. Mini-supercomputer graphics systems may bring about the possibility of realtime viewing of rendered object animation. This is a good system for visualization, as long as the system is used by a very limited number of users (excluding simultaneous viewing).

### 2.4.2 NETWORKING

Currently mini-supercomputer graphics systems are used by several supercomputer centers in the U.S.A. for visualization purposes. There are several mini-supercomputer graphics systems that are used as a main system. Whatever the system configuration, it can be networked and resources and data can be shared. The performance of the system is highly dependent on networking efficiency and traffic volume. Commonly used networking protocols are TCP/IP, OSI, Ethernet, and others.

### 2.4.3 EQUIPMENT AND DEVICES

Film and video recorders are no longer propriety items; they can be purchased off-the-shelf. Other peripherals, such as disc drives and tape drives, are gradually being standardized, and they are highly exchangeable and compatible with other systems.

#### 2.4.4.1 Software Engineering

Software design concepts are changing over the years. Computer graphics users do not necessarily develop their own software systems; their preference is to purchase from software system development companies. The development and update are no longer a user's responsibility. The software engineers are concentrating their effort on developing application and service software for the computer graphics users in general.

#### 2.4.4.2 Hardware Engineering

Hardware engineering for the mini-supercomputer concentrates on system integration and performance improvement. The engineers are looking forward to better networking devices, servers, I/O devices and peripherals. Since graphics subsystem devices are readily available, few custom-made systems will be built in the future.

## 2.5 CONCLUSION

The mini-supercomputer graphics system, a late comer, shows promise in realtime animation and object rendering. It has been used in scientific visualization in several computer centers. This system will grow continuously. The processing power will increase, and software systems will be improved and become easy to use. The cost of a mini-supercomputer is expected to decrease, an important factor for gaining a wider user base.

## 3 COMPUTER GRAPHICS WORKSTATION SYSTEMS

### 3.1 INTRODUCTION

Computer graphics workstations, which were based on earlier graphics terminal designs, reached users in the late 1970s and early 1980s. The price of a workstation at that time was about the price of a mini-supercomputer today. Workstations were mostly designed for engineering applications such as CAD/CAM operations. There were also a few workstations designed specifically for computer graphics, and they became available in the early 1980s.

An old-fashioned workstation system was built with a single microprocessor and with a math-coprocessor. Compared to today's workstations, it had limited graphics capabilities, and it was used for wire frame objects animation and/or object building. An old-fashioned workstation was essentially a vector (line) drawing machine.

About 1985, some special Very Large Scale Integrated (VLSI) chips were developed. These VLSIs did mathematical computations for three-dimensional transformations: rotation, translation, and scaling. These mathematical computations, which were normally done by software, were able to be computed by special computing engines. The workstation with such a computing engine VLSI implementation provided enough power for realtime animations of simple shaded objects. This is how the high-power computer graphics workstation development started.

Meanwhile, general purpose workstations have been developed for science and engineering applications. A new, general purpose workstation has used RISC processors to achieve high performance. Since then it has been easy for a general purpose workstation to interface with graphics peripherals and external devices, it can also be used for computer graphics applications.

Today, there are many workstations at a competitive price available to computer graphics users. The performance rating is about on an equal level, and the operating environment (e.g. UNIX/OS and window interface) is gradually becoming standardized. It is anticipated that the software will also become standardized. The main features of computer graphics stations are to be reviewed henceforth.

This article is intended to be used as a review paper of graphics workstation systems or, for its contents, as a reference for computer graphics system design.

### 3.2 SYSTEM ARCHITECTURE

A computer graphics workstation system consists of a data processing and a graphics subsystems. Some systems are designed with these two clearly separated, while others are having the two subsystems combined. Unlike mini-supercomputer systems, a computer graphics workstation system can also be designed by integrating a high-power, general purpose workstation and a graphics workstation. Indeed, since it is a flexible design approach, user designed systems are quite common. The architecture of a typical workstation system is shown in Figure 3.

#### 3.2.1 HARDWARE

##### 3.2.1.1 Data Processing Subsystem

###### 3.2.1.1.1 Processor

One CPU design is typical, but the design trend is one where multiple processors are used. A CPU is often a

Reduced Instruction Set Chip (RISC), and it is coupled with a math-coprocessor or VLSIs to handle heavy computational loads. Internal or external buses connect the CPU, co-processors, VLSI, memory, I/O subsystem, and graphic subsystem.

3.2.1.1.2 Memory

Internal memory typically consists of multi-board memory units, and it is expandable. Each board has a performance of more than a few hundred Mega Bytes per second.

3.2.1.1.3 I/O Subsystem

It typically consists of disc channels, keyboard for operating console, serial and parallel ports.

3.2.1.2 Graphics Subsystem

3.2.1.2.1 Display Unit Input Devices

Keyboard, Mouse, Digitizing tablet, Knob box and other viewing device (e.g. stereo viewer) are typical for most graphics subsystems.

3.2.1.2.2 Display Monitor

A color graphics monitor has at least 1280 by 1024 pixels and each pixel consists of three color planes with 8-bit-depth (24 bits total) resolutions. Some subsystems are designed with color registers, where only limited colors may be displayed at times.

3.2.1.2.3 Scanning Devices

External and Optional.

3.2.1.2.4 Recording Devices

Film Recorder: External and optional device. It can be used for producing high quality films. It is capable of recording most commercially available film formats with high pixel and color resolutions. However, for optimum operations, desk top recorders provide lower color and pixel resolutions and are adequate for ordinary science and engineering computer graphics applications.

Video Recorder: External and optional device. Video recorders are available for accepting digital image data and recording in video encode format (e.g. NTSC or PAL). A high-speed and high-resolution video recording is possible, but on-line, low resolution recording is adequate.

3.2.2 SOFTWARE

The UNIX operating system is currently the most widely used for graphics workstation systems. Some other operating systems are available. The major languages are C and Fortran.

3.2.2.1 General Utility

3.2.2.1.1 Text Editors: VI, EMACS and others.

3.2.2.1.2 Compiler: C, Fortran and others.

3.2.2.1.3 System Utility: NFS, and software tools.

### 3.2.2.2 Computer Graphics

#### 3.2.2.2.1 Input Data Processing Software

Object Building: Graphics primitives are available for building an object. The building process is highly interactive and easy to build. An object can also be built by digitizing.

Object Manipulations: Viewing, Scaling, Docking, Grouping and De-Grouping can be done with interactive tools.

Data Formatting: External graphics data can be converted to system software compatible data format.

#### 3.2.2.2.2 Preprocessing Software for Constructing Animation Sequences

Command Syntax Generating preprocessor and Interactive tools for animation control.

#### 3.2.2.2.3 Animation Control Software

Direct user controllable animation tools.

#### 3.2.2.2.4 Image Processing Software

Image data can be manipulated. The frame size and bit resolutions can be determined by the user through available interactive viewing/modifying tools. The image compositing, e.g. combining foreground objects and background scene, can be accomplished.

#### 3.2.2.2.5 Scene and Object Rendering Software

Major software component for the graphics subsystems. Scene and object colors can be manipulated by using interactive rendering tools.

#### 3.2.2.2.6 Archiving and Retrieving Software

Data compression and decompression routines are included.

## 3.3 OPERATIONS

### 3.3.1 UTILITY REQUIREMENTS

The workstation and external devices such as film and video recorders and other peripherals require air conditioning. However, environmental control is not highly critical.

### 3.3.2 MATERIALS

Magnetic tapes and discs are needed to backup a graphics workstation system. Film stocks and video tapes are needed for continuing productions.

### 3.3.3 MAINTENANCE

A weekly preventive maintenance (PM) is recommended. The maintenance downtime needs to be scheduled. Parts replacement, diagnostic and system tests should be conducted in the PM. The display and recording devices and other peripherals need to be checked periodically.

### 3.3.4 PERSONNEL

A system manager, a system analyst, a computer graphics specialist, programmers and visualization analysts are recommended staff members.

### 3.3.5 SYSTEM UTILIZATION

A graphics workstation system is expected to be used in day time for visualization purpose. For night time, it can be scheduled for recording activity.

## 3.4 SYSTEM EVALUATIONS

### 3.4.1 PROCESSING POWER

A workstation has limited processing and graphics capabilities. It is great for general purpose use and also for animation previewing and preparations. Some graphics workstations have great processing power and graphics capabilities, but then they are usually pepped up with many specialized internal and external subsystems. In this form, a complete system may become as expensive as a mini-supercomputer.

### 3.4.2 NETWORKING

Workstations are usually networked and share resources and data with other workstations and/or host computers. The performance of the networking system is highly dependent on the networking efficiency and traffic volumes. Commonly used networking protocols are TCP/IP, OSI, Ethernet, and others.

### 3.4.3 EQUIPMENT AND DEVICES

Film and video recorders are no longer propriety items. They can be purchased off-the-shelf. Other peripherals such as disc drives and tape drives are gradually being standardized, and they are highly exchangeable and compatible with other systems.

### 3.4.4 SYSTEM ENGINEERING

#### 3.4.4.1 Software Engineering

Software systems are available from software development companies. Since popular workstations are using the UNIX operating system, the software portability is becoming less of an issue. Software developed under UNIX system can be shared by other UNIX users. X-window is an interactive window tool, which can run programs of external computers of different operating systems, will become popular for workstation operations. This feature will enrich the system environment. Again, there will be less software engineering effort for an individual workstation.

The development and update are no longer a user's responsibility. The software engineers are directing their efforts to develop application and service software for the computer graphics users in general.

#### 3.4.4.2 Hardware Engineering

Hardware engineering for workstations is concentrated on system integration and performance improvement. The engineers are looking forward to better processing subsystems, networking devices, servers, I/O devices and peripherals. Since graphics subsystem devices are readily available, few custom-made systems will be built in the future.

## 3.5 CONCLUSION

It can be predicted that more workstations will be used for low-end, realtime animation and object rendering. They have been used in low-resolution, scientific visualization in multi-user's computer centers. Workstation graphics systems will be improved continuously. The processing power will increase, and software systems will become more interactive and easy to use. The cost of a workstation system is expected to be less expensive, an important factor for gaining an even wider user base.

# 4 SYSTEM ENGINEERING FOR A METEOROLOGICAL DATA VISUALIZATION SYSTEM

## 4.1 GRAPHICS OPERATION REQUIREMENTS AND SYSTEM ARCHITECTURE

There are at least three classes of computer systems that can be used for producing scientific visualization materials. Systems in operation today are configured with combinations of these computer systems. The graphics operation requirements dictate system architecture. Several system architecture examples are presented as follows.

### 4.1.1 High Speed and High Resolution System

Users demanding high speed and high resolution graphics can use a supercomputer for its processing power. A user can use a front-ended mini-supercomputer to gain access to supercomputer via a very high bandwidth communication channel.

### 4.1.2 Moderate Speed and High Resolution System

Users demanding moderate speed and high resolution graphics can use supercomputer for its processing power. However, there is no need for high-speed access. The computed results can even be transferred from a supercomputer to a mini-supercomputer in a time-delayed fashion. In a networking situation, two classes of computers can be linked with a moderate bandwidth channel. In a no connecting situation, no communication channel is needed. However, in either situation, a data storage device should be provided for mini-supercomputer for data storage and retrieval.

### 4.1.3 Low Speed and Medium Resolution System

Users demanding low speed and medium to high resolution graphics can choose a system with a single mini-supercomputer or a single high speed graphics workstation.

### 4.1.4 Low Speed and Low Resolution System

User demanding low speed and low resolution graphics can choose a system with a micro-computer that is accessing data from computers equipped with higher processing power. The data access is achieved by using a low bandwidth communication channel.

### 4.1.5 Multiple Speeds and Resolutions System

A system which can accommodate multiple processing speeds and resolutions will be configured with all classes of computers. This type of system architecture is used in some supercomputer centers in the U.S.A.

### 4.1.6 Meteorological Data Visualization System Architecture

An operational scenario for a meteorological data visualization service is that numerical weather prediction model simulation results will be produced periodically. These products are processed into graphics compatible data format and transmitted to a graphics mini-supercomputer. The mini-supercomputer creates graphics image products, where the image is compressed and disseminated to different workstations and micro-computers. A user of a workstation or a micro-computer will decompress, display or reprocess graphics image data using a window menu control. This scenario assumes that graphics resolution reduces at each dissemination step.

Based on this operational scenario, a meteorological data visualization services system will have an architecture similar to the one mentioned in 4.1.5.

## 4.2 INDIVIDUAL SYSTEM SELECTION GUIDELINES

### 4.2.1 Selection Criteria

#### 4.2.1.1 Standard

##### 4.2.1.1.1 Hardware

Communication protocols should be popular ones such as OSI, TCP/IP, and Ethernet, etc. Interfaces should be available for connecting to external devices.

##### 4.2.1.1.2 Software

The software provided by a vendor should be adhered to existing graphics standards. The popular standard software packages GKS, CGM, CORE, PHIGS, and PHIGS+, etc should be available. Most graphics primitives should be easily accessible.

#### 4.2.1.2 Completeness

##### 4.2.1.2.1 Hardware

The hardware system should be modifiable and allow for future expansion. The system should be allowed to add processors, add subsystems, expand memory and increase I/O.

##### 4.2.1.2.2 Software

The software system should be upgradable and allow for future expansion. The operating system, operational environment and programming languages provided should be commonly used and with full supports from the vendor.

#### 4.2.1.3 Cost

##### 4.2.1.3.1 Initial Procurement Cost

The cost of the system should be competitive with that of other similar systems.

##### 4.2.1.3.2 Operational and Maintenance Cost

The operational and maintenance cost should be evaluated before procurement. The cost of operational and maintenance should be comparable with that of other similar systems.

#### 4.2.1.4 System Life Expectancy

This is a hardest selection criterion to be dealt with. A system may become obsolete in a matter of few years. In order to make a better judgement, a constant look at technological trends is necessary.

When a system is under procurement consideration, it is important to examine vital subsystems/components or even look into boards and processors. They should be at least of state-of-the-art technology. The system should be expandable. The manufacturer should be in good financial status.

### 4.2.2 Benchmarking

Benchmarking activities should be conducted before a system is purchased.

#### 4.2.2.1 Conventional Benchmark Tools

System benchmarking tools used for evaluating system performance such as LINPAK, FLUID, a Numerical Weather Prediction Model, etc. should be used for comparing with other competitive systems.

#### 4.2.2.2 Special Benchmark Tools

System benchmarking tools designed by in-house system engineering staff should be used for comparing with other competitive systems. The tools should consist of major components of operational system software.

### 4.2.3 System Acceptance Testing

System acceptance testing activities should be conducted before a system is purchased. The system should be tested with a set of test data. The tests should emulate daily average and peak operating conditions. The test results should be confirmed with original performance specifications.

#### 4.2.3.1 Out-house Testing

The system should be tested by the vendor staff in the presence of an in-house system engineer.

#### 4.2.3.2 In-house Testing

The system should be tested by in-house system engineer team members exclusively.

## 4.3 SYSTEM INTEGRATION AND IMPLEMENTATION

### 4.3.1 System Evaluation

Individual systems evaluated in subsection 4.2 should be finally selected and each system should be evaluated for being part of a whole system. The interfaces should be evaluated also. The performance of an integrated system should be estimated from the individual system performance evaluated in subsection 4.2.

### 4.3.2 Purchasing

After final selection of individual systems, purchasing should be commenced.

### 4.3.3 Installation

Installation site should be selected and prepared for system installation. Power supply, air conditioning, cooling system, and other facility requirements should be prepared. The purchased computer systems should be installed at the selected site.

### 4.3.4 Testing and Release

An integrated system should be tested for its operational performance. If the performance is acceptable, the system should be released for general use.

## 4.4 SYSTEM OPERATION AND MAINTENANCE

The system should be scheduled for operation and maintenance periods. During maintenance, system diagnostics, system upgrade, system testing and other activities should take place. The actual schedule should be planned by system engineering staff.

## 5 ACKNOWLEDGEMENT

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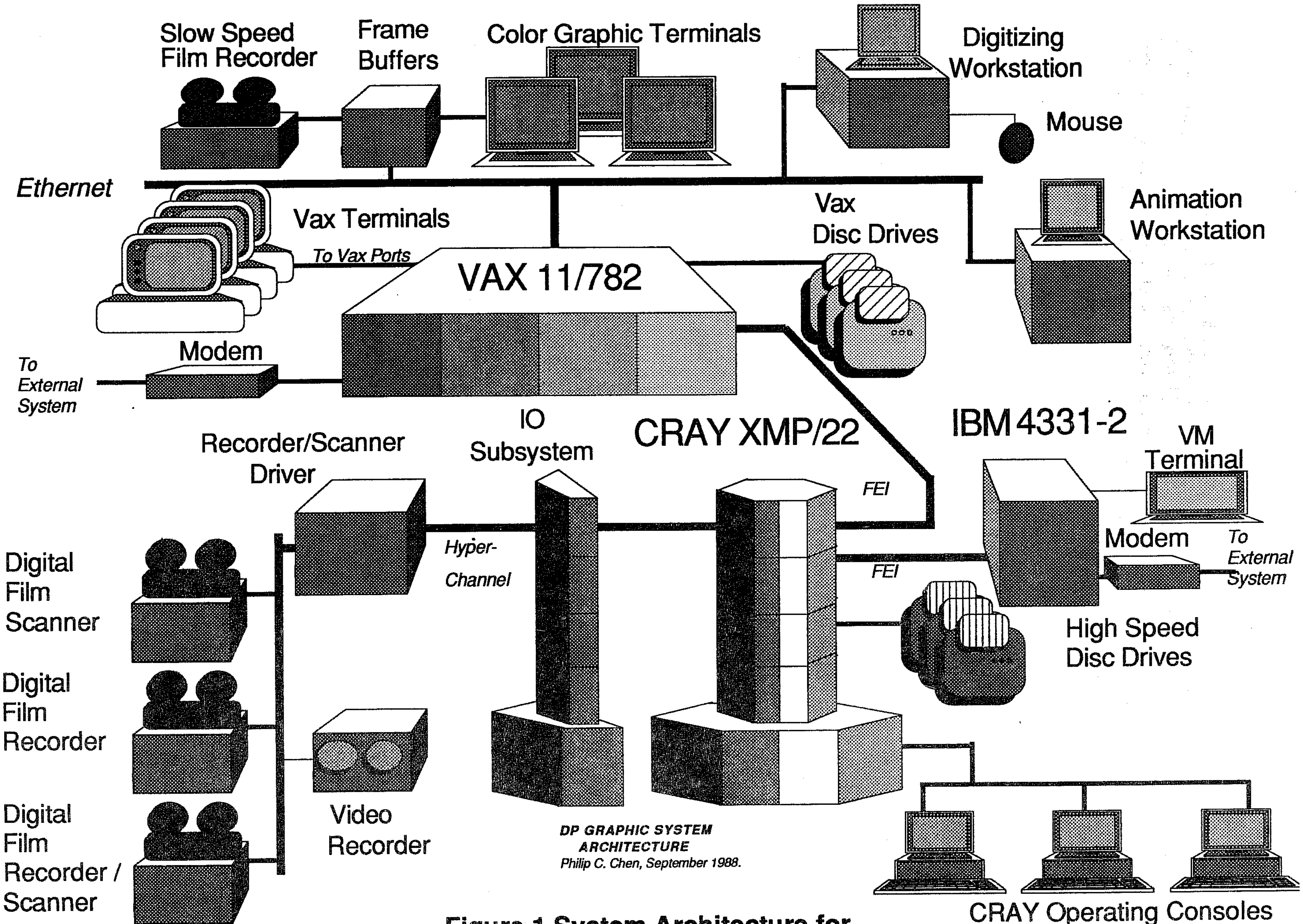


**Figure 1 System Architecture for a Supercomputer Graphics System**

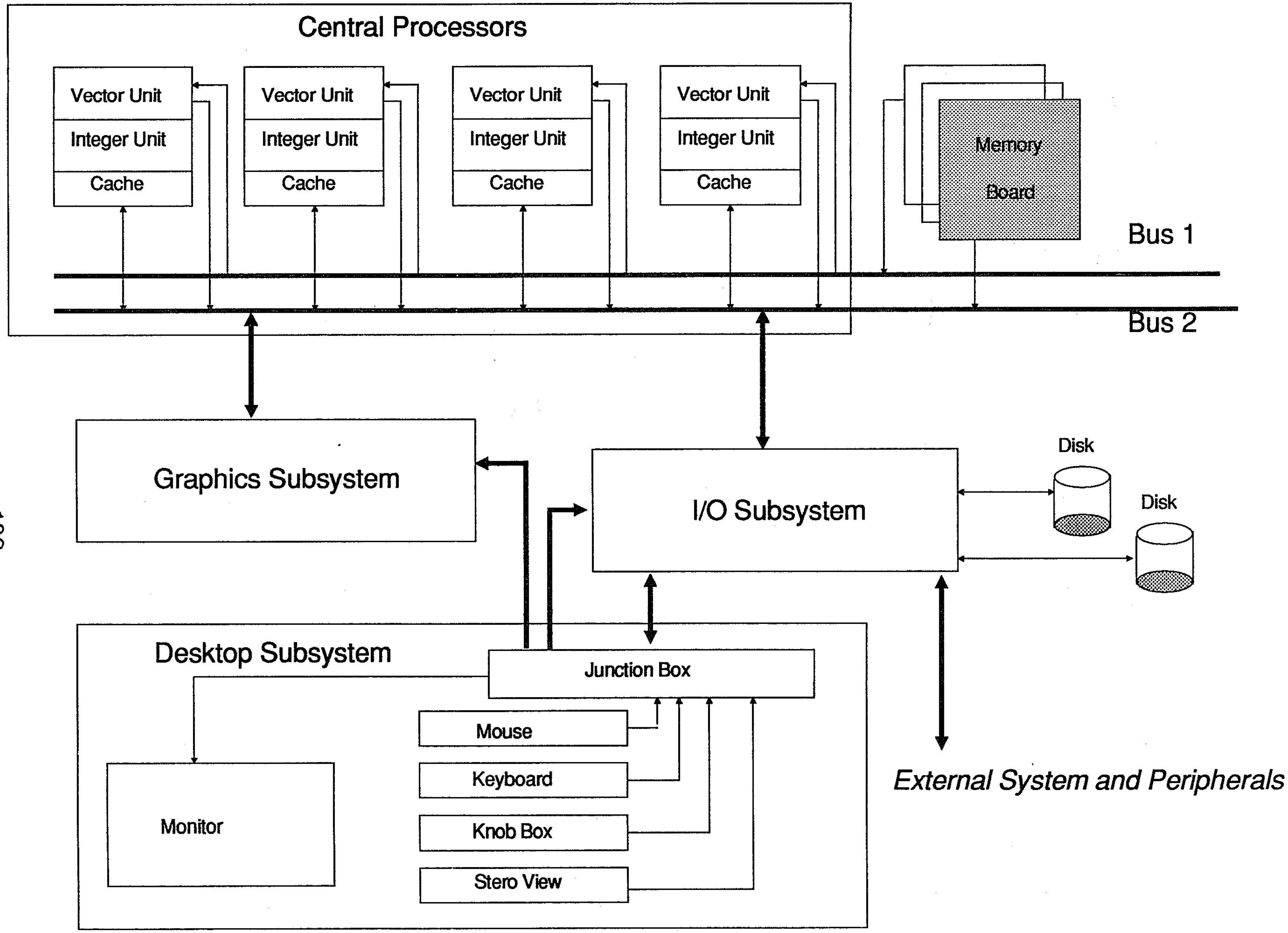


**Figure 2 System Architecture for a Mini-Supercomputer Graphics System**

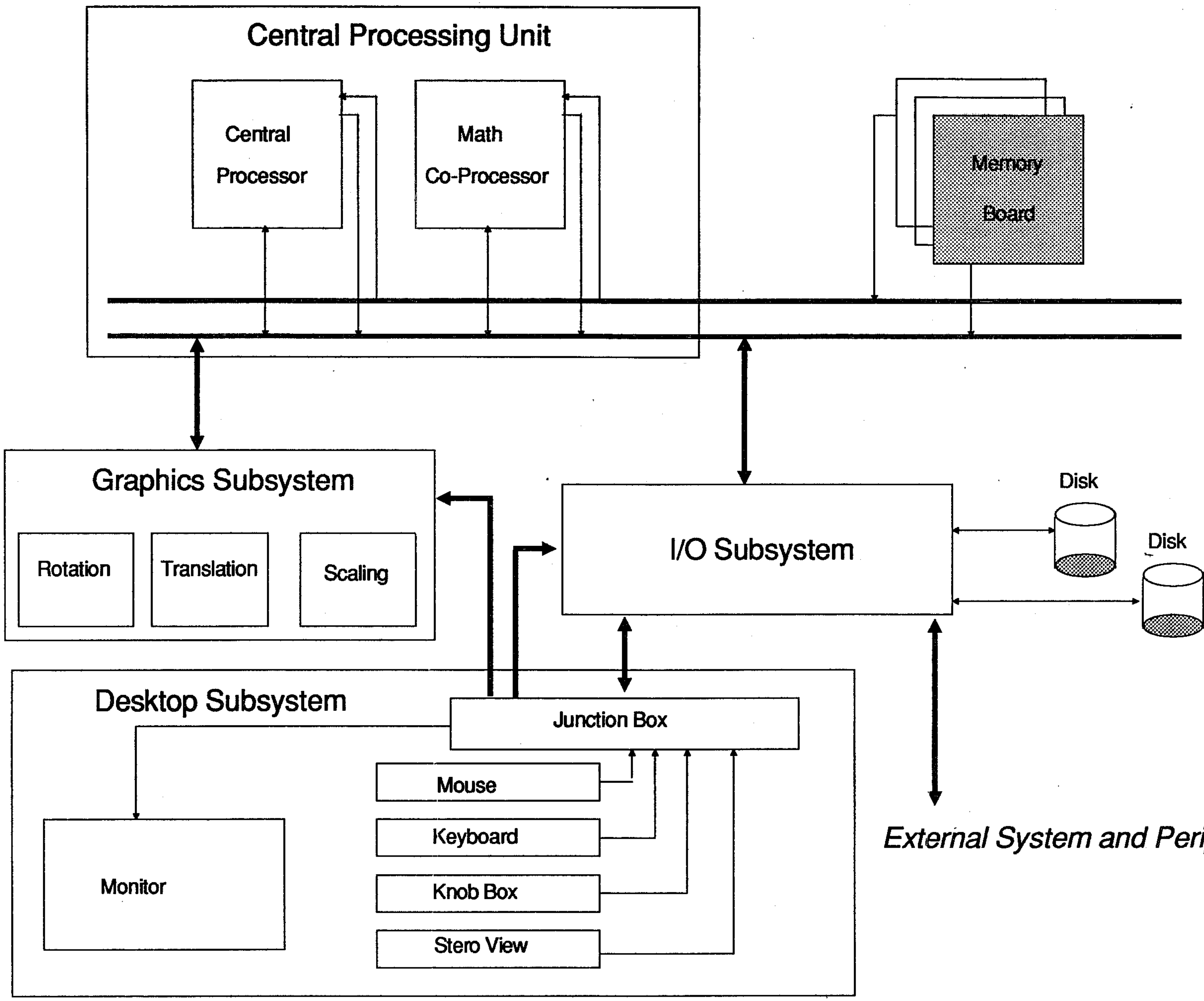


**Figure 3 System Architecture for a Graphics Workstation System**