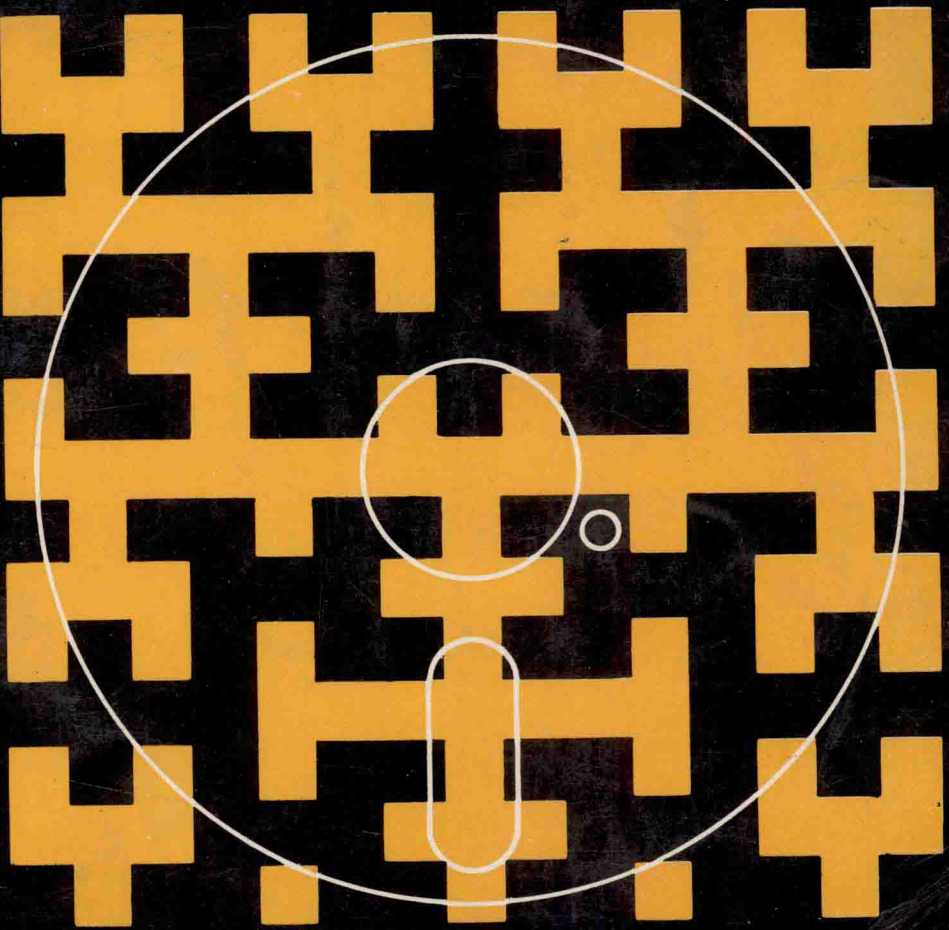
Computer Graphics for Engineers



R.G.S. ASTHANA
N.K. SINHA

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PUBLISHING FOR ONE WORLD
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ISBN: 81-224-0553-3

Published by H.S. Poplai for Wiley Eastern Limited, 4835/24, Ansari Road, Daryaganj, New Delhi 110 002. Printed at Baba Barkha Nath Printers, Kirti Nagar, New Delhi 110 015.

Printed in India.

Production: M.I. Thomas

Preface

The subject of Computer Graphics has become very important for all engineers, particularly due to the availability of inexpensive personal computers. At present, most engineering students in North America as well as Europe have their own computers. As engineers use graphics extensively, most progressive engineering schools now have a required undergraduate course on Computer Graphics. This has become especially important since computer graphics can be used in an interactive fashion, enabling a designer to view, almost immediately, the effect of modifying certain parameters. Therefore, we believe that there is a great need for a suitable text-book on this subject for engineering students as well as for practicing engineers. This book is an attempt to fill this gap.

The purpose of this book is to provide an introductory text for understanding the fundamental principles of computer graphics. To meet this objective, the book also includes a number of worked-out examples along with problems and references at the end of each chapter. Thus, it can act both as a tutorial and a reference source for readers interested in various aspects of computer graphics: hardware, software, data structures, manipulation of two-dimensional and three-dimensional graphical objects and surfaces, and the fundamental algorithms. Some salient features are chapters on data structures along with examples for manipulating pictures/graphical objects; interactive graphics covering i/o devices and systems that facilitate the man-machine graphic communication with emphasis on device-independent graphic programming; 2-D and 3-D graphics, application of graphics to real-life problems with sample source programs covering areas such as business graphics, graph plotting, line drawing, image processing, animation; 3-D solid-modelling, and multi-media.

This book covers and brings together collection of diverse topics, such as, graphical hardware devices, data structures, 2-D and 3-D transformations and homogeneous co-ordinates using matrix notations, interactive graphical concepts, interpolation and approximation of curves, 3-D graphics including projections, clipping, hidden line and surface removal, algorithms for generation and display of surfaces and applications of computer graphics to engineering and allied problems, into one volume.

A floppy disk containing a large number of program examples can be obtained from the publishers at a nominal price. These will help students in writing their own programs and build their confidence. In this way it will promote self-reliance. These programs, as teaching aids, add to the utility of the book.

The book is tailored mainly for the IBM PC and its compatibles, However, since programs are given in both Pascal and *C* languages, these can be ported easily to other platforms, for example, the Macintosh as well as work-stations. In addition, a Solutions Manual is available for professors using this as a text book. Most of the material in the book can be covered in a one-semester course on graphics, which can be taught either at the sophomore or the junior level to students in Computer Science or Computer Engineering programs. Very little mathematical background is expected, except the knowledge of matrix algebra, normally taught to engineering students at the sophomore level. It is also expected that the reader has some familiarity with programming in a structured language like Pascal or C, as is now common at the sophomore level in most engineering schools.

ACKNOWLEDGEMENTS

The final version of this book was prepared while one of the authors (Naresh K. Sinha) was visiting the Delhi Institute of Technology (January to April 1993). Special thanks are extended to Professor B.N. Mishra, Director of the Institute for providing all help and making available the computing and printing facilities of the Institute.

We also acknowledge the help received from several persons in the Centre for Railway Information Systems in preparation of different parts of the text, especially, some of the diagrams in the text. These include Mr Ankush Krishen, Mr. Sunil Jain, Mr. Ghanshyam Sharma and Ms. Urmila Bisht.

Just as one does not thank himself, expressing gratitude to one's wife in public is not a Hindu custom. The reason is that the wife and husband are considered one person. As such, the coauthorship of the wife is tacitly assumed in any book that the husband writes. There is little doubt that this book would not have been possible without the help, patience and encouragement of Geeta Asthana and Meena Sinha.

R.G.S. Asthana
N.K. Sinha
April 1993

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CHAPTER 1

INTRODUCTION

1.1 THE IMPORTANCE OF COMPUTER GRAPHICS

The old Chinese saying "one picture is worth a thousand words" can be modified in this computer age into "one picture is worth many kilobytes of data". It is natural to expect that graphical communication, which is an older and more popular method of exchanging information than verbal communication, will often be more convenient when computers are utilized for this purpose. This is especially true for a large number of engineering applications where one must describe objects in two-dimensional and three-dimensional spaces. Often it is much easier to display these objects on the screen than to attempt to visualize them from many pages of computer output describing their geometrical shapes.

For example, computer graphics methods are utilized in computer-aided design (CAD) to produce the drawings of certain parts of a machine from any viewing angle while specifying all the dimensions. Another example is in the field of computer-aided manufacturing (CAM) where by employing computer graphics techniques, one may display the manufacturing layout for a given part and trace the path taken by machine tools for a given manufacturing process. This information can then be used for numerical control of the machine tool.

Architects can use computer graphics to produce layouts of buildings and utilize them for computer-aided design. The appearance of the building can be viewed through three-dimensional displays, whereas floor plans can be used for designing locations of doors and windows, arrangements of rooms and the placement of various facilities. Not only is it very straight-forward to display these designs on the computer, but one can also modify them with very little effort.

Interactive graphics can be used by engineers in most disciplines to assist in design problems. For example, electrical engineers concerned with the design of large-scale integrated circuits can utilize the computer to display in a graphical form the response of the circuit as well as its layout. The effect of modifying the values of certain components can then be viewed on the computer and utilized for improving the design. Structural engineers can use the computer with interactive graphics for efficient design of structures on the basis of the analysis of stress in various elements of the structure. The main advantage, again, is the ability to view, immediately, the effect of certain changes in the design on the overall performance in a graphical form.

It is evident from the above examples that the engineer of the future will be using computer graphics quite extensively, irrespective of the particular discipline of engineering to which he or she belongs. Furthermore, a large number of progressive engineering schools have already made personal computers accessible to most of their undergraduates. Hence, it is very important for all engineering undergraduates to fully understand and utilize the graphics capabilities of personal computers.

1.2 COMPUTER GRAPHICS HARDWARE

Computers have been getting progressively more inexpensive, and it is envisaged that they will soon be as much the part of every household as the telephone or the television set is these days. It is of interest to review the history of their growth.

1.2.1 Brief History

In the early days of the development of computers, all the emphasis was placed on their use for number crunching for scientific applications. As computers were applied for solving engineering problems, the importance of visual presentation of the results was recognized. The high cost of the hardware for computer graphics remained the stumbling block which prevented their widespread use. The microelectronics revolution and the consequent reduction in the price of the hardware has completely changed the situation to the extent that it is now realistic to expect that all engineers of the future will be making extensive use of computer graphics.

The announcement of the IBM Personal Computer using the 16-bit Intel-8088 microprocessor on August 12, 1981, can be regarded as a historic event, which has had a profound effect in the world of computers. Prior to this date, all other personal computers were built around 8-bit microprocessors. Although such computers were very popular with hobbyists, they were not taken seriously by engineers since they did not have the computing power required for most engineering applications. The situation changed completely with the advent of the IBM Personal Computer, its more advanced versions (the PC-XT and the PC-AT) and many other "compatibles" that followed.

Computer graphics has, in the past, required sophisticated and rather expensive hardware. With the advent of inexpensive microprocessors, not only has there been a significant reduction in the cost but also a substantial increase in the graphics capabilities. It has also been recognized that it is not necessary to have a high-resolution graphics terminal to provide good visual representations for a large class of engineering design problems. In 1981, the IBM Personal Computer significantly improved the state of display technology in the world of personal computers. The first IBM PC used the Intel 8088 microprocessor, which is capable of addressing 1 M-byte in the address space and processing 16 bits internally. Two display adapters could reside in the address space : the Monochrome Display Adapter (MDA) and the Color Graphics Adapter (CGA). While the MDA could display 25 rows of 80-column text, the CGA could display graphics as well as text. Several graphics display modes were made available, including four-color graphics at a low resolution of 320×200 pixels and two medium resolution color graphics at 640×200 pixels. Since then, the 720×348 resolution of the Hercules Graphics Card and the 640×350 resolution of the Extended Graphics Adapter (EGA) have become commonplace. Several manufacturers of EGA compatible boards have reached out and touched the 640×480 mark. IBM also released, in the fall of 1984, a Professional Graphics Controller (PGC) with resolution of 640×480 and with 256 simultaneous colors selectable from a palette of 4096. The PGC had support for both two- and three-dimensional drawing, and was therefore, suitable for applications in computer-aided design and drafting.

The next major change in personal computer display technology was announced by the Apple Company in 1984, when it introduced the Macintosh Personal Computer. It was the first personal computer that did not include a text-based display but provided only a graphic display. The applications programs developed for the Macintosh advocated a WYSIWYG (What You See Is What You Get) style of interface, stressing fidelity between the contents of the screen as manipulated by the user and the final hard-copy output. This concept has now become a basic requirement in the area of desktop publishing.

In 1987, IBM announced four models of their new Personal System/2 : Models 30, 50, 60 and 80. Model 30 was smaller than the IBM PC, but processed most jobs more than twice as fast as the PC or the XT. Models 50 and 60 used the 80286 microprocessor from Intel, while model 80 used the Intel 80386. Models 50, 60 and 80 use a parallel bus architecture referred to as "micro-channel" by IBM and capable of handling several jobs at once, rather than the one-at-a-time approach of the old PC's. Model 80 was a 32-bit system that did jobs up to three and a half times faster than an IBM PC/AT. The personal system/2 ran PC DOS 3.3 on Model 30 and a new multitasking operating system OS/2 in models 50, 60 and 80. This provided an environment that could run most existing DOS programs. One of the protected-mode screen groups provided a graphics based windowing system. IBM called this the Presentation Manager while Microsoft called it the Windows Presentation Manager. Applications that use graphics can be written for the presentation manager and take advantage of the built-in graphics and dialogue box logic. The IBM PS/2 line of products introduced three new video standards, as given below:

i) Multi-Color Graphics Array (MCGA) built into Model 30,

ii) Video Graphic Array (VGA) built into models 50, 60 and 80. It is also available as an add-on-board used for Model 30 or existing PCs, XTs and ATs.

iii) 8514/A, a high resolution add-on board used on Models 50, 60 and 80.

The MCGA and VGA boards are capable of graphics mode of 640×480 pixels with 16 colors and 320×200 pixels with 256 colors. Text resolution is even sharper, with 720×400 pixels in either 16 colors or shades of gray in monochrome. The characters are constructed from a 9×16 matrix of screen dots. On the other hand, the 8514/A board can display 256 colors simultaneously with the resolution of 640×480 pixels.

The new video adapters and monitors used analog signals and could generate 64 values for each of the primary colors, red, green and blue. The result is that these systems can present 256 colors simultaneously on the screen from a palette of 262144 colors. The Apple Macintosh II can also provide a resolution of 640×480 pixels on displays with 16 colors. Optional adapters, such as, extended VGA(XGA) with 1024×768 displays are also available.

To develop a visual interface that is highly interactive, higher resolution and realism, more processing capability is required than currently available from the CPU. The solution is to provide a dedicated graphics processor. This has two clear benefits. First, the screen can be managed faster than possible with an equivalent software algorithm executed on the CPU. Secondly, a certain amount of parallelism can be obtained by letting the main CPU assemble the next graphic command while the graphic processor is completing the current graphic command. Several manufacturers of personal computers (e.g., Commodore Amiga, Mindset, IBM PS/2 with an 8514/A board) use a proprietary graphic processor. Other graphic processors coming into use include Intel 82786 and Texas Instruments 34010. The former is essentially a line drawing processor, while the latter is a high performance general purpose processor.

Although personal computers do not provide very sophisticated graphics images (the situation has improved with the new generation of graphics adapters), they can still be used successfully for learning the basic principles of graphics programming and applying these to engineering problems.

1.2.2 Current Scenario

It can be said, without any exaggeration, that the personal computers available today are comparable in power to the midsize mainframes that one could get in 1965, although costing less than one-hundredth as much. This will be illustrated by the following comparison:

	IBM P.C.	IBM 360-40
RAM Storage (megabytes)	1,4,8	0.032 - 0.262
Cycle time (nanoseconds)	15-60	2500
Price (including peripherals)	$1000-3000	$3000,000-600,000

In the above, the price of the IBM 360-45 has been stated as in 1965. The current prices of comparable mainframe computers are much lower. It may be argued that this is not a fair comparison in view of the fact that the mainframe allows many users simultaneously. However, it cannot be denied that the availability of personal computers at affordable prices has led to their widespread use in engineering.

It is pertinent to discuss the status of processor chip technology, architecture and level of integration available on the motherboard, particulary, as selection of right processor and mother-board is important for a graphic application. A prospective buyer of DOS-based system has multiple choices of CPU. Four companies - Intel, AMD, Cyrix and IBM - offer at least 14 varieties of 386- and 486-class processors with clock speeds ranging from 16-66 MHz. One cannot make a selection simply based on price and performance any more. The prime factors to be considered for an important application are power consumption, mathematical and graphical processing capability and level of integration. This all confuses the PC buyer to a good extent. It is difficult to answer whether a 386/40 is faster than 486SX/20 as one needs to know differences between SX- and DX-class chips. Each processor is designed for a specific application e.g. Intel's low-power 486SL is targetted for a note book PC where long battery life and high performance is important. Intel's 5th generation microprocessor will have name, not a number. Instead of calling it 80586, Intel will be launching it as the Pentinum early in 1993. This processor will integrate 3 million transistors and would run 100 million instructions per second (MIPS). It will drive advanced PCs, workstations, super-servers, and promises improved graphics, better networking and video on desktop PCs.

The major issues to be considered while selecting a system are upgradability, performance and drive. The policy to upgrade is most important for desktop users. Already, over-drive sockets for enhancing performance of an Intel 486 based system are beginning to appear on portable systems. Upgrading allows your older system to keep pace with the performance advances in CPUs so that need to replace the entire box can be avoided.
The July, 1992 issue of PC Magazine described several technological issues for design of a perfect personnel computer as follows :

- A high degree of chip-set integration lowers cost and improves system reliability.
- To save space, the parallel and serial ports, and IDE and video circuitry should be built-in on the mother board.
- To take advantage of a 32-bit operating system such as OS/2.x or Window-NT one will need at least 8 MB of RAM, 16 MB mother-board may prove limiting in the next couple of years.

- Metal SIMM sockets are preferred to the plastic ones.
- PC magazine mentions that a 1024 by 768 resolution at 60Hz is inadequate. It gives more flickery look than a monitor and video card operating at 70-72 Hz.
- Display adapters using VRAM are often twice as fast compared to DRAM based boards.

Digital Equipment Corporation(DEC) has also entered in the PC Market in a big way. In September 1992, DEC announced DECpc range of personal computers , based on ISA and EISA bus systems with industry standard processors, the 386SX, 386DX, 486DX and 486DX2 with in-built Windows, High performance display and easy upgradability - featuring simple strap-in daughter cards which make for an easy transition from 386 to 486 based computing. DEC claims that these machines conform to the perfect PC standards as advocated by the PC Magazine.

In an attempt to produce lower-cost desktops, IBM has redefined the PS/2 line, which had ranged from the 386SX/20 based PS/2 model 35 to the PS/2 Server 295. The new PS/2 exclusively support micro channel architecture, XGA-2 graphics on the motherboard, compliance with the latest ISO specifications for the work environment, SCSI, and come with pre-installed OS/2 2.0. The PS/2 model 80 and 90 will remain in production but model 70 will be phased out. The new systems are the 486 based PS/2 76 or 77 and the 486 SLC2 space based PS/2 56 and 57.

Graphic user interfaces(GUIs) like Microsoft Windows 3.x can choke a video adapter sitting on a 8-MHz, 16-bit industry standard architecture (ISA) expansion bus. Local Bus technology breaks the bottleneck by getting peripherals like video controllers up to clock speed. This allows the video controller to gain access to the CPUs 32-bit bus running on full clock speed, e.g. on a 33 Mhz, 486 local bus PC a video controller could match the 33 Mhz clock speed of the processor. The cost differential for a PC with local bus video can be of the order of $100 only. But the video performance is enhanced 2-15 times as compared to a standard VGA adapter. Unfortunately it is not possible to upgrade the motherboard. Local bus design is available easily on 486 mother board. Two local bus standards are evolving : VL-Bus, a standard proposed by VESA (Video Electronic Standard Association) Committee and PCI (Peripherals Component Interconnect) - a brain child of Intel Corp. EISA (Extended industry standard architecture) and MCA (IBMs Micro General Architecture) are similarly limited regarding the rate at which peripherals on the expansion bus can operate. The EISA expansion bus operates upto 8.33 MHz and the MCA upto 10 MHz. In special mode, MCA can operate upto 16 MHz. EISA and MCA cannot, however, run at the speed of the local bus.

There are two solutions to speeding up video/graphic processing: Graphic co-processor and graphic accelerator. The Graphic co-processor boosts video performance by assuming tasks normally handled by the CPU. These are programmable - i.e. they can execute a *C* program. An accelerator takes control of graphic task otherwise performed by the CPU but it is not programmable. It is a fixed function processor and carries out specific tasks which are hard-coded into the chip. While an accelerator may excel in one application, it can bog down in another.

If one is planning to do any serious work on graphics-based applications using Windows, OS/2, Windows NT, or UNIX, a system based on 486 CPU is practically a necessity. The environment of these operating systems demands fast video, as well as a large and fast hard

disk drive and lots of memory. It is worth mentioniong that 386 based systems offer enough processing power for standard DOS applications but 486 processor is a necessity for multi-tasking applications. A typical configuration includes the following:

- 486 CPU running at 33 MHz.
- 8 MB of RAM
- 1 or 2 floppy drives
- A keyboard
- A hard drive with capacity of 200 MB and
- a VGA, XGA, or super VGA adapter
- CD-ROM (recommended as number of vendors offer software and presentions on CD ROM, e.g., IEEE Computer Graphics and Applications Magazine is available on CD-ROM.)

1.3 OPERATING SYSTEMS AND PROGRAMMING LANGUAGES

Hardware is made up of chips, wires and boards. Software is made up of instructions, flow charts and modules. The programs which make the product function in accordance with specific requirements are termed "application" programs and those which help the applications are termed "system programs". A collection of system programs when bundled into one program is referred to as an "Operating System".

1.3.1 OPERATING SYSTEMS

On the earliest digital computers, a job had exclusive control of the computer for its complete duration. The user had to provide necessary protocol for handling of I/O devices and other resources without any assistance. When the program execution was completed, an operator manually halted the machine and prepared it for the next job. The concept of batch processing came into being in mid 1950s and early operating systems (OSs) did little more than loading programs and managing I/O devices. The concept of more generalised operaing systems emerged in late 1960s and included not only batch pocessing but also modes for time-sharing and some real-time processing.

Today, OSs include facilities, such as, distributed access, graphics, time-sharing, multi-processing, security, networking, multi-threads and multi-processor capability. Based on the computers on which an operating system runs, it can vary in size, complexity and functionality to fulfill user's requirements. OSs such as Digital Research's CP/M and Microsoft's MS-DOS are in fact little more than program loaders that also support a local disk drive.

In the following sub-sections, a brief description of operating systems currently used on micro-computers is given.

1.3.1.1 MS-DOS

It is the most widely used operating system for personnel computers. The salient features of MS-DOS Version 5.0 (the latest version) are described below:

- It can run MS-DOS in the high memory area if the host system has expanded memory. This makes more conventional memory available to a user program.
- It has device drivers and programs can be run in the upper memory area on a 80386 or higher systems. This feature improves the speed and performance of MS-DOS programs when run with Microsoft Windows version 3.x.
- It has an improved graphical interface in form of MS-DOS shell. The shell allows one to manage programs and switch between them, view the directory structure of any disk, view the contents of several directories and navigate through files and directories quickly.
- It has 2 new commands, Unformat and Undelete which provide added data security.
- Version 5.0 allows creation of disk partitions of upto 2 GB.
- Doskey program enables recalling, editing, and executing commands that one has already used. Doskey can be used to create macros to perform a series of tasks frequently.
- It has QBasic - an improved basic program and environment that includes extensive on-line help, graphical user environment and built-in graphical library.
- It supports 2.88-MB floppy disks.

1.3.1.2 MS-Windows

Microsoft Windows 3.x is more than just a front-end for DOS. It has released today's powerful PCs from the constraints of DOS, and led to the development of a whole new level of powerful applications on PC. Since it appeared in May, 1990, Windows has now become an operating environment of choice for the IBM compatible computers. Microsoft has sold over 12 million copies of Windows.

The success of Windows 3.x can be attributed to a variety of factors : easy to use GUI, multitasking, capability to access large amount of memory, integrated application environment, networking, extensive hardware support, device independence, and DOS compatibility. These factors are significant for users as well as for developers. Windows GUI provides a standard approach to computer operations such as starting an application, copying and removing files and so on. Windows requires Microsoft MS-DOS version 3.1 or later. It can operate in one of the following two modes:

- 386 enhanced mode: a personal computer with 80386 processor or higher and 640 KB of memory plus 1024 KB of extended memory, 8 MB of free disk space and atleast one floppy disk drive.
- Standard mode: a personal computer with 80286 processor or higher and 640 KB of conventional memory plus 340 KB of extended memory, 6 MB of free disk space, and at least one floppy disk drive. In this mode the hard disk is used as virtual memory upto 64 MB and multiple DOS sessions can be run, each in its own window.

The salient differences with respect to program execution between DOS and windows are as follows :

DOS	Windows
Programs are run sequentially	Programs are event-driven.
Static link	Dynamic link library (DLL)
EXE Files carry all run-time libraries inside the program DLL.	EXE files will load the required DLLs at run time. DLLs are re-entrant i.e., only single copy need be loaded.

Windows version 3.1 provides true-type fonts, such as fonts consisting of full set of characters with enough variety to meet virtually any printing need. These are scaleable i.e. one can use the same fonts at 12 points for the main text of a report and 16 points for topic head. The page you bring will appear quickly and will be seen clearly on the screen.

The other features include object linking and embedding, a new file manager, drag and drop features, and multi-media features. Multi-media features enable applications to use multi-media devices so that different kinds of media including sound graphics, animation and video can be edited to files and documents. Support for many popular sound devices, such as, sound cards and devices with musical instrument digital interface (MIDI) is also included. It allows playing MIDI information on a MIDI synthesizer. The following sound features are included with Windows:

i. Media Player to control the playing of various kinds of media files on hardware, such as, sound cards, CD-ROM drives, and videodisk player. It can play animation, sound, and MIDI sequencer files.

ii. Sound recorder to play, record, and edit sound files that have the WAVE format. The sound recorder window graphically displays the sound wave as if it were being displayed on an oscilloscope.

Windows NT looks like Windows 3.1 but internally, Windows NT is similar to Windows 3.1 as CPM is to VAX/VMS. It will run on 32-bit CPUs (80386 or higher) with recommmended configuration of 8 MB of RAM and 100 MB or more of disc space. The design of NT is completely object-based. Virtually everything in the operating system is defined as an object, an important component of NT - called the object manager - is dedicated solely to foreseeing the creation, usage, and destruction of the objects. NT is not a true object oriented OS as most of it is written in C, not C++. Thus, some of the advantages of C++, e.g. inheritance and polymorphism were not used. NT represents files, threads, RAM sections, drivers, and devices all as objects. NT offers a centralized security system that works hand in hand with the object manager to provide a uniform security system for virtually all systems resources, scalability to take advantage of high-end hardware and built-in networking support.

1.3.1.3 OS/2

The OS/2 operating system exploits complete capability of Intel 386 and Intel 486 technology. It supports multi-tasking, installation of other operating systems and support for existing DOS and Microsoft Windows applications. It features a complete GUI for all

applications including wordprocessing, printing, playing a game. In fact, one works with objects that graphically represent an activity to be performed. It allows features such as managing, copying, moving, printing, deleting, opening objects through pull-down menus and/or mouse interactions. For smooth running OS/2 needs 8 MB of RAM on the computer. However, it can work with 6 MB also. Running OS/2 with 4 MB is painful as the system will be accessing the hard disk a lot.

OS/2 2.0 supports a variety of display adapter hardware, e.g., video graphics array (VGA), enhanced graphic array (EGA), and colour graphic array (CGA). It allows OS/2 program, DOS program and windows program to run in both window session and full screen session. These programs can run successfully in both the foreground and the background. However, under certain conditions, DOS applications that use the graphical display mode may become suspended in the background session.

OS/2 2.0 provides DOS support as virtual DOS machines. The default DOS box uses a DOS Kernel that OS/2 supplies. The second method is to boot a specific version of DOS (say, DOS 5.0) from a floppy disk or a boot image built with OS/2s VMDISK command. Using default DOS box has advantage as it provides user defined settings to invoke features such as EMS, DPMI (DOS Protected Mode Interface), UMB (Upper Memory Block), video memory settings, and many other. DOS programs run easily under OS/2. The memory management is invisible and virtual memory upto 32 MB per program is available.

OS/2 supports Windows also in two modes: full screen and "seamless" - to open the folder called windows program. In the full screen mode, Windows applications multi-task on a normal window desktop under the control of program manager; in the seamless mode they occupy PM windows and obey the WPS (Work Place Shell). Programs such as PageMaker 4, Word for Windows, Excel, and Turbo Pascal for Windows run under OS/2 both in full screen and seamless mode. However, the virtual DOS machine overheads affect Windows performance under 2.0. Facilities of windows such as wall-paper are not supported.

The strength of OS/2 2.0 comes from features, such as, DOS support, multi-tasking support for windows 3.0 software, a 32-bit memory model, demand paged virtual memory, and threaded multi-tasking. Since, OS/2 is fully written in *C* language, it makes it easily portable on other platforms. Its weaknesses are in the areas of performance, stability, and ease of use.

The trend in development of OS/2 will be to compete with 16-bit windows while attempting to preampt Microsoft's unreleased 32-bit Windows NT. OS/2 will soon have multi-media, 32-bit graphics, Windows 3.x support and pan computing. A 32-bit graphic engine will provide developers with a memory model that will cure problems encountered from the previous 16-bit engine resource limit. The super VGA and HGA will allow for resizeable windows where the original version 2.0 permitted full screen windows only. Other facilities will include video drivers, Microsoft's Windows 3.x as an installable feature, support for desktop interactive devices (e.g. digitizing tablets) .

1.3.1.4 UNIX

The UNIX Operating System has evolved from its modest begining as a simple, small, portable, powerful, time-sharing operating system to one with commercial strength. It is still the most portable and configurable of all operating systems. UNIX has adopted to the new