Appendix A

COMPUTER HARDWARE AND SOFTWARE

In this appendix we discuss some of the issues in choosing hardware and software for image analysis. The purpose is to draw attention to the issues involved rather than to discuss the merits of particular manufacturers' products. This latter information would date very rapidly. The reader should consult recent computer journals and magazines, particularly those devoted to graphics. Even the issues involved may change with time.

Changing computer technology also affects the amount of time required by image analysis algorithms. The computing power available for a given amount of money appears to be increasing exponentially, and has been estimated as doubling every two years. The complexity of commercially available software has been growing at a similar rate.

In the two following sections we separately consider hardware and software requirements. Sometimes, they will be offered for sale as a package.

A.1 Hardware

Hardware consists of the physical components of an image analysis system. The main components are illustrated in Fig A.1.

It will be essential to have

- A **Central Processing Unit (CPU)**. This resides on a chip, and does the computing. It will have some **memory** to store the information it is currently using. There may be a memory specifically for storing digital images, usually called a **framestore**. This is often an added component in a computer system.

- A **display monitor** to look at digital images.

- Some image **storage** device to store digital images.
- An **image capture device** to create digital images from whatever is being studied.

It can also be useful to have

- Some **peripheral storage media**. These are ways of storing many images at low cost, although access will be slower. They also provide backup security should images on the main storage device become lost.
- A **printer** or other device to produce permanent copies of images.

There is an increasing trend for computing equipment to be joined to a network, and this applies to most of the equipment mentioned above. It has the advantage of allowing equipment and data to be easily shared among several users.

Since it will be necessary to acquire several items of equipment, an important issue will be **compatibility** — the extent to which different pieces of equipment can work properly together. It is the authors' experience that this can be a substantial problem. Two ways to overcome this are to buy all equipment from one manufacturer, or to buy a packaged system. These options may cost more than a separately bought configuration, and can be less flexible.

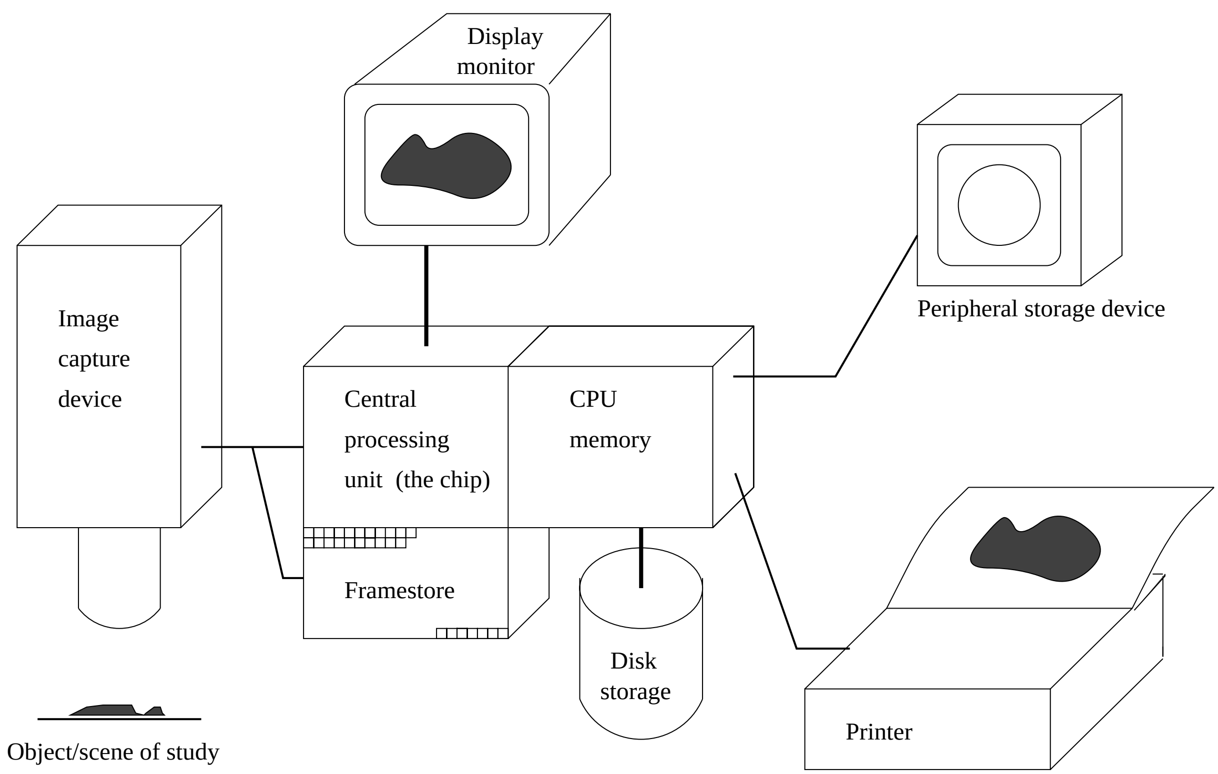

Figure A.1: Basic hardware components of an image analysis computer system.

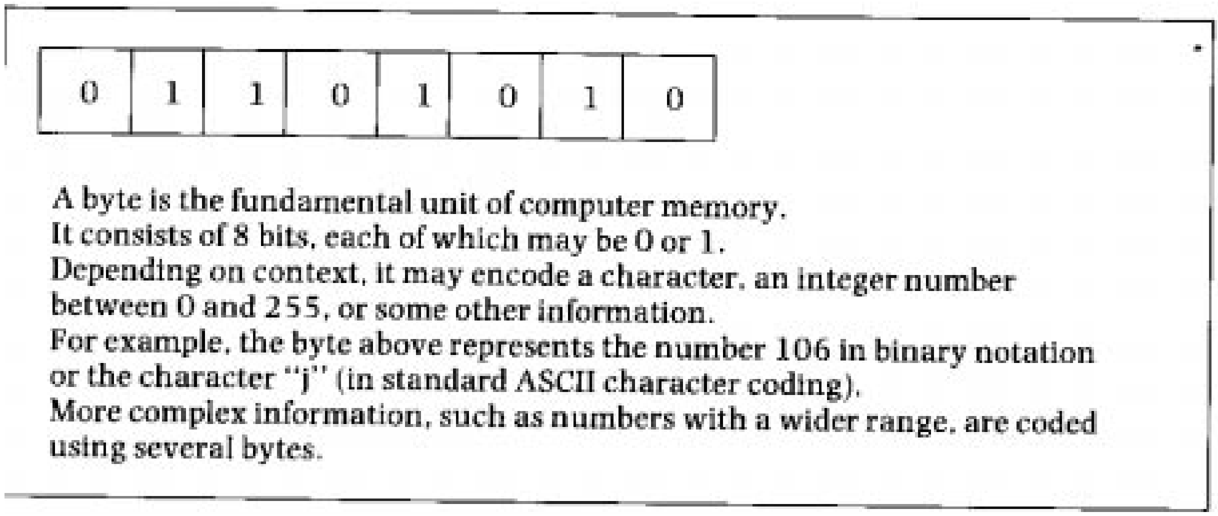

Figure A.2: Storing information in bytes

We next consider the issues involved in choosing each of the items of equipment mentioned above.

A.1.1 The central processing unit

The central processing unit (or *chip*) is the 'brain' of the computer. Although different manufacturers may produce computers with the same chip, the differences between them will be much less than those between computers with different chips. The chip is the main factor in determining the speed with which a system works. Naturally, faster chips tend to cost more. It can be difficult to judge before a system is in routine use how long it will take to complete particular tasks. If possible, advice should be sought from others working on similar tasks.

Associated with a CPU chip there will be a certain amount of CPU memory, which stores the information currently required where it can be accessed very quickly. All other information storage is much slower. The basic unit of computer memory is the **byte** (see Fig A.2), and CPU memory is usually measured in **megabytes (Mb)** or millions of bytes (actually 2^{20} bytes). CPU memory is relatively inexpensive, and it is usually worth spending money to have a good amount of it. The link between the CPU memory and the CPU (the **bus**) affects memory access, and therefore processing, times. There are also aspects to how the CPU memory is managed which will affect performance. For example, a **cache** memory on the CPU allows blocks of data to be processed and transferred quickly.

Most computers have only one CPU. Computers with more than one are also built, and designed so that computing tasks can be shared out and performed on different CPUs. This is **parallel computing**. Many image analysis tasks involve repeating the same operation many times and are well suited to parallel implementation.

A.1.2 The image capture device

The image capture device is the equipment which provides the link between the real world and the digital image in a computer. It can be any machine which records a signal from the object under study and converts it to a set of pixel values. They may be roughly divided into three types: electronic cameras, scanners and other imaging devices.

Electronic cameras are like the familiar video camera, which produces, as an electronic signal, images of the scene it is pointed at. Usually this is an analogue signal, but an **analogue-to-digital converter** will turn it into a digital signal, which may be arranged to form an image. This conversion is often done in the computer by an image framestore or framegrabber. A **still video** camera operates very like a photographic camera, but stores images in digital form, which can later be transferred to a computer.

Scanners work like photocopiers. They are widely available for use in desktop publishing (DTP). Scanners intended for scientific use are also produced. They are designed to produce more precise and repeatable results, and are more expensive. For most purposes, DTP scanners should be adequate. Although the principles they use are similar to cameras, they differ in that

- They can only scan flat objects placed in them, such as photographs. As a result they are not suitable for freezing an image at a chosen moment while observing a changing scene.
- An ordinary photograph must be produced as an intermediate stage between the scene and the scanner, except in rare cases where objects (such as electrophoresis gels) may be placed directly on the scanner.
- They can often produce higher spatial resolution and more pixels than cameras.
- Hand-held scanners, which are a cheaper option, produce poorer quality images.

Many other types of imaging equipment, particularly medical imaging equipment such as magnetic resonance imagers, ultrasound scanners and positron emission tomographs produce their images in digital form. From here, they can be transferred to a computer. Sometimes, substantial differences in hardware and software compatibility have to be overcome to do this.

The two critical aspects of any image capture equipment are its spatial and radiometric resolutions. The spatial resolution is basically the number of pixels per unit area the device produces. It determines how much detail is recorded in the object being studied. The radiometric resolution is the number of grey levels recorded. This must be at least two (for a binary image). It is sometimes 16 (half a byte), which is the minimum that can be considered useful in most applications, and is often 256 (a full byte). More than 256 is of little value in many applications.

Another aspect of image capture devices is whether they record colour. As described in chapter 2, this is done by recording more than one value at each pixel. Colour is a useful facility to have in some applications. The question to ask is: Can one see in a colour image features of interest which cannot be seen as clearly in a monochrome image? If so, then colour may help in the image analysis task planned. If not, it may simply add expense and extra processing effort without any benefits.

A.1.3 The framestore

Image analysis software will sometimes store the images it is working with in the CPU memory of the computer. In other cases, it will require a separate memory device in the computer, usually termed an image framestore or graphics device. There are many of these available. Usually they are more than simply storage devices, and can do some elementary processing of the image (such as zooming, arithmetic operations etc.) much more quickly than can be done by the CPU. They may also be the means whereby an image in some analogue form (e.g. a video camera signal) is converted into a digital image.

The size of the framestore will determine how much image data it can hold. The maximum image size will be determined by the number of rows and columns of pixels available in the framestore. The number of grey levels that can be handled is usually expressed in terms of the number of *bits* (see Fig A.2). Eight bits can accommodate $2^8 = 256$ grey levels. To store three such images simultaneously, usually in order to handle red, green and blue components, requires 24 bits. Some framestores will have extra bits to enable features to be drawn on an image without changing pixel values. Naturally, bigger framestores cost more.

A.1.4 Image storage

For many applications, it will be necessary to store digital images somewhere, so that they can be accessed on the computer in the future without the need to capture the image again. Computers usually store information on a disk, locally, or perhaps centrally if the computer is part of a network. Images stored here can be accessed quickly. Images for which rapid access is not needed can be stored on some other peripheral device. These include diskettes, cassettes, tapes of various sorts and various optical storage media. With the exception of diskettes, these are cheaper per amount of information stored than computer disks. They are all considered to be more secure than computer disks. Diskettes can store only a little information each, but are easy to use, convenient for transferring information between computers and can allow an individual more control, since they are not a shared facility. Compact Disc Read-Only Memory (CD-ROM) devices are an inexpensive way of storing a large amount of data or images, although they can only be written to once.

In deciding what storage is to be used, the amount of storage needed should be considered. Digital images occupy a lot of space. If the images are to be $n \times n$ pixels in size, with b bytes per pixel, then each image will occupy at least bn^2 bytes. For example, a 512×512 pixel image of 1-byte pixels will occupy $\frac{1}{4}$Mb.

If lots of images are to be stored, consideration should be given to **image compression** techniques. These are ways of storing images in smaller amounts of storage space. They make use of the property that adjacent pixels tend to be similar, or identical, in value and so image detail can be stored without the need to record each individual pixel. Compression has the disadvantage that images take longer to access. Some image analysis programs will offer compression as an option. Alternatively, stand-alone programs can be used to compress image (and possibly other) files stored on the computer. They can then be uncompressed (re-expanded) before use.

Many compression algorithms for binary images are very straightforward. For example, we can record for each row of the image what the starting value (0 or 1) is, and at which pixel positions along the row the value changes. This information is sufficient to reconstruct the image, and a considerable reduction in storage space can be achieved. With the turbinate image, the storage required using this algorithm is only 7% of the original uncompressed image. Images with less fine detail would be compressed even more.

Image compression can be with or without loss of information, sometimes termed **lossy** or **lossless**. If information is not lost, then the uncompressed image should be identical to what it was before compression. In some situations, some degradation of fine detail can be accepted in the compression process, in order to achieve higher compression ratios (the ratio of the size of the uncompressed to compressed images). Careful comparison of before and after compression images should be made before such algorithms are used.

Compression algorithms, whether with or without loss of information, differ in their speed of processing and the compression ratios they achieve. For a detailed discussion, see Jain (1989, Ch.11). At the time of writing, a very popular and widely available algorithm for lossless compression is the Lempel-Ziv algorithm (Lempel and Ziv, 1986). Similarly, for compression with loss, the JPEG standard (Wallace, 1991) is widely used. For descriptions of some other recent algorithms, see Devore, Jawerth and Lucier (1992), Nasiopoulos, Ward, and Morse (1991) and Martinelli, Ricotti and Marcone (1993).

A.1.5 Display

It is essential to be able to display the digital image on a monitor of some sort. Many of the issues in image display were discussed in chapter 2. Display monitors will differ in the number of pixels and the number of colours or levels of grey that can be displayed. Be aware that some systems may not allow all colours to be displayed at the same time, although this may not be as serious a drawback as it might seem — see §2.3.3.

Some framestores will be configured to use a dedicated monitor for image display, separate from the standard monitor on the computer.

A monitor with an adequate number of pixels and number of colours should be chosen. Naturally, colour monitors are more expensive than monochrome, and cost increases for monitors with greater numbers of display pixels. Monitors may have bigger screens without necessarily having more pixels. However, this may make the screen easier to look at.

A.1.6 Printing

It may be useful to produce printed copies of images. Most printers can produce some form of image printout, but the quality of the result can be very variable. Printers designed mainly for printing text will tend to produce very poor reproductions of images, only suitable for very limited purposes. Printers designed for desktop publishing, such as laser printers, will produce much better results. However, they usually print by using a very fine matrix of black dots. An image printed in this way will usually look inferior to a computer monitor display, and is unlikely to be acceptable for publication unless the image has little fine detail. Printers which can truly handle grey levels are, at the time of writing, rare and expensive, but this may change in the future. Also, colour printers are several times more expensive to buy and run than monochrome printers. The remarks made above about the number of colours that can be displayed on a monitor also apply to printers.

A variety of other devices that can produce permanent copies of images are also available. *Slidewriters*, for example, print copies of images onto standard 35mm transparencies. Finally, a crude but quite effective way of getting permanent copies of digital images is to photograph the monitor.

A.2 Software

A large amount of image analysis software, with a wide range of abilities, costs and computer customisation is now available. Any attempt to review it would rapidly become out of date. We can only give some general pointers in this section to the issues to be considered.

A.2.1 Choosing software

The first thing to realise is that all computers will be running basic computer management software called the **operating system**. Most are computer-specific, but some operating systems (e.g. Unix, DOS) are available on different computers, and some computers have a choice of operating systems. In some cases extra management tools (sometimes called **user interfaces**) will be provided as well. Window systems are an example. Many software packages will work with only one operating system, and will sometimes require a particular user interface to be available.

Some image analysis programs will require particular hardware, usually framestores, to be present. They may or may not offer a choice of framestores with which they will work.

The most important things to examine in any image analysis software are the facilities it provides. These should be considered in relation to the image analysis tasks to be performed. If possible, the package should be tested using images of the type to be studied. A list of the facilities that may be found in many packages is given in Table A.1.

Image input facilities — how an image can be read into the package.
Image spatial resolution. Is the number of pixels fixed or variable?
Handling of greyscale images.
Handling of multiple/colour images.
Bus and processing speeds — how will these affect efficiency of use?
Image storage — formats available.
Image printing.
Zooming and scrolling — looking at the image in detail.
Contrast stretching/enhancement.
Image registration.
Filters (smoothing, edge-enhancing etc.)
Binary morphological operations.
Greyscale morphological operations.
Segmentation algorithms.
Image feature measurement.
Image editing — manually editing image features or the results of analysis algorithms.
Algorithm building — ability to store a sequence of operations for single step execution.
Ability to incorporate user-written algorithms in high level languages.

Table A.1: Facilities in image analysis packages. These facilities should not be considered to be requirements, unless they are needed for the tasks the package is to perform.

Flexibility is an important feature, and one which can be hard to judge before a program has been used extensively. The program may perform its tasks in a very restricted way, or it may allow the user to modify how it does things. One point to remember is that flexibility is often sacrificed to greater ease of use. In the long term, the gains in ease of use may not justify the loss of flexibility. A well-written package should have both ease of use and flexibility, in such a way that the user can do straightforward operations very readily, and progress to the more advanced features which provide the flexibility required when experience and confidence have been gained.

Many packages provide their image manipulations in the form of building blocks which can be put together by the user to construct whole tasks. This is a form of programming, and can provide great flexibility. It is useful if the program also provides some standard combinations of operations through an easy-to-use interface. It is also sometimes possible to write image analysis software from scratch using standard programming languages such as C or Fortran. This gives the ultimate in flexibility, but requires a lot of time and effort and should only be attempted by those with experience of these languages. Libraries of image analysis routines in these languages can be bought, and incorporated into one's own programs.

Finally, it is worth noting that in the authors' experience there is much less correlation between cost and such qualities as usefulness, power, flexibility and reliability in software than there is in hardware. We have found that even software which is free of charge and available in the public domain can be powerful and flexible. With more expensive packages, one will usually get more support from the software's producers.

A.2.2 Software compatibility and image formats

Sometimes a user may wish to handle images in more than one program. For example, an image analysis program can produce scientific results, and a DTP program can be used to incorporate images into documents. Also, one may wish to use more than one image analysis package, perhaps on different computers. This gives rise to the question of compatibility. It arises because digital images may be stored in computer files in several different formats. These differ in how the pixel values are arranged, what extra information is included in the file etc. At the time of writing there is a plethora of different formats in use (TIFF, GIF, RLE, PPM, BMP, Sunraster, PCX and many, many more). Most packages will read and write a subset of these, and compatibility will be a problem if these subsets do not overlap. Standardisation may come in the future, but until then the user will need to be aware in what format their images are being stored, and what other possibilities are available in the programs being used. If necessary, programs (many of which are in the public domain) that convert between different formats may be used.