LABORATORY COMPUTER ISSUES AND CONSIDERATIONS

This chapter provides an overview of the **IBM PC** and **Apple Macintosh —** the two most popular lines of personal computers. Also discussed are the issues facing scientists when setting up a laboratory workstation for the acquisition and analysis of electrophysiological data. For concise information on a recommended computer configuration see *Compatibility Problems* and *Recommended Computer Configurations* at the end of this chapter. The earlier sections give more detailed information on computer options and the issue of price *vs.* performance. The last section provides a glossary of the terms used in this chapter.

Select the Software First

The first consideration when setting up a personal computer workstation is to determine which software packages will be used, and what kind of computer that software will run on. For specialized applications, such as scientific analysis packages, it is not safe to assume that comparable packages are available for both the Macintosh and IBM-compatible computers. If one needs a software package for the acquisition and analysis of microelectrode voltage-clamp and current-clamp data, Axon Instruments' pCLAMP program suite is available for IBM-compatible computers and the AxoData and AxoGraph packages are available for the Apple Macintosh. However, for a complete programming environment that is geared towards electrophysiology and compatible with the BASIC-23 programs developed for the DEC PDP-11 computers, AxoBASIC for IBM-compatible computers is the only choice.

How Much Computer Do You Need?

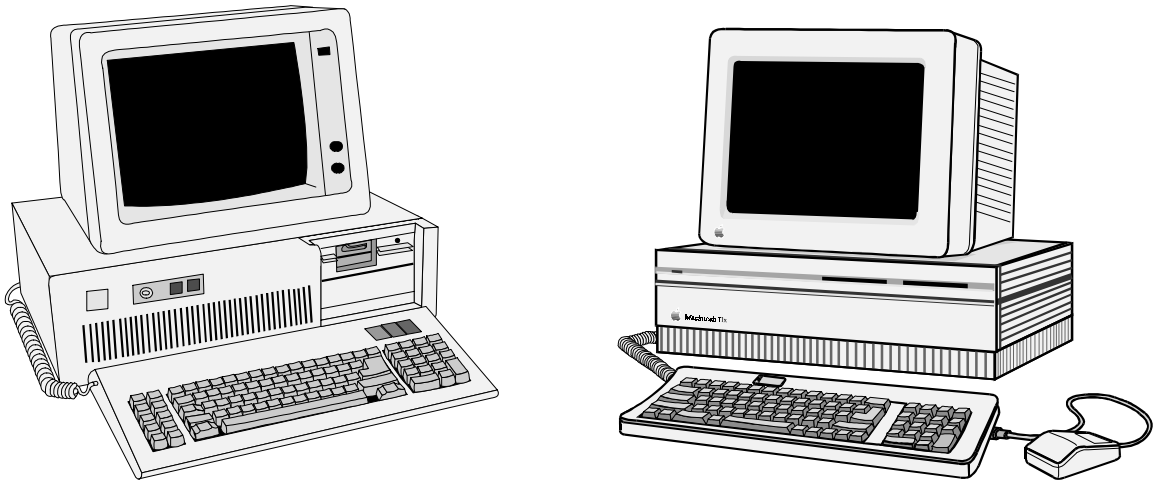

Figure 8-1. IBM PC and Apple Macintosh Computers

The Machine Spectrum: Capability vs. Price

Once you have determined the type of computer you are going to buy, you need to decide how much you are willing to spend for performance and convenience. There are two major considerations when choosing an IBM-compatible computer: the type of **microprocessor** the computer is built around, and the type of **expansion bus** used. Choosing a Macintosh is simpler because there are fewer designs to choose from. There are several essential peripherals needed to complete a computer system, which are available in varying performance and price levels. These peripherals will be discussed in later sections.

The Microprocessor

The microprocessor is a single chip that is the main control center of a computer. For users, the choices differ most significantly in speed and the ability to manage memory. The relevant points are discussed below and in the section on memory. The type of microprocessor is the most important indicator of the computer's amount of "power."

Intel

The IBM PC line of computers are all based on the Intel 80x86 line of microprocessors. The more powerful modern designs have maintained compatibility with the original IBM PC's 8088 while adding advanced capabilities. Unfortunately, the MS-DOS operating system does not support the advanced capabilities of the newer designs. The ramification is that memory problems exist for many people who use IBM-compatible computers. The problems and some solutions are discussed in the section on memory.

Motorola The Macintosh line of computers are all based on the Motorola 680X0 line of microprocessors. The Motorola 680X0 microprocessor never had the memory constraints of the original Intel processors, so Macintosh users do not experience the types of memory problems that have plagued business and scientific users of IBM-type computers. The main benefit of the newer 680X0 designs is a significant increase in speed.

The Expansion Bus (I/O bus)

The expansion bus is a facility for adding optional devices to your computer. This is where you plug in your add-in cards, such as video card, disk drive controller, and data acquisition card. There are several designs, but the choice of bus is important only if the computer's primary activities require communicating on the bus often. For instance, a network "file server" computer sends many files over the network; its hard disk is accessed through the bus. Consequently, the system would benefit from having an efficient bus design. The needs of scientists are generally more computation-intensive, so the microprocessor is usually the most important consideration.

PC/XT/AT The IBM PC and XT have an 8-bit bus (*i.e.*, data is transferred eight bits at a time). Most add-in cards are compatible with this bus. The IBM AT has a more efficient 16-bit bus that is a superset of the PC/XT bus, so it will also run any 8-bit PC/XT card. A 16-bit video card or disk drive controller offers improved performance over its 8-bit predecessors based on its higher data transfer rates. The 16-bit AT bus is now known as the "Industry Standard Architecture" (ISA) bus.

MCA The IBM "Micro Channel Architecture" (MCA) bus is a 32-bit bus offered on the IBM PS/2 line of computers (models 50 and above). It offers better performance than the AT bus, but it will not run cards designed for the PC/XT/AT bus.

EISA EISA stands for "Extended Industry Standard Architecture." It is a 32-bit superset of the AT bus developed jointly by several manufacturers of IBM compatibles. It will run any AT card, as well as 32-bit EISA cards that offer better performance similar to the MCA bus.

NuBus NuBus is a 32-bit Apple expansion bus available only on the Macintosh II computers. Since this is the only bus to choose from, there is no decision to make.

The IBM PC-Compatible World

When IBM introduced the original PC in 1981, it spawned a whole industry of computer makers who were allowed to imitate IBM's designs to create "PC-compatible" computers. The Microsoft Disk Operating System (MS-DOS) became the most popular operating system, and thousands of programs were written for the IBM PC/MS-DOS combination. IBM introduced several models based on the original PC, so the terms "PC-compatible" and

"IBM-compatible" are used interchangeably and generally refer to the whole line, rather than any particular model. In 1987, IBM stopped making the PC line and introduced a more advanced line of computers called PS/2 which had the MCA bus. These new computers were compatible with PC software, but could not run PC add-in cards such as video display cards and modems. However, the PC-compatible industry never lost momentum, and the majority of personal computers now sold are PC compatibles. The IBM PS/2 and the few PS/2-compatible models make up only a small percentage of computer sales.

IBM introduced two basic models of the PC. The original PC (and the very similar XT), based on the 8088 microprocessor, was excruciatingly slow by today's standards. In 1984 IBM introduced the AT, based on the 80286 microprocessor. The AT was compatible with the PC, and added several features. This design became the standard upon which most of today's high-powered personal computers are based. Although IBM never made a PC-style computer with a microprocessor more powerful than the 80286 (until recently), all IBM-compatible manufacturers have incorporated more advanced microprocessors into their latest computers while maintaining AT compatibility. This section discusses the critical features of the PC and PS/2 computers.

8088 (and 8086) PC/XT-Compatible

Computers compatible with the original IBM PC and XT, based on the 8088 or 8086 microprocessor, are the least expensive as well as the slowest and least capable computers of the IBM compatibles. Their slow performance usually makes them unsuitable for doing acquisition and analysis of data. They are also incapable of running the most advanced software and operating systems.

80286 AT-Compatible

Computers compatible with the IBM AT, based on the 80286 microprocessor (or "286"), offer greatly improved speed over 8088 machines, at an excellent price. Although the 286 is more advanced than the 8088, its limitations essentially make it a fast 8088 when running under the MS-DOS operating system. The 286 computer allows the addition of 16-bit add-in cards, which give better performance over the 8-bit cards that the PC supports.

286 computers are capable of running the OS/2 and Xenix (Unix-like) operating systems. Currently this is not much of an issue since the vast majority of software has been written for MS-DOS (called PC-DOS on IBM computers). The biggest issue, however, is compatibility. The 286 AT compatibles were the first IBM AT-compatible designs, and suffered from compatibility problems with software and hardware designed for the IBM AT. Especially trouble-prone were 286 computers running at 12 MHz or faster. These problems have mostly been eliminated in the more modern 386 and 486 AT-compatible designs.

80386SX
IBM- AT Compatible

Computers based on the 80386SX (or 386SX) microprocessor allow the user to run any software that requires an 80386 (see below). The 386SX is a 32-bit microprocessor that currently runs at up to 25 MHz. It communicates to the rest of the computer over a 16-bit pathway, and allows a computer to be built with economical 16-bit parts. Consequently, a 386SX computer can be sold very inexpensively.

80386
IBM-AT Compatible

The 386 computer offered the flexibility and power that made it the workhorse computer of the early 1990's. The 386 computer operates with a full 32-bit data pathway, although the AT bus design still limits expansion cards to 16 bits. The 386 microprocessor has much better facilities for managing memory than the 286 when running MS-DOS. This enables a better use of memory when running memory-starved DOS programs (see the next section on memory), and makes it easier to run several programs concurrently. This memory management ability applies equally to 386SX computers.

80486SX
IBM AT-Compatible

The 80486SX microprocessor is equivalent to an 80486DX (see below), but with a disabled coprocessor. The 80487SX coprocessor must be installed to add this capability. Since scientific software benefits from a coprocessor, the 486DX is recommended, and the 486SX is not.

80486DX
IBM-AT Compatible

IBM AT-compatible computers based on the 80486 (or 486) microprocessor are very similar to, but more expensive than, 386 computers. The 486 is available in 33, 50 and 66 MHz versions, offering very fast performance. The 486 also has a built-in math coprocessor, eliminating the need to buy an math coprocessor, which is practically required for doing scientific work (see the section below on math coprocessors). The 486 microprocessor integrates several devices that previously were separate components on the 386 system board.

IBM PS/2

The IBM PS/2 computers are available with the above-mentioned microprocessors; therefore, the above comments apply. The major difference between a PC-compatible and a PS/2 is that an add-in card must be designed for one or the other; the same card will not run on both computers. Although a data acquisition program designed for a PC would also run on a PS/2, the program would have to support an acquisition board designed specifically for the PS/2. The MCA bus on the PS/2 offers better performance than the AT bus, but this does not appear to be an important factor for most people.

EISA

A 386 or 486 AT-compatible based on the EISA bus will run all DOS programs and can use any PC/XT or AT add-in card. In addition, the EISA bus will also accept a 32-bit EISA card that offers a higher rate of data transfer than a PC or AT card. EISA allows backward hardware compatibility to the PC, XT and AT, whereas a PS/2 would require you to buy all new cards. Currently, there are few EISA cards available supported by software.

Neither the MCA nor EISA bus offer much improvement over the AT bus for most people, unless a particular hardware product that interests the user was developed specifically for one of these bus designs.

The Macintosh World

The Macintosh line of computers from Apple Computers is based on the 680x0 family of microprocessors. This microprocessor is not compatible with Intel's 80x86 family of microprocessors, so hardware and software designed for IBM-compatible computers will not work with Apple Macintosh computers. The original Macintosh design (with built-in screen) has extremely limited expandability. The later Macintosh II, Quadra and Centris series offer both the expandability and power necessary for the needs of today's scientists.

Apple Macintosh Plus, Classic, SE

The original Macintosh design integrated a computer based on the 68000 CPU with a small monochrome monitor into a correspondingly small case. Although these systems have been upgraded for more power and color, their limited expandability still makes them unsuitable for data acquisition.

Apple Macintosh II si, ci, fx, cx

The Macintosh II series of computers was originally based on the 68020 CPU, and introduced a powerful expansion bus, the NuBus. The NuBus allows for I/O cards to be added for the digital and analog data transfer and control needed by scientists. Later versions of the Macintosh II have powerful 68030 CPUs that run at higher speeds. The number of expansion slots available range from 1 to 6, so hardware needs should be considered before purchasing a system based on price alone. A math coprocessor (FPU) chip is usually not included in these computers.

Apple Macintosh Quadra 700 - 950

The Macintosh Quadra series of computers is based on the 68040 CPU, and is Apple's top-of-the-line computer. The Quadras start at speeds of 33 MHz, and include a math coprocessor. They are meant to compete with the IBM-compatible 486 computers.

Apple Macintosh Centris 610, 650

Like the Quadras, the Macintosh Centris series of computers are based on the 68040 CPU but run at a slower speed and do not include an FPU. The Centris is considered Apple's more affordable middle-of-the-road computer, in between the Quadra and the Mac II.

Memory

RAM (Random Access Memory) is the physical device used to store programs and data while the computer is running. When the computer power is off, RAM cannot hold any information, so it is referred to as "volatile" memory. It is used because instructions and data can be read from, and written to, RAM much faster than any other type of memory device. How much RAM you need and can use depends on the type of computer you buy as well as the capabilities of the programs you use.

Macintosh/Motorola 68000

The Macintosh has what is called a "flat memory model." If there are 20 MB (megabytes) of RAM memory, memory is addressed continuously from address zero to address 20 million. For Macintosh users, nothing else needs to be said. This seems like a simple and reasonable way to do things, but for users of IBM-type DOS computers, life is more complicated. . .

IBM/Intel 80x86/MS-DOS

The ability to use large amounts of RAM memory in the IBM PC-compatible world is restricted by the designs used in the original PC. This is based partly on the architecture of the original IBM PC (with its 8088 processor), as well as the MS-DOS operating system and the programs that run under it. Every byte of memory must have an address, which is a number that refers to its location. The limited range of numbers available to be used as addresses has become the bane of many users of IBM and compatible computers running DOS. Refer to Figure 8-2 while reading the descriptions below.

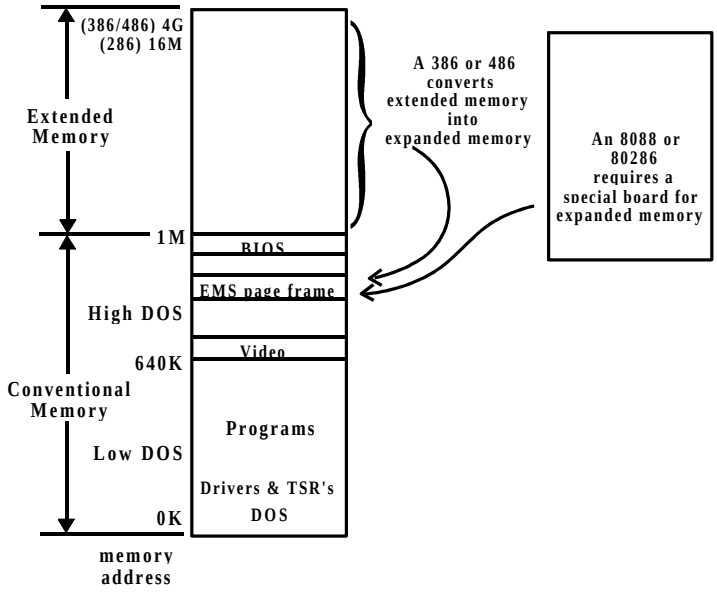

Figure 8-2. Memory Architecture of the PC

Types of Memory

Following are descriptions of the different types of memory used on PC computers running MS-DOS.

Conventional

Conventional memory simply refers to memory with an address below 1 MB (one megabyte), because the 8088 microprocessor's 20-bit addressing scheme allows it to address a maximum of 1,048,576 bytes (1 MB) of memory.

RAM memory below the 640K address is referred to as low DOS memory. **Generally, only the lower 640K of memory is available to programs.** The architecture of IBM computers reserves the upper 384K (referred to as high DOS memory) of the 1 MB address range for system use, such as for video memory and the ROM-BIOS routines. Although there are 384K addresses, usually only some of these addresses are occupied with actual memory used for specific purposes. If a computer is equipped with 1 MB RAM, 640K of that RAM resides at the first 640K addresses; the next 384K addresses are skipped by RAM; and the remaining 384K of RAM is extended memory, with addresses starting at the 1 MB address.

Extended

Extended memory is merely memory with an address **above** 1 MB. This means that the 8088 PC is incapable of having extended memory since it can address only **up to** 1 MB. While 286 and 386 computers are capable of addressing many megabytes of memory, DOS is not. Therefore, programs running under DOS normally cannot access extended memory. Extended memory *can* be used, but in a limited way (see the section below on *Using Extended or Expanded Memory*).

Expanded

Expanded memory is additional memory addressed using the Expanded Memory Specification (EMS), an early software specification for allowing programs under DOS to access more than 640K of memory. Not all of the 384K of system address space is used by the system, so the expanded memory manager software (EMM.SYS) reserves part of the address range. The reserved address range is called the "page frame." Chunks of expanded memory are then mapped (given addresses different from their actual physical addresses) to the page frame in 16K "pages." This way, large amounts of expanded memory can be accessed by using the same address range and by switching entire pages. An 8088 or 80286 computer requires an expanded memory board as well as the EMS software driver to use expanded memory. The 80386 microprocessor has built-in features allowing 386 memory manager software to use extended memory to emulate expanded memory. DOS programs must be specifically written to access expanded memory.

Choosing Memory for Your Computer

The usefulness of extra memory (more than the standard 640K of RAM) depends on the operating system. The OS/2 and Unix operating systems use extended memory. MS-DOS (PC-DOS) was originally designed for the 8088, and cannot normally use extended memory. Since the vast majority of software used on personal computers has been written for DOS, the next section will describe the use of memory on a computer running DOS.

8088 IBM PC/XT Compatibles

Because computers based on the 8088/8086 microprocessors are only capable of addressing 1 MB of memory, extended memory is useless. An expanded memory board must be used to make extra memory available.

80286 IBM AT Compatibles

Extended memory can be accessed with a 286 computer. When the computer is operating under DOS, extended memory is only useful with disk cache or RAM disk software, or the few programs (such as Lotus 1-2-3) specifically designed to use extended memory. An expanded memory board will give the 286 machine the normal expanded memory capabilities.

80386/80486 IBM Compatibles

Expanded memory boards are unnecessary, because the 386 and 486 microprocessors have the memory-mapping features necessary for expanded memory. By adding extended memory and using 386 memory manager software, one can configure the system for exactly the amount of extended and expanded memory needed.

Using Extended or Expanded Memory

The problem with extended or expanded memory is that each program you run must be specifically designed to access it. If the programs you use do not support extended or expanded memory, there still are ways to take advantage of the extra memory to improve overall system performance.

Disk Cache

A disk cache program will take data just read from (or written to) the disk drive and store it in a reserved part of RAM memory. If the same data are needed soon, they will be read from the RAM memory rather than from the much slower disk. This improves performance greatly if the program frequently requests data from the disk, or when switching often between programs. A program that uses overlays (only part of the program is loaded into memory from the hard disk, as needed) will have much greater performance using a disk cache. An important safeguard is that nothing is ever held in the cache without being written to disk. If there is a power failure, no data are lost. In order for this to hold true, the *write-cache* feature (if present) must be disabled.

RAM Disk

RAM disk software, such as the DOS VDISK.SYS or RAMDRIVE.SYS driver, configures part of RAM memory to be used like a disk drive. Writing to and reading from RAM is much faster than accessing an actual disk. Unfortunately, if power is lost, the data in the RAM disk are lost as well, so you must frequently copy the contents of the RAM disk to your actual disk drive. For most purposes a disk cache is preferable to a RAM disk except in the case of very fast data acquisition, where writing to an actual disk will limit the maximum rate of acquisition.

386 Memory Managers

A 386 memory manager such as QEMM-386 from Quarterdeck or 386MAX from Qualitas serves several purposes. One is to convert extended memory on a 386 or 486 computer to expanded memory without the need for a special expanded memory board. Another is to load device drivers (such as the MOUSE.SYS driver) and "memory-resident" programs (such as the Axon Instruments print-screen utility PPRTSC.EXE) into high DOS memory (system address space between 640K and 1 MB) by re-mapping extended memory to high DOS addresses. This allows the loading of all needed device drivers and memory resident utilities while retaining enough low DOS memory to run big programs. QEMM-386 used in conjunction with DESQview software (see the next section) allows one to run several programs concurrently on a 386 or 486 computer.

Operating Systems and Environments

Macintosh

The Macintosh operating system ("System") is the dominant operating system for the Macintosh computers. There is only one "environment" to use: the environment built into the operating system. The Macintosh operating system had the first commercially-available "graphic user interface" (GUI), designed to make computers easier to use. This environment has aged well and has spawned several systems for other computers that have imitated and expanded upon the idea. To run Axon Instruments software you need at least version 6.0 of the Macintosh operating system.

IBM Operating Systems

Since most software for IBM and compatible computers is written for MS-DOS, only the various versions of MS-DOS will be discussed. Axon Instruments software requires at least DOS 3.0. The versions most commonly found on PC computers are 3.3, 4.01 and 5.0. DOS version 4.01 added support for large hard disks. Previous versions only supported a drive "volume" up to 32 MB in size. To use an 80 MB disk, one had to create three drives (C, D and E) of 32, 32 and 16 MB. DOS 4.01 allows the hard disk to be one large drive, enabling one to have a huge C drive. Unfortunately, DOS 4.01 has one serious problem: it occupies more memory than any other version, leaving less room to load drivers and programs. Axon Instruments strongly recommends the use of MS-DOS 5.0 or higher, which manages memory much better than previous versions.

Successor to DOS?

Since the 80286 AT became available, the microprocessor could operate in what is called "protected mode," allowing huge amounts of RAM memory to be accessed. So why has DOS not been modified to run the 80286 (and 386, 486, etc.) in protected mode? DOS was originally written for the 8088, and when DOS runs on the more advanced microprocessors, it runs them in "real mode," which emulates the 8088 and its 1 MB memory limit. DOS allows programs free reign to directly access hardware resources, rather than being forced to go through the operating system. Although this allows for highly optimized programs, it makes it difficult and time-consuming to convert the programs to run under the stricter programming requirements of protected mode. OS/2, intended to be the successor to DOS, is a protected-mode operating system. However, there has so far been little software developed for it because of the expense required and the poor acceptance of OS/2. With its expensive hardware requirements, not many users have switched from DOS to OS/2. The MS-DOS operating system, despite its shortcomings, is not about to die too soon.

Environments

The efforts to create a more productive computing environment within DOS has led to two major products designed to extend its abilities. Microsoft Windows and Quarterdeck's DESQview software are "multi-tasking" environments that run on top of DOS. A multitasking environment has the ability to run a program in the "background" while you are doing some other task in the "foreground." Their most obvious benefits are the ability to run many programs concurrently, and to switch between programs instantly. Besides this similarity, Windows and DESQview are designed with different goals in mind.

Microsoft Windows is designed to be a graphics environment for running programs and communicating between them. Its primary appeal, besides running programs concurrently, is a consistent graphics-oriented, icon-based user interface, which makes learning a new program easier and quicker. It also allows text and graphics to be easily mixed in applications. Windows is meant as a whole new operating environment to replace the DOS prompt. As such, programs must be designed specifically for Windows to take advantage of its features. There are many programs available for Windows, but many users are reluctant to give up their faithful old word processor or spreadsheet program. Therefore, Windows also has the ability to run regular DOS programs.

The latest incarnation of Windows, version 3.1, is a protected-mode program that allows access to megabytes of RAM. A program written specifically for Windows 3.1 no longer has the DOS curse of the 640K memory limit. This opens up considerably more space for more sophisticated, powerful programs, and for programs that need lots of data space. However, the general impression users get is that Windows 3.1 will solve all of one's memory problems. This is not true. Only programs specifically written for Windows 3.1 have large amounts of memory available. A regular DOS program is subject to how much memory Windows 3.1 can allocate for it. This depends on the amount of free RAM that is available *before* Windows is loaded. Therefore, the abilities of memory managers to load resident programs and device drivers into high DOS memory is crucial. In particular, versions 5.1 and later of both QEMM-386 and 386MAX support loading programs into high DOS memory and also support the "Enhanced" operating mode of Windows 3.1 (see the above section on memory managers).

DESQview from Quarterdeck was designed with a different philosophy in mind. It is meant primarily to run regular DOS programs in windows, and to switch between them easily. DESQview multitasks DOS programs, and also has the ability to run Windows programs in a DESQview window, although not in the "Enhanced" protected mode. As a program switcher for regular DOS programs, it performs very well and saves you from the frustration of having to "quit" to switch from one program to another.

Because these environments operate between DOS and application programs, the user does not know how processor time is being divided between the environment and each program. A program running in the foreground can be configured to not share processor time with programs in the background, but the environment still may use processor time to manage some tasks. For this reason, if the user wants to perform data acquisition in one of these environments, experimentation is advised to ensure that data is not lost. Data acquisition in the foreground should work fine, but data acquisition as a background operation will probably not work. A multi-tasking environment becomes valuable for automated analysis in the background, or for switching quickly between analysis programs and spreadsheet or graphics programs.

Peripherals and Options

One of the design principles of personal computers has been the modularity of design to accommodate user-specific functionality. The descriptions below discuss the peripherals most pertinent to laboratory setups.

Coprocessors

A "math coprocessor" is a companion processor designed to support the computer's main microprocessor. Its primary function is to execute calculations on floating-point numbers, which it can perform much faster than the main processor. Since the coprocessor is expensive, it is usually offered as an option when purchasing a computer. Programs for data analysis usually do many floating-point calculations, so the addition of a math coprocessor increases performance dramatically. A coprocessor is required to run many scientific programs, including pCLAMP.

For the IBM compatibles, the choice of coprocessor depends on the main processor. For an 80x86 chip, get an 80x87 coprocessor of the same speed. The 80486DX microprocessor has a built-in math coprocessor (however, the 80486SX does not).

The Macintosh IIci, IIfx and Quadras come standard with a 68882 coprocessor. The coprocessor is an option on the Macintosh IIsi.

Magnetic Disk Storage

As storage space for programs and data always seems to become scarce with time, a hard disk with plenty of storage capacity is highly recommended. For a computer with one user, an 80 MB disk will allow plenty of data to be stored without resorting to other means. An alternative to the common "fixed disk" drive is the removable-cartridge hard disk drive. The cartridges typically hold 20 MB each and are cost-effective. However, removable cartridges do not hold as much as fixed disks, and the performance is slower. A removable-cartridge drive in addition to a fixed

disk drive can be a versatile data back-up solution, as well as a useful way to store files not needed often.

A disk drive and its controller card operate with a certain protocol for encoding data on the disk. The original protocol used on the IBM PC was called MFM. Less common was a more space-efficient protocol called RLL. Currently the most popular drives are called "IDE" drives, which have an integrated controller built into the drive, eliminating the need to match a drive to a controller. IDE drives offer very good performance and easy setup. Once common ESDI drives are rapidly losing popularity. Macintosh computers use the SCSI protocol.

Hard disk drive performance specifications are the average seek time (AST) and the data transfer rate (DTR). The average seek time, given in milliseconds, is the time it takes to locate any random piece of data on the disk. The data transfer rate, given in kilobytes per second, is how fast the drive can continuously transfer the data to memory or another device.

For data acquisition, hard disk drive performance may be important. To record long segments of unbroken data, direct acquisition to disk (rather than memory) is necessary, and the speed of acquisition is limited by the drive performance. Here is an example of the performance of one system:

- 33 MHz 80486 IBM-compatible computer
- 200 MB hard disk drive, 777 Kb/sec DTR, 16.4 ms AST

FETCHEX 6.0, acquiring with the real-time display turned off, sustained a continuous acquisition of 200 kHz to the unfragmented hard disk.

Optical Disk Storage

With the advent of rewritable optical disk drives, it is now possible to store 600 MB (and more!) of data on a single rewritable optical disk cartridge. The availability of huge storage capacity on a small removable cartridge is the major selling point of optical drives. Although the drives are very expensive, the fact that the cartridges are removable and replaceable makes them very cost-effective for users with huge data storage needs. Optical drives have a slower average seek time than a good hard disk, but offer high data transfer rates, so they are well suited for continuous data acquisition of up to several kilohertz.

An older technology called WORM (Write Once, Read Many times) offers a less expensive alternative, but the optical cartridges are not rewritable. Since the storage capacities of optical drives are huge, this may be a practical option.

Video Display Systems

The Macintosh IIsi, IIci and IIfx all come with built-in video support. Choosing a graphics display system for an IBM-compatible computer is difficult since the issue of graphics standards in the IBM-compatible world is cloudy. Standards have traditionally been set by IBM, but other hardware vendors have been trying to set standards of their own. Currently, the true standard is IBM VGA, which defines a graphic screen with a resolution of 640 dots horizontally by 480 dots vertically, with 16 colors. Putting more dots on the screen creates sharper graphics. The hardware vendor NEC brought nine video card companies together several years ago to define a "SuperVGA" 800 by 600 dot standard. This organization, called VESA, has since defined

several SuperVGA protocols. Many software packages, however, do not yet support resolutions beyond VGA, so the SuperVGA definitions have not yet become accepted standards. Most video cards come with "driver" software that allows Microsoft Windows and some other popular graphics programs to run at higher resolutions. Currently, support for higher resolutions comes mainly from the video card manufacturers, not the software companies.

To buy a display system that will not become obsolete in a year, get a "multi-scanning" monitor that will support "non-interlaced" 1024x768 resolution. Multi-scanning monitors offer more flexibility than "fixed-frequency" monitors; there is a greater chance that a multi-scanning monitor bought today will support a future standard. Buy a non-interlaced 1024x768 video card that is provided with high-resolution drivers for popular software packages. VESA support is recommended.

Axon Instruments has supported the IBM video standards up to now. However, if a clear alternative video standard (*i.e.*, supported by popular software packages) emerges from another manufacturer, Axon will support it as well.

Graphic Output: Pen Plotters vs. Laser Printers

Traditional graphic output for scientific software has been for pen plotters, which provide very high-resolution vector graphics, and allow plotting in several colors. The plotting output of Axon Instruments IBM-specific software is in the Hewlett Packard Graphics Language (HPGL), a common standard supported by the Hewlett Packard plotters as well as many other brands.

The existence of HPGL emulation utilities for Hewlett Packard laser printers makes using a laser printer an attractive alternative to a pen plotter. Since most published graphs are only in one color (black), multi-color plotting is usually not a necessity. The HP LaserJet's resolution of 300 DPI (dots per inch) produces sharp publication-quality graphics. On a 386 computer the software emulation utility included with pCLAMP and AxoTape will produce a plot much faster than a pen plotter. The software can also "tag" several plotter files and print them while you go to lunch. This is much more efficient than plotting graphs one at a time. The HP LaserJet is also much more versatile than a plotter. The latest model is the LaserJet 4, which has two features that make it very attractive. It has built-in HPGL emulation, so an HPGL plot can be sent directly to it as if it were an HP pen plotter. It also has built-in scalable typefaces for changing text styles and font sizes quickly and easily.

Data Backup

As "hi-tech" as personal computers are, hard disks are complex mechanical devices requiring precise tolerances in their operation, and are subject to mechanical failure. The lifetime of hard disks is usually several years, but manufacturing defects, physical shocks, or too many power-on cycles can make YOUR hard disk ready to fail at any moment. It is essential that a disk full of programs and data be backed up regularly.

There are two common methods of backing up data. If you have only a few megabytes of data to back up, using a "back-up" program to back up files onto floppy disks is sufficient. This can be tedious because of the need to switch floppy disks often. An easier alternative if you have many megabytes of data is a cartridge tape backup drive. This will allow unattended back-up. Moreover, many megabytes of data can be stored on a compact tape cartridge.

A less common method of backup is to use a removable-cartridge hard disk drive. This is a more versatile storage method than a tape drive. Retrieving individual files from backup is also much faster (see the section above on *Magnetic Disk Storage*).

I/O Interfaces

An I/O interface defines the physical interface and communication method for devices attached to the computer, such as the display, printer, mouse and disk storage device. For devices attached internally, such as the display adapter, the physical I/O interface is the computer's expansion bus. This is described above in *The Machine Spectrum*. For external devices, *e.g.* the mouse or printer, there are several interfaces implemented on the IBM and Macintosh computers.

Parallel Centronics

Also known as the "parallel port," this interface, which exists primarily in the IBM world, allows eight bits of data to be transferred at a time ("in parallel"). It offers high speed, but its design allows mostly one-way communication; the external device is very limited in the signals it can send back to the computer. As a result the only devices designed to use the parallel port are those that mostly receive data, the most common example being the printer. The Lambda-10 filter changer from Axon Instruments also uses the parallel port. DOS addresses the parallel port as LPT1 or LPT2. At least one parallel port is recommended.

Serial Port

The serial port is a general communication interface that allows full, two-way communication, thereby making it much more versatile than the parallel port. It exists on many types of computer systems. Common devices which attach to the serial port include the mouse and the modem, as well as plotters and some printers. The Macintosh comes with two serial ports. Only two external serial ports may be attached to an IBM PC; two are definitely recommended. Two additional serial devices may be attached, but only through the expansion bus. For instance, an internal modem may be installed on the expansion bus but is addressed as a serial device by the computer. Although DOS supports up to four serial ports (addressed as COM1 - COM4), the ROM-BIOS in PC compatibles only supports two serial ports. Therefore, software must be able to address these additional serial devices directly through hardware.

Compatibility Problems

Compatibility is an issue when a manufacturer makes a product that tries to conform to some "standard" design, which is either defined by some industry committee or is a *de facto* standard based on market dominance. Since Apple makes all Macintosh computers, this is not an issue for the Macintosh. For IBM-type computers, however, this is an important issue. There are many manufacturers of computers that claim to be compatible to the *de facto* standard that has evolved around the IBM AT architecture. Compatibility is accomplished to various degrees, but the large number of manufacturers makes compatibility problems inevitable.

Past Problems

Just a few years ago IBM PC compatibility was a major issue since "clone" makers did a sloppy job of producing "PC-compatible" computers. One big problem was the PC compatibility of the built-in software routines (the ROM-BIOS) that help run the computer. Another major problem was with very fast 80286-based AT compatible computers. The expansion bus usually ran too fast for many add-in cards, which were designed for the IBM AT's 8 MHz expansion bus. Today, compatibility is not as much of a problem as it had been, but there are steps you should take to avoid headaches.

How to Avoid Problems

The first thing to understand is that the only 100% IBM AT-compatible machine is the one with the letters "IBM" on it. Ironically, although IBM-compatible computers with the AT bus are by far the largest segment of the market, AT-bus computers constitute only a minor part of IBM's current computer line. The AT "standard" has also evolved slightly over the years. With any computer there is a slight risk that the software or hardware you want to run on it will have problems. The safest solution is to find a vendor that claims to sell 100% PC-compatible computers, and make sure that if a problem develops, the vendor will work with you to solve the problem, even if it means replacing the computer. Buying a "brand name" computer is generally a safe bet, although the cost is greater than a "no-name clone." If you know a local computer dealer that gives good service, a no-name computer will probably work just as well as a brand name, at a much lower cost. A big mail order house with a reputation for having responsive service is also a good choice. Remember, the biggest risk you take is whether the dealer will be willing to help you if/when you have problems.

The vast majority of computers have had no problems running the Axon Instruments software packages. For the data acquisition boards we sell, there have been some finicky computers (*e.g.*, the board only works in some bus slots but not others), but the "feature" to look out for is a fast expansion bus. Buy only a computer with an expansion bus running at about 8 MHz, which is the IBM AT standard. Most add-in cards are designed for this speed and have problems with fast buses. The biggest problems have been fast 286 machines with a clock running at 12 to 20 MHz. The bus often runs as fast as the clock. Most 386 and 486 computers, which run at speeds from 16 to 66 MHz, have expansion buses running at 8 MHz. We recommend buying a 386 or 486 computer for this reason and for the much greater performance and flexibility when running software.

Recommended Computer Configurations

IBM PC Compatible

Our recommendations for a minimum IBM-compatible system and for a higher performance (and higher price) system are listed below. Both are suitable for running the Axon Instruments pCLAMP and AxoTape software programs.

Minimal System	**Ideal System**
80386 or 80386SX motherboard	80486DX motherboard
80387 or 80387SX numeric coprocessor *(required)*	(80486DX has built-in coprocessor)
40 MB hard disk and controller	120 MB IDE hard disk drive
MS-DOS 5.0	MS-DOS 5.0
1 MB RAM	4 MB RAM
VGA graphics adapter card	16-bit SuperVGA graphics adapter, 1 MB RAM
VGA color monitor	High-resolution, low-noise multi-scanning monitor
One floppy disk drive (1.2 MB 5¼" or 1.44 MB 3½")	Both a 1.2 MB 5¼" and 1.44 MB 3½" floppy drive
Two serial ports, one parallel port	Two serial ports, one parallel port
HP DeskJet printer	HP LaserJet 4 printer
	120 MB cartridge tape drive
	Microsoft-compatible mouse

AxoBASIC Requirements

- System ***must*** have an 80386 or 80386SX with an 80387 numeric coprocessor, and at least 1 MB of RAM.
- If there is only 1 MB RAM available, the shadow RAM BIOS ***must*** be disabled.
- A two-monitor system is also supported by AxoBASIC. Two adjacent free expansion slots on the motherboard are required. Substitute the following equipment for the VGA graphics adapter and monitor:

  Princeton Graphics Systems Imager Monitor
  Number Nine Pepper 1600-1 (1 MB) 1600 x 1200 graphics adapter
  Monochrome monitor (*e.g.*, Amdek 410), **not** VGA monochrome
  Hercules monochrome graphics adapter or clone
- A mouse is required.
- A cartridge tape archival system is strongly recommended.

MACINTOSH

Our recommendations for a minimum Macintosh system and a higher performance (and higher price) system are listed below. Both are suitable for running the Axon Instruments AxoData, AxoGraph and AxoVideo software programs.

Minimal System	**Ideal System**
Macintosh IIci	Macintosh or Quadra 950
68882 floating-point unit with NuBus adapter	(floating-point comes standard)
40 MB hard disk	80 MB or larger hard disk
System 6	System 7
4 MB RAM	8 MB RAM
640x480 color display	640x480 or higher resolution color display
40 MB cartridge tape drive	60 MB or larger cartridge tape drive
Low-cost printer	Apple LaserWriter

Glossary

68000 The Apple Macintosh, as well as several other brands of computers, is based on the Motorola 68000 family of microprocessors.

8-bit, **16-bit**, **32-bit** A computer or its individual components can be described by how many bits of data at a time are manipulated or are transferred from one place to another. The original IBM PC's 8088 microprocessor operated with 16 bits internally, but the data pathways and the rest of the components only supported 8-bit transfers. Thus the computer was more accurately described as an 8-bit computer. See *bit* and *bus*.

80x86 The IBM PC and compatible computers are all based on the Intel 80x86 family of microprocessors, which are all compatible with the original 8086 and 8088 microprocessors.

80x87 The Intel 80x86 microprocessors are matched with companion processors called math coprocessors for executing operations on floating-point numbers.

A/D converter An **A**nalog-to-**D**igital converter converts analog measurements to digital numbers that the computer can store and use in calculations. See *analog* and *digital*.

Analog Real signals in the physical world are described as *analog*, meaning that the values change in a continuous manner. A mercury thermometer is an analog measurement device; the mercury rises smoothly in response to changing temperature. However, the computer requires discrete *digital* numbers to describe measurements of the data. See *A/D converter* and *digital*.

ASCII American Standard Code for Information Interchange. A standardized 7-bit code for exchanging information between computer systems. The 128-character set consists of the alpha-numeric and punctuation characters, as well as control codes such as Escape and Carriage Return. Text files on a computer are often stored in a simple ASCII format, so that they can be read easily.

AT Most IBM-compatible computers sold are compatible with the IBM PC model AT. They are often referred to simply as "AT computers."

Average seek time A measure of how quickly a hard disk drive can locate any random piece of data on the disk. Measured in milliseconds. See also *data transfer rate*.

BIOS The *Basic Input/Output System* is permanently-installed software for controlling hardware devices. A user should be aware of the BIOS because sometimes an application program will be incompatible with the computer's BIOS.

Bit Information is stored in computer memory as a series of *bits*, which are binary switches (numbers) that can either be on (1) or off (0). A group of eight bits is called a *byte*, which is a common unit for addressing and storing information.

Boot To *boot* a computer refers to the sequence of events that occurs when a computer is switched on. When the computer is turned on, its built-in software instructs the computer to load the operating system from disk into memory, and turns over control of the computer to the operating system.

Bus A bus is the physical structure, and includes the protocol for passing information between devices in a computer. A computer can have several buses, such as a memory bus for reading data from and writing data to RAM memory, and an expansion bus for adding peripheral devices.

A bus is characterized by how fast it passes information and how many data bits it passes at a time. See *expansion bus*.

Byte A byte is a series of eight bits of data. Since a bit can have two values (zero and one), a byte can have 2^8 (256) values. A character on an IBM text screen is stored in a byte of memory, so there are 256 distinct characters available. A byte is a typical unit for storing data and computer instructions. See *word*.

Cache A cache is a place to store often-accessed data or computer instructions, and is designed to provide quicker access for increased performance. A *memory cache* is faster-than-usual RAM for storing data that the microprocessor requires often from the normal RAM storage area. A *disk cache* is a RAM storage area for data that is stored on disk but is being read frequently.

CGA The Color Graphics Adapter was the first color graphics display adapter for the PC line of computers. It offered 320x200 resolution with four colors or 640x200 with two colors. This is primitive by today's standards. See *EGA* and *VGA*.

Conventional memory In the PC world, memory with an address below one megabyte.

Coprocessor A coprocessor is a specialized processor meant to complement the function of a main processor. It most commonly refers to a processor designed to execute mathematical operations on *floating-point* numbers. Another type of coprocessor called a "graphics coprocessor" helps speed graphic screen operations, and is usually built into a specialized video board.

CPU See *Microprocessor*

Data acquisition In the context of computers, data acquisition refers to the analog-to-digital conversion of measurements for storage and analysis by the computer.

Data transfer rate The rate at which data can be transferred from one device to another. For instance, a hard disk drive can transfer several hundred kilobytes of data per second to memory.

Device driver Software that acts as an extension to the operating system, usually for supporting a hardware device. Mouse pointing devices and network cards are common devices that require a device driver to be loaded when booting the system up. On PC computers, device drivers are files that traditionally have an .SYS filename extension.

Digital Data represented in discrete, discontinuous form is *digital*, as opposed to the smooth representation of data as measured by an analog device, such as a pen chart recorder. Computers require discrete digital numbers for storage and processing. See *A/D* and *analog*.

DOS See *Microsoft Disk Operating System*.

DPI *Dots Per Inch* is a measure of resolution on a printed page or computer screen. The more dots per inch, the sharper that text or a graphic image will appear. A laser printer typically has a resolution of 300 DPI.

EGA The *Enhanced Graphics Adapter* for the PC line of computers offered 640x350 screen resolution with 16 colors, as well as all of the resolutions available on the CGA card.

EISA *Extended Industry Standard Architecture* is a 32-bit superset of the ISA expansion bus.

Environment (1) The "DOS environment" is a memory space that programs and users can use to create text strings (such as the PATH string) to pass information to programs. (2) An *environment* describes the protocol that defines the user's interactions with the computer, such as the keystrokes or

mouse clicks used to launch programs, as well as the visual presentation of information on the screen. Microsoft Windows is a *graphical environment* that makes use of a mouse to quickly launch programs and to move and resize windows on the screen.

Expansion bus Personal computers are typically designed with only partial functionality built in. Video circuitry and hard disk storage are usually optional items that come in various levels of capacity and performance, so that the computer's configuration can be tailored for the user's needs and budget. PC compatibles and the Macintosh II incorporate an *expansion bus*, which provides plug-in slots, into the computers' designs. This provides a convenient way to design products that the user can plug directly into the computer. Also called the I/O bus.

Extended memory In the PC world, memory with an address above one megabyte.

Floating point A method of representing real numbers, used when a data set contains non-integer numbers. Microprocessors handle integers very well but are usually inefficient with calculations on numbers stored in a floating point format. Only recently has a microprocessor been designed with special circuitry built-in for handling floating point calculations efficiently. The Intel 80486DX handles floating point numbers very quickly, while most other micro-processors require a *coprocessor* for handling floating point calculations efficiently.

HPGL The *Hewlett Packard Graphics Language* is used to control Hewlett Packard pen plotters. Many software packages support HPGL graphic output. HPGL is the standard emulated by other brands of plotters.

I/O bus Input/Output bus. Same as *expansion bus*.

ISA *Industry Standard Architecture* is the 16-bit expansion bus design of the IBM AT and compatible computers.

Kb A *kilobyte*, which is not exactly 1,000 bytes. The computer's natural system of numbers is in base two. A kilobyte actually refers to 2^{10} (1,024) bytes. It is abbreviated with a capital K to distinguish it from the abbreviation for 1,000, as in kHz.

MB A *megabyte* is actually 1,024 kilobytes, or 1,048,576 bytes. See *Kb*.

MCA *Micro Channel Architecture* is the expansion bus design of the IBM PS/2 line of computers.

Memory See *RAM* and *ROM*.

Memory manager In the PC world, software for managing large amounts of RAM memory in an 80286, 80386 or 80486 computer.

Memory-resident program In the PC world, a program that is loaded and is usually dormant while another program is running, but runs when signaled by the user or another program. The Axon Instruments memory-resident print-screen program PrtSc lies dormant until the Print Screen key is hit. PrtSc interrupts the currently running program, prints the contents of the computer screen on a printer, then returns control of the computer to the interrupted program.

Microprocessor A microprocessor is a single integrated circuit chip that combines functions for doing logical and mathematical operations, managing memory and communicating with external devices. It is the main control center of a microcomputer.

Microsoft Disk Operating System See *MS-DOS*.

Modem A device for converting the digital signals of the computer into audio signals for communicating over phone lines with other modem-equipped computers.

MS-DOS The *Microsoft Disk Operating System* is the most popular operating system for the IBM PC. IBM's almost identical version is called PC-DOS.

NuBus *NuBus* is the expansion bus design of the Apple Macintosh II line of computers.

Operating system An *operating system* manages the hardware in a computer and provides a set of services for an application program, such as writing data to a disk drive.

OS/2 *OS/2* was designed as a more powerful successor to the MS-DOS operating system. OS/2 features multitasking, which allows several programs to run at the same time, as well as easier access to large amounts of memory. The cost of OS/2 as well as its expensive hardware requirements has delayed its acceptance.

Overlay On a computer with memory limitations, such as the IBM PC, a programming technique for conserving memory is to load only part of a program into memory at a time. If the user accesses another part of the program, another piece of the program is read into memory, *overlaying* code that is not in use. A program that uses overlays will benefit from the use of a disk cache. See *cache*.

Parallel port A type of communication interface that transfers data across several parallel lines. Communication is mostly one-way, and the length of the connecting cable is limited. In the PC, the parallel port is used mainly for connecting printers.

PC Originally referred to the IBM PC, but now refers to any computer compatible with the IBM PC designs.

PC-DOS See *MS-DOS*.

PC/XT/AT bus See *ISA*.

Protected mode Intel's advanced microprocessors (80286 and up) can run in an operating mode that allows greater memory access than the original PC's 8088, but DOS cannot run in this *protected mode*. OS/2 is a protected-mode operating system for the PC.

PS/2 The IBM PS/2 line of computers replaced IBM's PC line, although it has not been nearly as successful as PC computers. The PS/2 and PC have software compatibility, but the PS/2 utilizes the MCA bus, so add-in cards are not compatible.

RAM *Random Access Memory* is an integrated circuit for storing programs and data. RAM can be quickly read from and written to, so programs execute quickly. However, when the computer power is off, RAM cannot hold any information.

RAM disk RAM disk software configures DOS to simulate the presence of an extra disk drive, using RAM as the storage medium. Programs that need to read data from disk often will run faster if the data is stored in the RAM disk. The data in the RAM disk need to be transferred to a real disk before the computer is turned off.

Real mode The DOS operating system runs the Intel microprocessors in what is now called real mode. Real mode imposes the memory limitations that plague the PC world.

Resolution The "sharpness" of images and characters on the computer screen or on printer output. Most accurately described in units of dots per inch.

ROM *Read Only Memory* is an integrated circuit that holds information which is not lost when power is turned off. The contents of the ROM are usually loaded by the manufacturer and are not alterable by the user.

ROM-BIOS See *BIOS*.

RS-232 serial port A common, standard protocol for communicating over serial ports. It is a general two-way communication interface that transmits data on a single line and receives data on a single line. The serial interface exists in most types of computers. Also known as a serial port.

System The Macintosh operating system.

Throughput A measure of performance describing how much data per unit of time can be transferred from device to device in a computer system.

TSR See *memory-resident program*.

Unix A powerful multi-user, multi-tasking operating system common on minicomputers and "workstations," which are both more powerful and expensive than PCs. Unix for the PC and Macintosh exists but is not nearly as popular as MS-DOS or the Mac System.

VGA *Video Graphics Array* is an IBM graphic standard that describes a 320x200 screen with 256 colors, or a 640x480 screen with 16 colors, as well as all the resolutions available on the EGA and CGA. An extension to the VGA standard called "SuperVGA" was created by IBM competitors. SuperVGA describes 800x600 and 1024x768 screens with both 16 and 256 colors.

Video display card To give users the option of choosing the complexity of graphics to fit their needs and budgets, IBM designed the original PC without built-in video capability. All video options are on cards that plug into the computer's expansion bus.

Volatile memory RAM cannot hold information when the computer is turned off; consequently, it is referred to as *volatile* memory. Information must be saved to disk for long-term storage.

Volume A floppy or hard disk in a drive is called a volume by DOS. Also, a single hard disk drive may be configured to appear as several disk drives to the operating system, with the storage area for each logically-separate drive referred to as a volume.

Word A microprocessor's "natural" communication abilities determines the size of a word. Although a byte always means eight bits, on a 16-bit microprocessor a word means two bytes and on a 32-bit microprocessor a word means four bytes.

WORM *Write Once, Read Many Times* is a technology for data storage in which a small optical disk can have information written to it only once. Since the capacity of the optical disk is so big, this is a viable technology until rewritable optical disks become comparable in price.

Xenix Xenix is a simplified version of the Unix operating system. It was the first multi-user, multi-tasking operating system to run on IBM-AT computers.