2

THE COMPUTER

OVERVIEW

A computer system comprises various elements, each of which affects the user of the system.

- Input devices for interactive use, allowing text entry, drawing and selection from the screen:
  - text entry: traditional keyboard, phone text entry, speech and handwriting
  - pointing: principally the mouse, but also touchpad, stylus and others
  - 3D interaction devices.
- Output display devices for interactive use:
  - different types of screen mostly using some form of bitmap display
  - large displays and situated displays for shared and public use
  - digital paper may be usable in the near future.
- Virtual reality systems and 3D visualization which have special interaction and display devices.
- Various devices in the physical world:
  - physical controls and dedicated displays
  - sound, smell and haptic feedback
  - sensors for nearly everything including movement, temperature, bio-signs.
- Paper output and input: the paperless office and the less-paper office:
  - different types of printers and their characteristics, character styles and fonts
  - scanners and optical character recognition.
- Memory:
  - short-term memory: RAM
  - long-term memory: magnetic and optical disks
  - capacity limitations related to document and video storage
  - access methods as they limit or help the user.
- Processing:
  - the effects when systems run too slow or too fast, the myth of the infinitely fast machine
  - limitations on processing speed
  - networks and their impact on system performance.

2.1 INTRODUCTION

In order to understand how humans interact with computers, we need to have an understanding of both parties in the interaction. The previous chapter explored aspects of human capabilities and behavior of which we need to be aware in the context of human–computer interaction; this chapter considers the computer and associated input–output devices and investigates how the technology influences the nature of the interaction and style of the interface.

We will concentrate principally on the traditional computer but we will also look at devices that take us beyond the closed world of keyboard, mouse and screen. As well as giving us lessons about more traditional systems, these are increasingly becoming important application areas in HCI.

Exercise: how many computers?

In a group or class do a quick survey:

- How many computers do you have in your home?
- How many computers do you normally carry with you in your pockets or bags?

Collate the answers and see who the techno-freaks are!

Discuss your answers.

After doing this look at /e3/online/how-many-computers/

When we interact with computers, what are we trying to achieve? Consider what happens when we interact with each other – we are either passing information to other people, or receiving information from them. Often, the information we receive is in response to the information that we have recently imparted to them, and we may then respond to that. Interaction is therefore a process of information transfer. Relating this to the electronic computer, the same principles hold: interaction is a process of information transfer, from the user to the computer and from the computer to the user.

The first part of this chapter concentrates on the transference of information from the user to the computer and back. We begin by considering a current typical computer interface and the devices it employs, largely variants of keyboard for text entry (Section 2.2), mouse for positioning (Section 2.3) and screen for displaying output (Section 2.4).

Then we move on to consider devices that go beyond the keyboard, mouse and screen: entering deeper into the electronic world with virtual reality and 3D interaction

(Section 2.5) and outside the electronic world looking at more physical interactions (Section 2.6).

In addition to direct input and output, information is passed to and fro via paper documents. This is dealt with in Section 2.7, which describes printers and scanners. Although not requiring the same degree of user interaction as a mouse or keyboard, these are an important means of input and output for many current applications.

We then consider the computer itself, its processor and memory devices and the networks that link them together. We note how the technology drives and empowers the interface. The details of computer processing should largely be irrelevant to the end-user, but the interface designer needs to be aware of the limitations of storage capacity and computational power; it is no good designing on paper a marvellous new interface, only to find it needs a Cray to run. Software designers often have high-end machines on which to develop applications, and it is easy to forget what a more typical configuration feels like.

Before looking at these devices and technology in detail we'll take a quick bird's-eye view of the way computer systems are changing.

2.1.1 A typical computer system

Consider a typical computer setup as shown in Figure 2.1. There is the computer 'box' itself, a keyboard, a mouse and a color screen. The screen layout is shown alongside it. If we examine the interface, we can see how its various characteristics are related to the devices used. The details of the interface itself, its underlying principles and design, are discussed in more depth in Chapter 3. As we shall see there are variants on these basic devices. Some of this variation is driven by different hardware configurations: desktop use, laptop computers, PDAs (personal digital assistants). Partly the diversity of devices reflects the fact that there are many different types of

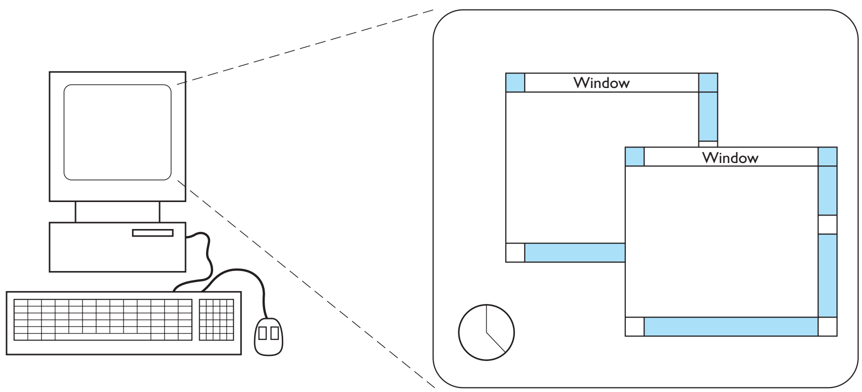


Figure 2.1 A typical computer system

data that may have to be entered into and obtained from a system, and there are also many different types of user, each with their own unique requirements.

2.1.2 Levels of interaction – batch processing

In the early days of computing, information was entered into the computer in a large mass – batch data entry. There was minimal interaction with the machine: the user would simply dump a pile of punched cards onto a reader, press the start button, and then return a few hours later. This still continues today although now with pre-prepared electronic files or possibly machine-read forms. It is clearly the most appropriate mode for certain kinds of application, for example printing pay checks or entering the results from a questionnaire.

With batch processing the interactions take place over hours or days. In contrast the typical desktop computer system has interactions taking seconds or fractions of a second (or with slow web pages sometimes minutes!). The field of Human–Computer Interaction largely grew due to this change in interactive pace. It is easy to assume that faster means better, but some of the paper-based technology discussed in Section 2.7 suggests that sometimes slower paced interaction may be better.

2.1.3 Richer interaction – everywhere, everywhen

Computers are coming out of the box! Information appliances are putting internet access or dedicated systems onto the fridge, microwave and washing machine: to automate shopping, give you email in your kitchen or simply call for maintenance when needed. We carry with us WAP phones and smartcards, have security systems that monitor us and web cams that show our homes to the world. Is Figure 2.1 really the typical computer system or is it really more like Figure 2.2?

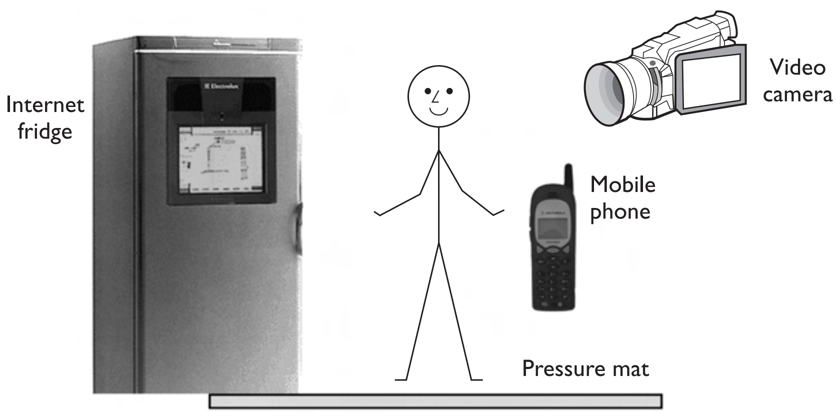


Figure 2.2 A typical computer system? Photo courtesy Electrolux

2.2 TEXT ENTRY DEVICES

Whether writing a book like this, producing an office memo, sending a thank you letter after your birthday, or simply sending an email to a friend, entering text is one of our main activities when using the computer. The most obvious means of text entry is the plain keyboard, but there are several variations on this: different keyboard layouts, 'chord' keyboards that use combinations of fingers to enter letters, and phone key pads. Handwriting and speech recognition offer more radical alternatives.

2.2.1 The alphanumeric keyboard

The keyboard is still one of the most common input devices in use today. It is used for entering textual data and commands. The vast majority of keyboards have a standardized layout, and are known by the first six letters of the top row of alphabetical keys, QWERTY. There are alternative designs which have some advantages over the QWERTY layout, but these have not been able to overcome the vast technological inertia of the QWERTY keyboard. These alternatives are of two forms: 26 key layouts and chord keyboards. A 26 key layout rearranges the order of the alphabetic keys, putting the most commonly used letters under the strongest fingers, or adopting simpler practices. In addition to QWERTY, we will discuss two 26 key layouts, alphabetic and DVORAK, and chord keyboards.

The QWERTY keyboard

The layout of the digits and letters on a QWERTY keyboard is fixed (see Figure 2.3), but non-alphanumeric keys vary between keyboards. For example, there is a difference between key assignments on British and American keyboards (in particular, above the 3 on the UK keyboard is the pound sign £, whilst on the US keyboard there is a dollar sign $). The standard layout is also subject to variation in the placement of brackets, backslashes and suchlike. In addition different national keyboards include accented letters and the traditional French layout places the main letters in different locations – the top line starts AZERTY.

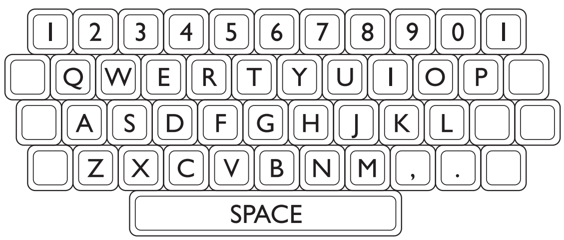


Figure 2.3 The standard QWERTY keyboard

The QWERTY arrangement of keys is not optimal for typing, however. The reason for the layout of the keyboard in this fashion can be traced back to the days of mechanical typewriters. Hitting a key caused an arm to shoot towards the carriage, imprinting the letter on the head on the ribbon and hence onto the paper. If two arms flew towards the paper in quick succession from nearly the same angle, they would often jam – the solution to this was to set out the keys so that common combinations of consecutive letters were placed at different ends of the keyboard, which meant that the arms would usually move from alternate sides. One appealing story relating to the key layout is that it was also important for a salesman to be able to type the word 'typewriter' quickly in order to impress potential customers: the letters are all on the top row!

The electric typewriter and now the computer keyboard are not subject to the original mechanical constraints, but the QWERTY keyboard remains the dominant layout. The reason for this is social – the vast base of trained typists would be reluctant to relearn their craft, whilst the management is not prepared to accept an initial lowering of performance whilst the new skills are gained. There is also a large investment in current keyboards, which would all have to be either replaced at great cost, or phased out, with the subsequent requirement for people to be proficient on both keyboards. As whole populations have become keyboard users this technological inertia has probably become impossible to change.

How keyboards work

Current keyboards work by a keypress closing a connection, causing a character code to be sent to the computer. The connection is usually via a lead, but wireless systems also exist. One aspect of keyboards that is important to users is the 'feel' of the keys. Some keyboards require a very hard press to operate the key, much like a manual typewriter, whilst others are featherlight. The distance that the keys travel also affects the tactile nature of the keyboard. The keyboards that are currently used on most notebook computers are 'half-travel' keyboards, where the keys travel only a small distance before activating their connection; such a keyboard can feel dead to begin with, but such qualitative judgments often change as people become more used to using it. By making the actual keys thinner, and allowing them a much reduced travel, a lot of vertical space can be saved on the keyboard, thereby making the machine slimmer than would otherwise be possible.

Some keyboards are even made of touch-sensitive buttons, which require a light touch and practically no travel; they often appear as a sheet of plastic with the buttons printed on them. Such keyboards are often found on shop tills, though the keys are not QWERTY, but specific to the task. Being fully sealed, they have the advantage of being easily cleaned and resistant to dirty environments, but have little feel, and are not popular with trained touch-typists. Feedback is important even at this level of human–computer interaction! With the recent increase of repetitive strain injury (RSI) to users' fingers, and the increased responsibilities of employers in these circumstances, it may be that such designs will enjoy a resurgence in the near future. RSI in fingers is caused by the tendons that control the movement of the fingers becoming inflamed owing to overuse and making repeated unnatural movements.

There are a variety of specially shaped keyboards to relieve the strain of typing or to allow people to type with some injury (e.g. RSI) or disability. These may slope the keys towards the hands to improve the ergonomic position, be designed for single-handed use, or for no hands at all. Some use bespoke key layouts to reduce strain of finger movements. The keyboard illustrated is produced by PCD Maltron Ltd. for left-handed use. See www.maltron.com/

Source: www.maltron.com, reproduced courtesy of PCD Maltron Ltd.

Ease of learning – alphabetic keyboard

One of the most obvious layouts to be produced is the alphabetic keyboard, in which the letters are arranged alphabetically across the keyboard. It might be expected that such a layout would make it quicker for untrained typists to use, but this is not the case. Studies have shown that this keyboard is not faster for properly trained typists, as we may expect, since there is no inherent advantage to this layout. And even for novice or occasional users, the alphabetic layout appears to make very little difference to the speed of typing. These keyboards are used in some pocket electronic personal organizers, perhaps because the layout looks simpler to use than the QWERTY one. Also, it dissuades people from attempting to use their touch-typing skills on a very small keyboard and hence avoids criticisms of difficulty of use!

Ergonomics of use – DVORAK keyboard and split designs

The DVORAK keyboard uses a similar layout of keys to the QWERTY system, but assigns the letters to different keys. Based upon an analysis of typing, the keyboard is designed to help people reach faster typing speeds. It is biased towards right-handed people, in that 56% of keystrokes are made with the right hand. The layout of the keys also attempts to ensure that the majority of keystrokes alternate between hands, thereby increasing the potential speed. By keeping the most commonly used keys on the home, or middle, row, 70% of keystrokes are made without the typist having to stretch far, thereby reducing fatigue and increasing keying speed. The layout also aims to minimize the number of keystrokes made with the weak fingers. Many of these requirements are in conflict, and the DVORAK keyboard represents one possible solution. Experiments have shown that there is a speed improvement of between 10 and 15%, coupled with a reduction in user fatigue due to the increased ergonomic layout of the keyboard [230].

Other aspects of keyboard design have been altered apart from the layout of the keys. A number of more ergonomic designs have appeared, in which the basic tilted planar base of the keyboard is altered. Moderate designs curve the plane of the keyboard, making it concave, whilst more extreme ones split the keys into those for the left and right hand and curve both halves separately. Often in these the keys are also moved to bring them all within easy reach, to minimize movement between keys. Such designs are supposed to aid comfort and reduce RSI by minimizing effort, but have had practically no impact on the majority of systems sold.

2.2.2 Chord keyboards

Chord keyboards are significantly different from normal alphanumeric keyboards. Only a few keys, four or five, are used (see Figure 2.4) and letters are produced by pressing one or more of the keys at once. For example, in the *Microwriter*, the pattern of multiple keypresses is chosen to reflect the actual letter shape.

Such keyboards have a number of advantages. They are extremely compact: simply reducing the size of a conventional keyboard makes the keys too small and close together, with a correspondingly large increase in the difficulty of using it. The

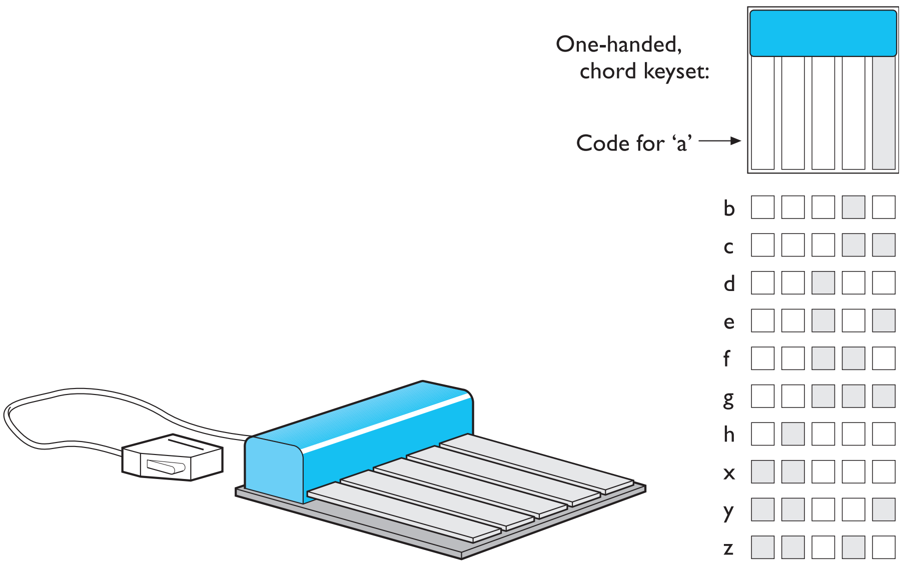


Figure 2.4 A very early chord keyboard (left) and its lettercodes (right)

learning time for the keyboard is supposed to be fairly short – of the order of a few hours – but social resistance is still high. Moreover, they are capable of fast typing speeds in the hands (or rather hand!) of a competent user. Chord keyboards can also be used where only one-handed operation is possible, in cramped and confined conditions.

Lack of familiarity means that these are unlikely ever to be a mainstream form of text entry, but they do have applications in niche areas. In particular, courtroom stenographers use a special form of two-handed chord keyboard and associated shorthand to enter text at full spoken speed. Also it may be that the compact size and one-handed operation will find a place in the growing wearables market.

DESIGN FOCUS

Numeric keypads

Alphanumeric keyboards (as the name suggests) include numbers as well as letters. In the QWERTY layout these are in a line across the top of the keyboard, but in most larger keyboards there is also a separate number pad to allow faster entry of digits. Number keypads occur in other contexts too, including calculators, telephones and ATM cash dispensers. Many people are unaware that there are two different layouts for numeric keypads: the calculator style that has '123' on the bottom and the telephone style that has '123' at the top.

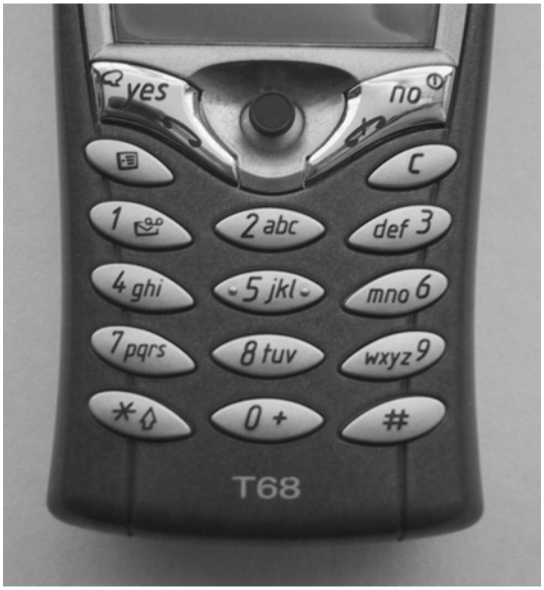
It is a demonstration of the amazing adaptability of humans that we move between these two styles with such ease. However, if you need to include a numeric keypad in a device you must consider which is most appropriate for your potential users. For example, computer keyboards use calculator-style layout, as they are primarily used for entering numbers for calculations.

One of the authors was caught out by this once when he forgot the PIN number of his cash card. He half remembered the digits, but also his fingers knew where to type, so he 'practiced' on his calculator. Unfortunately ATMs use telephone-style layout!

calculator

ATM

phone



Typical key mapping:
1 – space, comma, etc. (varies)
2 – a b c
3 – d e f
4 – g h i
5 – j k l
6 – m n o
7 – p q r s
8 – t u v
9 – w x y z
0 – +, &, etc.

Figure 2.5 Mobile phone keypad. Source: Photograph by Alan Dix (Ericsson phone)

2.2.3 Phone pad and T9 entry

With mobile phones being used for SMS text messaging (see Chapter 19) and WAP (see Chapter 21), the phone keypad has become an important form of text input. Unfortunately a phone only has digits 0–9, not a full alphanumeric keyboard.

To overcome this for text input the numeric keys are usually pressed several times – Figure 2.5 shows a typical mapping of digits to letters. For example, the 3 key has 'def' on it. If you press the key once you get a 'd', if you press 3 twice you get an 'e', if you press it three times you get an 'f'. The main number-to-letter mapping is standard, but punctuation and accented letters differ between phones. Also there needs to be a way for the phone to distinguish, say, the 'dd' from 'e'. On some phones you need to pause for a short period between successive letters using the same key, for others you press an additional key (e.g. '#').

Most phones have at least two *modes* for the numeric buttons: one where the keys mean the digits (for example when entering a phone number) and one where they mean letters (for example when typing an SMS message). Some have additional modes to make entering accented characters easier. Also a special mode or setting is needed for capital letters although many phones use rules to reduce this, for example automatically capitalizing the initial letter in a message and letters following full stops, question marks and exclamation marks.

This is all very laborious and, as we will see in Chapter 19, experienced mobile phone users make use of a highly developed shorthand to reduce the number of keystrokes. If you watch a teenager or other experienced txt-er, you will see they often develop great typing speed holding the phone in one hand and using only their thumb. As these skills spread through society it may be that future devices use this as a means of small format text input. For those who never develop this physical dexterity some phones have tiny plug-in keyboards, or come with fold-out keyboards.

Another technical solution to the problem is the T9 algorithm. This uses a large dictionary to disambiguate words by simply typing the relevant letters once. For example, '3926753' becomes 'example' as there is only one word with letters that match (alternatives like 'ewbosld' that also match are not real words). Where there are ambiguities such as '26', which could be an 'am' or an 'an', the phone gives a series of options to choose from.

2.2.4 Handwriting recognition

Handwriting is a common and familiar activity, and is therefore attractive as a method of text entry. If we were able to write as we would when we use paper, but with the computer taking this form of input and converting it to text, we can see that it is an intuitive and simple way of interacting with the computer. However, there are a number of disadvantages with handwriting recognition. Current technology is still fairly inaccurate and so makes a significant number of mistakes in recognizing letters, though it has improved rapidly. Moreover, individual differences in handwriting are enormous, and make the recognition process even more difficult. The most significant information in handwriting is not in the letter shape itself but in the stroke information – the way in which the letter is drawn. This means that devices which support handwriting recognition must capture the stroke information, not just the final character shape. Because of this, online recognition is far easier than reading handwritten text on paper. Further complications arise because letters within words are shaped and often drawn very differently depending on the actual word; the context can help determine the letter's identity, but is often unable to provide enough information. Handwriting recognition is covered in more detail later in the book, in Chapter 10. More serious in many ways is the limitation on speed; it is difficult to write at more than 25 words a minute, which is no more than half the speed of a decent typist.

The different nature of handwriting means that we may find it more useful in situations where a keyboard-based approach would have its own problems. Such situations will invariably result in completely new systems being designed around the handwriting recognizer as the predominant mode of textual input, and these may bear very little resemblance to the typical system. Pen-based systems that use handwriting recognition are actively marketed in the mobile computing market, especially for smaller pocket organizers. Such machines are typically used for taking notes and jotting down and sketching ideas, as well as acting as a diary, address book and organizer. Using handwriting recognition has many advantages over using a keyboard. A pen-based system can be small and yet still accurate and easy to use, whereas small keys become very tiring, or even impossible, to use accurately. Also the pen-based approach does not have to be altered when we move from jotting down text to sketching diagrams; pen-based input is highly appropriate for this also.

Some organizer designs have dispensed with a keyboard completely. With such systems one must consider all sorts of other ways to interact with the system that are not character based. For example, we may decide to use *gesture recognition*, rather than commands, to tell the system what to do, for example drawing a line through a word in order to delete it. The important point is that a different input device that was initially considered simply as an alternative to the keyboard opens up a whole host of alternative interface designs and different possibilities for interaction.

Signature authentication

Handwriting recognition is difficult principally because of the great differences between different people's handwriting. These differences can be used to advantage in *signature authentication* where the purpose is to identify the user rather than read the signature. Again this is far easier when we have stroke information as people tend to produce signatures which *look* slightly different from one another in detail, but are formed in a similar fashion. Furthermore, a forger who has a copy of a person's signature may be able to copy the appearance of the signature, but will not be able to reproduce the pattern of strokes.

2.2.5 Speech recognition

Speech recognition is a promising area of text entry, but it has been promising for a number of years and is still only used in very limited situations. There is a natural enthusiasm for being able to talk to the machine and have it respond to commands, since this form of interaction is one with which we are very familiar. Successful recognition rates of over 97% have been reported, but since this represents one letter in error in approximately every 30, or one spelling mistake every six or so words, this is stoll unacceptable (*sic*)! Note also that this performance is usually quoted only for a restricted vocabulary of command words. Trying to extend such systems to the level of understanding natural language, with its inherent vagueness, imprecision and pauses, opens up many more problems that have not been satisfactorily solved even for keyboard-entered natural language. Moreover, since every person speaks differently, the system has to be trained and tuned to each new speaker, or its performance decreases. Strong accents, a cold or emotion can also cause recognition problems, as can background noise. This leads us on to the question of practicality within an office environment: not only may the background level of noise cause errors, but if everyone in an open-plan office were to talk to their machine, the level of noise would dramatically increase, with associated difficulties. Confidentiality would also be harder to maintain.

Despite its problems, speech technology has found niche markets: telephone information systems, access for the disabled, in hands-occupied situations (especially military) and for those suffering RSI. This is discussed in greater detail in Chapter 10, but we can see that it offers three possibilities. The first is as an alternative text entry device to replace the keyboard within an environment and using software originally designed for keyboard use. The second is to redesign a system, taking full advantage of the benefits of the technique whilst minimizing the potential problems. Finally, it can be used in areas where keyboard-based input is impractical or impossible. It is in the latter, more radical areas that speech technology is currently achieving success.

2.3 POSITIONING, POINTING AND DRAWING

Central to most modern computing systems is the ability to point at something on the screen and thereby manipulate it, or perform some function. There has been a long history of such devices, in particular in *computer-aided design* (CAD), where positioning and drawing are the major activities. Pointing devices allow the user to point, position and select items, either directly or by manipulating a pointer on the screen. Many pointing devices can also be used for free-hand drawing although the skill of drawing with a mouse is very different from using a pencil. The mouse is still most common for desktop computers, but is facing challenges as laptop and handheld computing increase their market share. Indeed, these words are being typed on a laptop with a touchpad and no mouse.

2.3.1 The mouse

The mouse has become a major component of the majority of desktop computer systems sold today, and is the little box with the tail connecting it to the machine in our basic computer system picture (Figure 2.1). It is a small, palm-sized box housing a weighted ball – as the box is moved over the tabletop, the ball is rolled by the table and so rotates inside the housing. This rotation is detected by small rollers that are in contact with the ball, and these adjust the values of potentiometers. If you remove the ball occasionally to clear dust you may be able to see these rollers. The changing values of these potentiometers can be directly related to changes in position of the ball. The potentiometers are aligned in different directions so that they can detect both horizontal and vertical motion. The relative motion information is passed to the computer via a wire attached to the box, or in some cases using wireless or infrared, and moves a pointer on the screen, called the *cursor*. The whole arrangement tends to look rodent-like, with the box acting as the body and the wire as the tail; hence the term ‘mouse’. In addition to detecting motion, the mouse has typically one, two or three buttons on top. These are used to indicate selection or to initiate action. Single-button mice tend to have similar functionality to multi-button mice, and achieve this by instituting different operations for a single and a double button click. A ‘double-click’ is when the button is pressed twice in rapid succession. Multi-button mice tend to allocate one operation to each particular button.

The mouse operates in a planar fashion, moving around the desktop, and is an indirect input device, since a transformation is required to map from the horizontal nature of the desktop to the vertical alignment of the screen. Left–right motion is directly mapped, whilst up–down on the screen is achieved by moving the mouse away–towards the user. The mouse only provides information on the relative movement of the ball within the housing: it can be physically lifted up from the desktop and replaced in a different position without moving the cursor. This offers the advantage that less physical space is required for the mouse, but suffers from being less intuitive for novice users. Since the mouse sits on the desk, moving it about is easy and users suffer little arm fatigue, although the indirect nature of the medium can lead to problems with hand–eye coordination. However, a major advantage of the mouse is that the cursor itself is small, and it can be easily manipulated without obscuring the display.

The mouse was developed around 1964 by Douglas C. Engelbart, and a photograph of the first prototype is shown in Figure 2.6. This used two wheels that slid across the desktop and transmitted *x–y* coordinates to the computer. The housing was carved in wood, and has been damaged, exposing one of the wheels. The original design actually offers a few advantages over today's more sleek versions: by tilting it so that only one wheel is in contact with the desk, pure vertical or horizontal motion can be obtained. Also, the problem of getting the cursor across the large screens that are often used today can be solved by flicking your wrist to get the horizontal wheel spinning. The mouse pointer then races across the screen with no further effort on your behalf, until you stop it at its destination by dropping the mouse down onto the desktop.

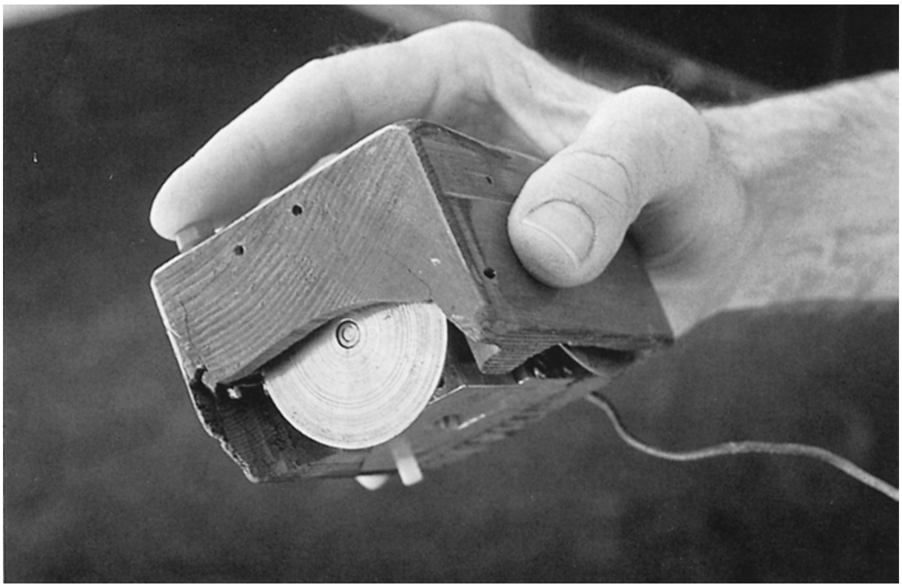


Figure 2.6 The first mouse. Photograph courtesy of Douglas Engelbart and Bootstrap Institute

Optical mice

Optical mice work differently from mechanical mice. A light-emitting diode emits a weak red light from the base of the mouse. This is reflected off a special pad with a metallic grid-like pattern upon which the mouse has to sit, and the fluctuations in reflected intensity as the mouse is moved over the gridlines are recorded by a sensor in the base of the mouse and translated into relative *x*, *y* motion. Some optical mice do not require special mats, just an appropriate surface, and use the natural texture of the surface to detect movement. The optical mouse is less susceptible to dust and dirt than the mechanical one in that its mechanism is less likely to become blocked up. However, for those that rely on a special mat, if the mat is not properly aligned, movement of the mouse may become erratic – especially difficult if you are working with someone and pass the mouse back and forth between you.

Although most mice are hand operated, not all are – there have been experiments with a device called the *footmouse*. As the name implies, it is a foot-operated device, although more akin to an isometric joystick than a mouse. The cursor is moved by foot pressure on one side or the other of a pad. This allows one to dedicate hands to the keyboard. A rare device, the footmouse has not found common acceptance!

Interestingly foot pedals are used heavily in musical instruments including pianos, electric guitars, organs and drums and also in mechanical equipment including cars, cranes, sewing machines and industrial controls. So it is clear that in principle this is a good idea. Two things seem to have limited their use in computer equipment (except simulators and games). One is the practicality of having foot controls in the work environment: pedals under a desk may be operated accidentally, laptops with foot pedals would be plain awkward. The second issue is the kind of control being exercised. Pedals in physical interfaces are used predominantly to control one or more single-dimensional analog controls. It may be that in more specialized interfaces appropriate foot-operated controls could be more commonly and effectively used.

2.3.2 Touchpad

Touchpads are touch-sensitive tablets usually around 2–3 inches (50–75 mm) square. They were first used extensively in Apple Powerbook portable computers but are now used in many other notebook computers and can be obtained separately to replace the mouse on the desktop. They are operated by stroking a finger over their surface, rather like using a simulated trackball. The feel is very different from other input devices, but as with all devices users quickly get used to the action and become proficient.

Because they are small it may require several strokes to move the cursor across the screen. This can be improved by using acceleration settings in the software linking the trackpad movement to the screen movement. Rather than having a fixed ratio of pad distance to screen distance, this varies with the speed of movement. If the finger moves slowly over the pad then the pad movements map to small distances on the screen. If the finger is moving quickly the same distance on the touchpad moves the cursor a long distance. For example, on the trackpad being used when writing this section a very slow movement of the finger from one side of the trackpad to the other moves the cursor less than 10% of the width of the screen. However, if the finger is moved very rapidly from side to side, the cursor moves the whole width of the screen.

In fact, this form of acceleration setting is also used in other indirect positioning devices including the mouse. Fine settings of this sort of parameter makes a great difference to the 'feel' of the device.

2.3.3 Trackball and thumbwheel

The trackball is really just an upside-down mouse! A weighted ball faces upwards and is rotated inside a static housing, the motion being detected in the same way as for a mechanical mouse, and the relative motion of the ball moves the cursor. Because of this, the trackball requires no additional space in which to operate, and is therefore a very compact device. It is an indirect device, and requires separate buttons for selection. It is fairly accurate, but is hard to draw with, as long movements are difficult. Trackballs now appear in a wide variety of sizes, the most usual being about the same as a golf ball, with a number of larger and smaller devices available. The size and 'feel' of the trackball itself affords significant differences in the usability of the device: its weight, rolling resistance and texture all contribute to the overall effect.

Some of the smaller devices have been used in notebook and portable computers, but more commonly trackpads or nipples are used. They are often sold as alternatives to mice on desktop computers, especially for RSI sufferers. They are also heavily used in video games where their highly responsive behavior, including being able to spin the ball, is ideally suited to the demands of play.

Thumbwheels are different in that they have two orthogonal dials to control the cursor position. Such a device is very cheap, but slow, and it is difficult to manipulate the cursor in any way other than horizontally or vertically. This limitation can sometimes be a useful constraint in the right application. For instance, in CAD the designer is almost always concerned with exact verticals and horizontals, and a device that provides such constraints is very useful, which accounts for the appearance of thumbwheels in CAD systems. Another successful application for such a device has been in a drawing game such as Etch-a-Sketch in which straight lines can be created on a simple screen, since the predominance of straight lines in simple drawings means that the motion restrictions are an advantage rather than a handicap. However, if you were to try to write your signature using a thumbwheel, the limitations would be all too apparent. The appropriateness of the device depends on the task to be performed.

Although two-axis thumbwheels are not heavily used in mainstream applications, single thumbwheels are often included on a standard mouse in order to offer an alternative means to scroll documents. Normally scrolling requires you to grab the scroll bar with the mouse cursor and drag it down. For large documents it is hard to be accurate and in addition the mouse dragging is done holding a finger down which adds to hand strain. In contrast the small scroll wheel allows comparatively intuitive and fast scrolling, simply rotating the wheel to move the page.

2.3.4 Joystick and keyboard nipple

The joystick is an indirect input device, taking up very little space. Consisting of a small palm-sized box with a stick or shaped grip sticking up from it, the joystick is a simple device with which movements of the stick cause a corresponding movement of the screen cursor. There are two types of joystick: the *absolute* and the *isometric*. In the absolute joystick, movement is the important characteristic, since the position of the joystick in the base corresponds to the position of the cursor on the screen. In the isometric joystick, the pressure on the stick corresponds to the velocity of the cursor, and when released, the stick returns to its usual upright centered position. This type of joystick is also called the velocity-controlled joystick, for obvious reasons. The buttons are usually placed on the top of the stick, or on the front like a trigger. Joysticks are inexpensive and fairly robust, and for this reason they are often found in computer games. Another reason for their dominance of the games market is their relative familiarity to users, and their likeness to aircraft joysticks: aircraft are a favorite basis for games, leading to familiarity with the joystick that can be used for more obscure entertainment ideas.

A smaller device but with the same basic characteristics is used on many laptop computers to control the cursor. Some older systems had a variant of this called the keymouse, which was a single key. More commonly a small rubber nipple projects in the center of the keyboard and acts as a tiny isometric joystick. It is usually difficult for novices to use, but this seems to be related to fine adjustment of the speed settings. Like the joystick the nipple controls the rate of movement across the screen and is thus less direct than a mouse or stylus.

2.3.5 Touch-sensitive screens (touchscreens)

Touchscreens are another method of allowing the user to point and select objects on the screen, but they are much more direct than the mouse, as they detect the presence of the user's finger, or a stylus, on the screen itself. They work in one of a number of different ways: by the finger (or stylus) interrupting a matrix of light beams, or by capacitance changes on a grid overlaying the screen, or by ultrasonic reflections. Because the user indicates exactly which item is required by pointing to it, no mapping is required and therefore this is a direct device.

The touchscreen is very fast, and requires no specialized pointing device. It is especially good for selecting items from menus displayed on the screen. Because the screen acts as an input device as well as an output device, there is no separate hardware to become damaged or destroyed by dirt; this makes touchscreens suitable for use in hostile environments. They are also relatively intuitive to use and have been used successfully as an interface to information systems for the general public.

They suffer from a number of disadvantages, however. Using the finger to point is not always suitable, as it can leave greasy marks on the screen, and, being a fairly blunt instrument, it is quite inaccurate. This means that the selection of small regions is very difficult, as is accurate drawing. Moreover, lifting the arm to point to a vertical screen is very tiring, and also means that the screen has to be within about a meter of the user to enable it to be reached, which can make it too close for comfort. Research has shown that the optimal angle for a touchscreen is about 15 degrees up from the horizontal.

2.3.6 Stylus and light pen

For more accurate positioning (and to avoid greasy screens), systems with touch-sensitive surfaces often emply a stylus. Instead of pointing at the screen directly a small pen-like plastic stick is used to point and draw on the screen. This is particularly popular in PDAs, but they are also being used in some laptop computers.

An older technology that is used in the same way is the light pen. The pen is connected to the screen by a cable and, in operation, is held to the screen and detects a burst of light from the screen phosphor during the display scan. The light pen can therefore address individual pixels and so is much more accurate than the touchscreen.

Both stylus and light pen can be used for fine selection and drawing, but both can be tiring to use on upright displays and are harder to take up and put down when used together with a keyboard. Interestingly some users of PDAs with fold-out keyboards learn to hold the stylus held outwards between their fingers so that they can type whilst holding it. As it is unattached the stylus can easily get lost, but a closed pen can be used in emergencies.

Stylus, light pen and touchscreen are all very direct in that the relationship between the device and the thing selected is immediate. In contrast, mouse, touchpad, joystick and trackball all have to map movements on the desk to cursor movement on the screen.

However, the direct devices suffer from the problem that, in use, the act of pointing actually obscures the display, making it harder to use, especially if complex detailed selections or movements are required in rapid succession. This means that screen designs have to take into account where the user's hand will be. For example, you may want to place menus at the bottom of the screen rather than the top. Also you may want to offer alternative layouts for right-handed and left-handed users.

2.3.7 Digitizing tablet

The digitizing tablet is a more specialized device typically used for freehand drawing, but may also be used as a mouse substitute. Some highly accurate tablets, usually using a puck (a mouse-like device), are used in special applications such as digitizing information for maps.

The tablet provides positional information by measuring the position of some device on a special pad, or *tablet*, and can work in a number of ways. The *resistive* *tablet* detects point contact between two separated conducting sheets. It has advantages in that it can be operated without a specialized stylus – a pen or the user's finger is sufficient. The *magnetic tablet* detects current pulses in a magnetic field using a small loop coil housed in a special pen. There are also capacitative and electrostatic tablets that work in a similar way. The *sonic tablet* is similar to the above but requires no special surface. An ultrasonic pulse is emitted by a special pen which is detected by two or more microphones which then triangulate the pen position. This device can be adapted to provide 3D input, if required.

Digitizing tablets are capable of high resolution, and are available in a range of sizes. Sampling rates vary, affecting the resolution of cursor movement, which gets progressively finer as the sampling rate increases. The digitizing tablet can be used to detect relative motion *or* absolute motion, but is an indirect device since there is a mapping from the plane of operation of the tablet to the screen. It can also be used for text input; if supported by character recognition software, handwriting can be interpreted. Problems with digitizing tablets are that they require a large amount of desk space, and may be awkward to use if displaced to one side by the keyboard.

2.3.8 Eyegaze

Eyegaze systems allow you to control the computer by simply looking at it! Some systems require you to wear special glasses or a small head-mounted box, others are built into the screen or sit as a small box below the screen. A low-power laser is shone into the eye and is reflected off the retina. The reflection changes as the angle of the eye alters, and by tracking the reflected beam the eyegaze system can determine the direction in which the eye is looking. The system needs to be calibrated, typically by staring at a series of dots on the screen, but thereafter can be used to move the screen cursor or for other more specialized uses. Eyegaze is a very fast and accurate device, but the more accurate versions can be expensive. It is fine for selection but not for drawing since the eye does not move in smooth lines. Also in real applications it can be difficult to distinguish deliberately gazing at something and accidentally glancing at it.

Such systems have been used in military applications, notably for guiding air-to-air missiles to their targets, but are starting to find more peaceable uses, for disabled users and for workers in environments where it is impossible for them to use their hands. The rarity of the eyegaze is due partly to its novelty and partly to its expense, and it is usually found only in certain domain-specific applications. Within HCI it is particularly useful as part of evaluation as one is able to trace exactly where the user is looking [81]. As prices drop and the technology becomes less intrusive we may see more applications using eyegaze, especially in virtual reality and augmented reality areas (see Chapter 20).

2.3.9 Cursor keys and discrete positioning

All of the devices we have discussed are capable of giving near continuous 2D positioning, with varying degrees of accuracy. For many applications we are only

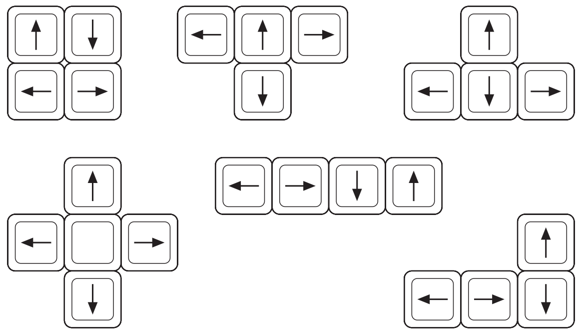


Figure 2.7 Various cursor key layouts

interested in positioning within a sequential list such as a menu or amongst 2D cells as in a spreadsheet. Even for moving within text discrete up/down left/right keys can sometimes be preferable to using a mouse.

Cursor keys are available on most keyboards. Four keys on the keyboard are used to control the cursor, one each for up, down, left and right. There is no standardized layout for the keys. Some layouts are shown in Figure 2.7, but the most common now is the inverted 'T'.

Cursor keys used to be more heavily used in character-based systems before windows and mice were the norm. However, when logging into remote machines such as web servers, the interface is often a virtual character-based terminal within a telnet window. In such applications it is common to find yourself in a 1970s world of text editors controlled sometimes using cursor keys and sometimes by more arcane combinations of control keys!

Small devices such as mobile phones, personal entertainment and television remote controls often require discrete control, either dedicated to a particular function such as volume, or for use as general menu selection. Figure 2.8 shows examples of these. The satellite TV remote control has dedicated '+/–' buttons for controlling volume and stepping between channels. It also has a central cursor pad that is used for on-screen menus. The mobile phone has a single central joystick-like device. This can be pushed left/right, up/down to navigate within the small 3×3 array of graphical icons as well as select from text menus.

2.4 DISPLAY DEVICES

The vast majority of interactive computer systems would be unthinkable without some sort of display screen, but many such systems do exist, though usually in specialized applications only. Thinking beyond the traditional, systems such as cars, hi-fis and security alarms all have different outputs from those expressible on a screen, but in the personal computer and workstation market, screens are pervasive.

Figure 2.8 Satellite TV remote control and mobile phone. Source: Photograph left by Alan Dix with permission from British Sky Broadcasting Limited, photograph right by Alan Dix (Ericsson phone)

In this section, we discuss the standard computer display in detail, looking at the properties of bitmap screens, at different screen technologies, at large and situated displays, and at a new technology, 'digital paper'.

2.4.1 Bitmap displays – resolution and color

Virtually all computer displays are based on some sort of bitmap. That is the display is made of vast numbers of colored dots or pixels in a rectangular grid. These pixels may be limited to black and white (for example, the small display on many TV remote controls), in grayscale, or full color.

The color or, for monochrome screens, the intensity at each pixel is held by the computer's video card. One bit per pixel can store on/off information, and hence only black and white (the term 'bitmap' dates from such displays). More bits per pixel give rise to more color or intensity possibilities. For example, 8 bits/pixel give rise to $2^8 = 256$ possible colors *at any one time*. The set of colors make up what is called the *colormap*, and the colormap can be altered at any time to produce a different set of colors. The system is therefore capable of actually displaying many more than the number of colors in the colormap, but not simultaneously. Most desktop computers now use 24 or 32 bits per pixel which allows virtually unlimited colors, but devices such as mobile phones and PDAs are often still monochrome or have limited color range.

As well as the number of colors that can be displayed at each pixel, the other measure that is important is the resolution of the screen. Actually the word 'resolution' is used in a confused (and confusing!) way for screens. There are two numbers to consider:

- the *total number* of pixels: in standard computer displays this is always in a 4:3 ratio, perhaps 1024 pixels across by 768 down, or 1600×1200; for PDAs this will be more in the order of a few hundred pixels in each direction.
- the *density* of pixels: this is measured in pixels per inch. Unlike printers (see Section 2.7 below) this density varies little between 72 and 96 pixels per inch.

To add to the confusion, a monitor, liquid crystal display (LCD) screen or other display device will quote its maximum resolution, but the computer may actually give it less than this. For example, the screen may be a 1200×900 resolution with 96 pixels per inch, but the computer only sends it 800×600. In the case of a cathode ray tube (CRT) this typically will mean that the image is stretched over the screen surface giving a lower density of 64 pixels per inch. An LCD screen cannot change its pixel size so it would keep 96 pixels per inch and simply not use all its screen space, adding a black border instead. Some LCD projectors will try to stretch or reduce what they are given, but this may mean that one pixel gets stretched to two, or two pixels get 'squashed' into one, giving rise to display 'artifacts' such as thin lines disappearing, or uniform lines becoming alternately thick or thin.

Although horizontal and vertical lines can be drawn perfectly on bitmap screens, and lines at 45 degrees reproduce reasonably well, lines at any other angle and curves have 'jaggies', rough edges caused by the attempt to approximate the line with pixels.

When using a single color jaggies are inevitable. Similar effects are seen in bitmap fonts. The problem of jaggies can be reduced by using high-resolution screens, or by a technique known as *anti-aliasing*. Anti-aliasing softens the edges of line segments, blurring the discontinuity and making the jaggies less obvious.

Look at the two images in Figure 2.9 with your eyes slightly screwed up. See how the second anti-aliased line looks better. Of course, screen resolution is much higher, but the same principle holds true. The reason this works is because our brains are constantly 'improving' what we see in the world: processing and manipulating the raw sensations of the rods and cones in our eyes and turning them into something meaningful. Often our vision is blurred because of poor light, things being out of focus, or defects in our vision. Our brain compensates and tidies up blurred images. By deliberately blurring the image, anti-aliasing triggers this processing in our brain and we appear to see a smooth line at an angle.

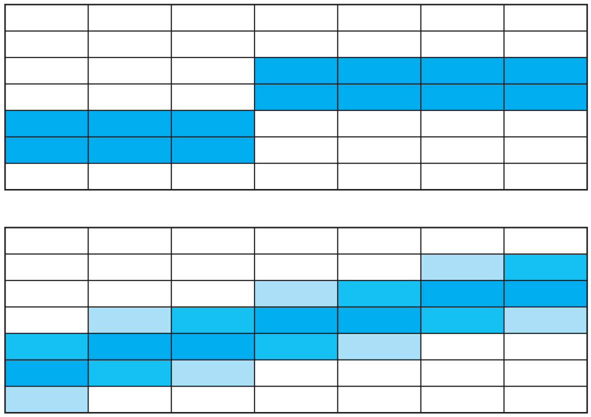


Figure 2.9 Magnified anti-aliased lines

2.4.2 Technologies

Cathode ray tube

The cathode ray tube is the television-like computer screen still most common as we write this, but rapidly being displaced by flat LCD screens. It works in a similar way to a standard television screen. A stream of electrons is emitted from an electron gun, which is then focussed and directed by magnetic fields. As the beam hits the phosphor-coated screen, the phosphor is excited by the electrons and glows (see Figure 2.10). The electron beam is scanned from left to right, and then flicked back to rescan the next line, from top to bottom. This is repeated, at about 30 Hz (that is, 30 times a second), per frame, although higher scan rates are sometimes used to reduce the flicker on the screen. Another way of reducing flicker is to use *interlacing*, in which the odd lines on the screen are all scanned first, followed by the even lines. Using a high-persistence phosphor, which glows for a longer time when excited, also reduces flicker, but causes image smearing especially if there is significant animation.

Black and white screens are able to display grayscale by varying the intensity of the electron beam; color is achieved using more complex means. Three electron guns are used, one each to hit red, green and blue phosphors. Combining these colors can

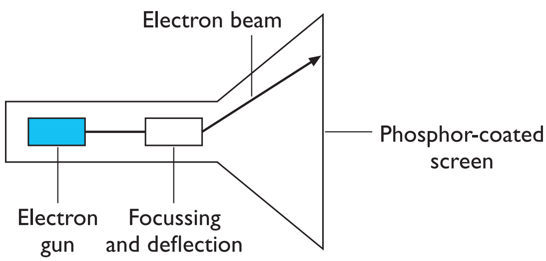


Figure 2.10 CRT screen

produce many others, including white, when they are all fully on. These three phosphor dots are focussed to make a single point using a *shadow mask*, which is imprecise and gives color screens a lower resolution than equivalent monochrome screens.

An alternative approach to producing color on the screen is to use *beam penetration*. A special phosphor glows a different color depending on the intensity of the beam hitting it.

The CRT is a cheap display device and has fast enough response times for rapid animation coupled with a high color capability. Note that animation does not necessarily mean little creatures and figures running about on the screen, but refers in a more general sense to the use of motion in displays: moving the cursor, opening windows, indicating processor-intensive calculations, or whatever. As screen resolution increases, however, the price rises. Because of the electron gun and focussing components behind the screen, CRTs are fairly bulky, though recent innovations have led to flatter displays in which the electron gun is not placed so that it fires directly at the screen, but fires parallel to the screen plane with the resulting beam bent through 90 degrees to hit the screen.

Health hazards of CRT displays

Most people who habitually use computers are aware that screens can often cause eyestrain and fatigue; this is usually due to flicker, poor legibility or low contrast. There have also been many concerns relating to the emission of radiation from screens. These can be categorized as follows:

- X-rays which are largely absorbed by the screen (but not at the rear!)
- ultraviolet and infrared radiation from phosphors in insignificant levels
- radio frequency emissions, plus ultrasound (approximately 16 kHz)
- electrostatic field which leaks out through the tube to the user. The intensity is dependent on distance and humidity. This can cause rashes in the user
- electromagnetic fields (50 Hz to 0.5 MHz) which create induction currents in conductive materials, including the human body. Two types of effects are attributed to this: in the visual system, a high incidence of cataracts in visual display unit (VDU) operators, and concern over reproductive disorders (miscarriages and birth defects).

Research into the potentially harmful effect of these emissions is generally inconclusive, in that it is difficult to determine precisely what the causes of illness are, and many health scares have been the result of misinformed media opinion rather than scientific fact. However, users who are pregnant ought to take especial care and observe simple precautions. Generally, there are a number of common-sense things that can be done to relieve strain and minimize any risk. These include

- not sitting too close to the screen
- not using very small fonts
- not looking at the screen for a long time without a break
- working in well-lit surroundings
- not placing the screen directly in front of a bright window.

Liquid crystal display

If you have used a personal organizer or notebook computer, you will have seen the light, flat plastic screens. These displays utilize liquid crystal technology and are smaller, lighter and consume far less power than traditional CRTs. These are also commonly referred to as flat-panel displays. They have no radiation problems associated with them, and are matrix addressable, which means that individual pixels can be accessed without the need for scanning.

Similar in principle to the digital watch, a thin layer of liquid crystal is sandwiched between two glass plates. The top plate is transparent and polarized, whilst the bottom plate is reflective. External light passes through the top plate and is polarized, which means that it only oscillates in one direction. This then passes through the crystal, reflects off the bottom plate and back to the eye, and so that cell looks white. When a voltage is applied to the crystal, via the conducting glass plates, the crystal twists. This causes it to turn the plane of polarization of the incoming light, rotating it so that it cannot return through the top plate, making the activated cell look black. The LCD requires refreshing at the usual rates, but the relatively slow response of the crystal means that flicker is not usually noticeable. The low intensity of the light emitted from the screen, coupled with the reduced flicker, means that the LCD is less tiring to use than standard CRT ones, with reduced eyestrain.

This different technology can be used to replace the standard screen on a desktop computer, and this is now common. However, the particular characteristics of compactness, light weight and low power consumption have meant that these screens have created a large niche in the computer market by monopolizing the notebook and portable computer systems side. The advent of these screens allowed small, light computers to be built, and created a large market that did not previously exist. Such computers, riding on the back of the technological wave, have opened up a different way of working for many people, who now have access to computers when away from the office, whether out on business or at home. Working in a different location on a smaller machine with different software obviously represents a different style of interaction and so once again we can see that differences in devices may alter the human–computer interaction considerably. The growing notebook computer market fed back into an investment in developing LCD screen technology, with supertwisted crystals increasing the viewing angle dramatically. Response times have also improved so that LCD screens are now used in personal DVD players and even in home television.

When the second edition of this book was being written the majority of LCD screens were black and white or grayscale, We wrote then ‘it will be interesting to see whether color LCD screens supersede grayscale by the time the third edition of this book is prepared’. Of course, this is precisely the case. Our expectation is that by the time we produce the next edition LCD monitors will have taken over from CRT monitors completely.

Special displays

There are a number of other display technologies used in niche markets. The one you are most likely to see is the gas plasma display, which is used in large screens (see Section 2.4.3 below).

The random scan display, also known as the *directed beam refresh*, or *vector display*, works differently from the bitmap display, also known as raster scan, that we discussed in Section 2.4.1. Instead of scanning the whole screen sequentially and horizontally, the random scan draws the lines to be displayed directly. By updating the screen at at least 30 Hz to reduce flicker, the direct drawing of lines at any angle means that jaggies are not created, and higher resolutions are possible, up to 4096 × 4096 pixels. Color on such displays is achieved using beam penetration technology, and is generally of a poorer quality. Eyestrain and fatigue are still a problem, and these displays are more expensive than raster scan ones, so they are now only used in niche applications.

The *direct view storage tube* is used extensively as the display for an analog storage oscilloscope, which is probably the only place that these displays are used in any great numbers. They are similar in operation to the random scan CRT but the image is maintained by flood guns which have the advantage of producing a stable display with no flicker. The screen image can be incrementally updated but not selectively erased; removing items has to be done by redrawing the new image on a completely erased screen. The screens have a high resolution, typically about 4096 × 3120 pixels, but suffer from low contrast, low brightness and a difficulty in displaying color.

2.4.3 Large displays and situated displays

Displays are no longer just things you have on your desktop or laptop. In Chapter 19 we will discuss meeting room environments that often depend on large shared screens. You may have attended lectures where the slides are projected from a computer onto a large screen. In shops and garages large screen adverts assault us from all sides.

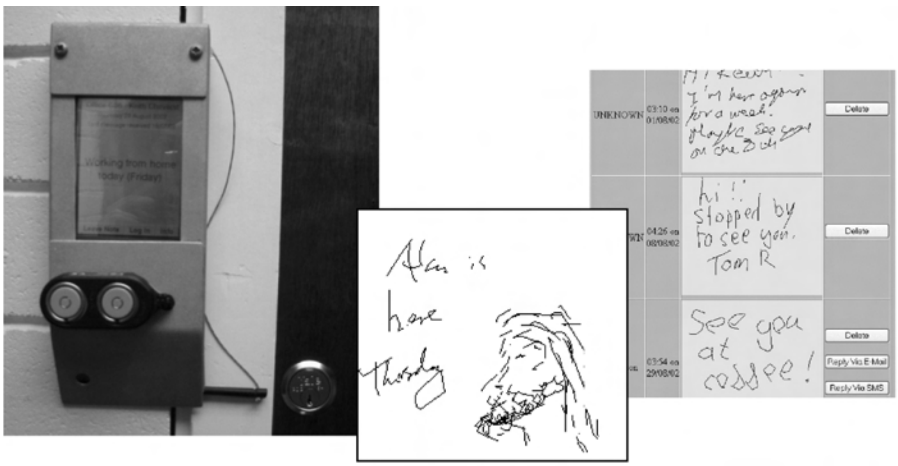
There are several types of large screen display. Some use gas plasma technology to create large flat bitmap displays. These behave just like a normal screen except they are big and usually have the HDTV (high definition television) wide screen format which has an aspect ratio of 16:9 instead of the 4:3 on traditional TV and monitors.

Where very large screen areas are required, several smaller screens, either LCD or CRT, can be placed together in a video wall. These can display separate images, or a single TV or computer image can be split up by software or hardware so that each screen displays a portion of the whole and the result is an enormous image. This is the technique often used in large concerts to display the artists or video images during the performance.

Possibly the large display you are most likely to have encountered is some sort of projector. There are two variants of these. In very large lecture theatres, especially older ones, you see projectors with large red, green and blue lenses. These each scan light across the screen to build a full color image. In smaller lecture theatres and in small meetings you are likely to see LCD projectors. Usually the size of a large book, these are like ordinary slide projectors except that where the slide would be there is a small LCD screen instead. The light from the projector passes through the tiny screen and is then focussed by the lens onto the screen.

The disadvantage of projected displays is that the presenter's shadow can often fall across the screen. Sometimes this is avoided in fixed lecture halls by using back projection. In a small room behind the screen of the lecture theatre there is a projector producing a right/left reversed image. The screen itself is a semi-frosted glass so that the image projected on the back can be seen in the lecture theatre. Because there are limits on how wide an angle the projector can manage without distortion, the size of the image is limited by the depth of the projection room behind, so these are less heavily used than front projection.

As well as for lectures and meetings, display screens can be used in various public places to offer information, link spaces or act as message areas. These are often called *situated displays* as they take their meaning from the location in which they are situated. These may be large screens where several people are expected to view or interact simultaneously, or they may be very small. Figure 2.11 shows an example of a small experimental situated display mounted by an office door to act as an electronic sticky note [70].



(i) Door display (ii) Occupant's note (iii) Web interface

Figure 2.11 Situated door display. Source: Courtesy of Keith Cheverst

Design Focus

Hermes: a situated display

Office doors are often used as a noticeboard with messages from the occupant such as 'just gone out' or 'timetable for the week' and from visitors 'missed you, call when you get back'. The Hermes system is an electronic door display that offers some of the functions of sticky notes on a door [70]. Figure 2.11(i) shows an installed Hermes device fixed just beside the door, including the socket to use a Java iButton to authenticate the occupant. The occupant can leave messages that others can read (Figure 2.11(ii)) and people coming to the door can leave messages for the occupant. Electronic notes are smaller than paper ones, but because they are electronic they can be read remotely using a web interface (Figure 2.11(iii)), or added by SMS (see Chapter 19, Section 19.3.2).

The fact that it is situated – by a person's door – is very important. It establishes a context, 'Alan's door', and influences the way the system is used. For example, the idea of anonymous messages left on the door, where the visitor has had to be physically present, feels different from, say, anonymous emails.

See the book website for the full case study: /e3/casestudy/hermes/

2.4.4 Digital paper

A new form of 'display' that is still in its infancy is the various forms of digital paper. These are thin flexible materials that can be written to electronically, just like a computer screen, but which keep their contents even when removed from any electrical supply.

There are various technologies being investigated for this. One involves the whole surface being covered with tiny spheres, black one side, white the other. Electronics embedded into the material allow each tiny sphere to be rotated to make it black or white. When the electronic signal is removed the ball stays in its last orientation. A different technique has tiny tubes laid side by side. In each tube is light-absorbing liquid and a small reflective sphere. The sphere can be made to move to the top surface or away from it making the pixel white or black. Again the sphere stays in its last position once the electronic signal is removed.

Probably the first uses of these will be for large banners that can be reprogrammed or slowly animated. This is an ideal application, as it does not require very rapid updates and does not require the pixels to be small. As the technology matures, the aim is to have programmable sheets of paper that you attach to your computer to get a 'soft' printout that can later be changed. Perhaps one day you may be able to have a 'soft' book that appears just like a current book with soft pages that can be turned and skimmed, but where the contents and cover can be changed when you decide to download a new book from the net!

2.5 DEVICES FOR VIRTUAL REALITY AND 3D INTERACTION

Virtual reality (VR) systems and various forms of 3D visualization are discussed in detail in Chapter 20. These require you to navigate and interact in a three-dimensional space. Sometimes these use the ordinary controls and displays of a desktop computer system, but there are also special devices used both to move and interact with 3D objects and to enable you to see a 3D environment.

2.5.1 Positioning in 3D space

Virtual reality systems present a 3D virtual world. Users need to navigate through these spaces and manipulate the virtual objects they find there. Navigation is not simply a matter of moving to a particular location, but also of choosing a particular orientation. In addition, when you grab an object in real space, you don't simply move it around, but also twist and turn it, for example when opening a door. Thus the move from mice to 3D devices usually involves a change from two degrees of freedom to six degrees of freedom, not just three.

Cockpit and virtual controls

Helicopter and aircraft pilots already have to navigate in real space. Many arcade games and also more serious applications use controls modeled on an aircraft cockpit to 'fly' through virtual space. However, helicopter pilots are very skilled and it takes a lot of practice for users to be able to work easily in such environments.

In many PC games and *desktop virtual reality* (where the output is shown on an ordinary computer screen), the controls are themselves virtual. This may be a simulated form of the cockpit controls or more prosaic up/down left/right buttons. The user manipulates these virtual controls using an ordinary mouse (or other 2D device). Note that this means there are two levels of indirection. It is a tribute to the flexibility of the human mind that people can not only use such systems but also rapidly become proficient.

The 3D mouse

There are a variety of devices that act as 3D versions of a mouse. Rather than just moving the mouse on a tabletop, you can pick it up, move it in three dimensions, rotate the mouse and tip it forward and backward. The 3D mouse has a full six degrees of freedom as its position can be tracked (three degrees), and also its up/down angle (called *pitch*), its left/right orientation (called *yaw*) and the amount it is twisted about its own axis (called *roll*) (see Figure 2.12). Various sensors are used to track the mouse position and orientation: magnetic coils, ultrasound or even mechanical joints where the mouse is mounted rather like an angle-poise lamp.

With the 3D mouse, and indeed most 3D positioning devices, users may experience strain from having to hold the mouse in the air for a long period. Putting the

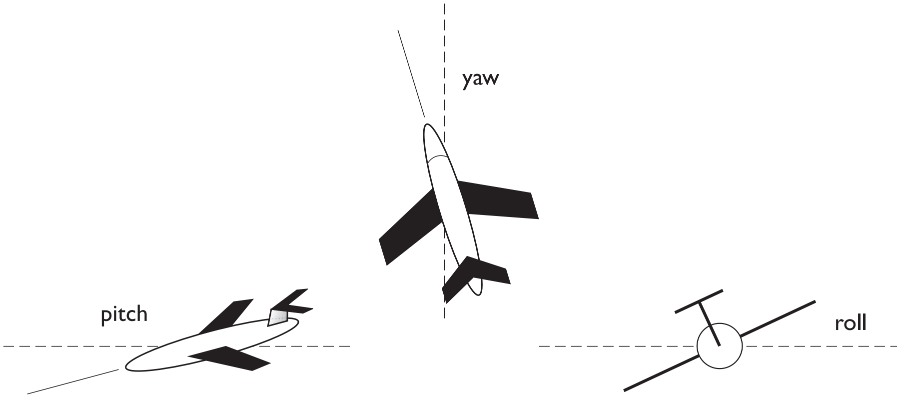


Figure 2.12 Pitch, yaw and roll

3D mouse down may even be treated as an action in the virtual environment, that is taking a nose dive.

Dataglove

One of the mainstays of high-end VR systems (see Chapter 20), the dataglove is a 3D input device. Consisting of a lycra glove with optical fibers laid along the fingers, it detects the joint angles of the fingers and thumb. As the fingers are bent, the fiber optic cable bends too; increasing bend causes more light to leak from the fiber, and the reduction in intensity is detected by the glove and related to the degree of bend in the joint. Attached to the top of the glove are two sensors that use ultrasound to determine 3D positional information as well as the angle of roll, that is the degree of wrist rotation. Such rich multi-dimensional input is currently a solution in search of a problem, in that most of the applications in use do not require such a comprehensive form of data input, whilst those that do cannot afford it. However, the availability of cheaper versions of the dataglove will encourage the development of more complex systems that are able to utilize the full power of the dataglove as an input device. There are a number of potential uses for this technology to assist disabled people, but cost remains the limiting factor at present.

The dataglove has the advantage that it is very easy to use, and is potentially very powerful and expressive (it can provide 10 joint angles, plus the 3D spatial information and degree of wrist rotation, 50 times a second). It suffers from extreme expense, and the fact that it is difficult to use in conjunction with a keyboard. However, such a limitation is shortsighted; one can imagine a keyboard drawn onto a desk, with software detecting hand positions and interpreting whether the virtual keys had been hit or not. The potential for the dataglove is vast; gesture recognition and sign language interpretation are two obvious areas that are the focus of active research, whilst less obvious applications are evolving all the time.

Virtual reality helmets

The helmets or goggles worn in some VR systems have two purposes: (i) they display the 3D world to each eye and (ii) they allow the user's head position to be tracked. We will discuss the former later when we consider output devices. The head tracking is used primarily to feed into the output side. As the user's head moves around the user ought to see different parts of the scene. However, some systems also use the user's head direction to determine the direction of movement within the space and even which objects to manipulate (rather like the eyegaze systems). You can think of this rather like leading a horse in reverse. If you want a horse to go in a particular direction, you use the reins to pull its head in the desired direction and the horse follows its head.

Whole-body tracking

Some VR systems aim to be immersive, that is to make the users feel as if they are really in the virtual world. In the real world it is possible (although not usually wise) to walk without looking in the direction you are going. If you are driving down the road and glance at something on the roadside you do not want the car to do a sudden 90-degree turn! Some VR systems therefore attempt to track different kinds of body movement. Some arcade games have a motorbike body on which you can lean into curves. More strangely, small trampolines have been wired up so that the user can control movement in virtual space by putting weight on different parts of the trampoline. The user can literally surf through virtual space. In the extreme the movement of the whole body may be tracked using devices similar to the dataglove, or using image-processing techniques. In the latter, white spots are stuck at various points of the user's body and the position of these tracked using two or more cameras, allowing the location of every joint to be mapped. Although the last of these sounds a little constraining for the fashion conscious it does point the way to less intrusive tracking techniques.

2.5.2 3D displays

Just as the 3D images used in VR have led to new forms of input device, they also require more sophisticated outputs. Desktop VR is delivered using a standard computer screen and a 3D impression is produced by using effects such as shadows, occlusion (where one object covers another) and perspective. This can be very effective and you can even view 3D images over the world wide web using a VRML (virtual reality markup language) enabled browser.

Seeing in 3D

Our eyes use many cues to perceive depth in the real world (see also Chapter 1). It is in fact quite remarkable as each eye sees only a flattened form of the world, like a photograph. One important effect is *stereoscopic vision* (or simply *stereo vision*).

Because each eye is looking at an object from a slightly different angle each sees a different image and our brain is able to use this to assess the relative distance of different objects. In desktop VR this stereoscopic effect is absent. However, various devices exist to deliver true stereoscopic images.

The start point of any stereoscopic device is the generation of images from different perspectives. As the computer is generating images for the virtual world anyway, this just means working out the right positions and angles corresponding to the typical distance between eyes on a human face. If this distance is too far from the natural one, the user will be presented with a giant's or gnat's eye view of the world!

Different techniques are then used to ensure that each eye sees the appropriate image. One method is to have two small screens fitted to a pair of goggles. A different image is then shown to each eye. These devices are currently still quite cumbersome and the popular image of VR is of a user with head encased in a helmet with something like a pair of inverted binoculars sticking out in front. However, smaller and lighter LCDs are now making it possible to reduce the devices towards the size and weight of ordinary spectacles.

An alternative method is to have a pair of special spectacles connected so that each eye can be blanked out by timed electrical signals. If this is synchronized with the frame rate of a computer monitor, each eye sees alternate images. Similar techniques use polarized filters in front of the monitor and spectacles with different polarized lenses. These techniques are both effectively using similar methods to the red–green 3D spectacles given away in some breakfast cereals. Indeed, these red–green spectacles have been used in experiments in wide-scale 3D television broadcasts. However, the quality of the 3D image from the polarized and blanked eye spectacles is substantially better.

The ideal would be to be able to look at a special 3D screen and see 3D images just as one does with a hologram – 3D television just like in all the best sci-fi movies! But there is no good solution to this yet. One method is to inscribe the screen with small vertical grooves forming hundreds of prisms. Each eye then sees only alternate dots on the screen allowing a stereo image at half the normal horizontal resolution. However, these screens have very narrow *viewing angles*, and are not ready yet for family viewing.

In fact, getting stereo images is not the whole story. Not only do our eyes see different things, but each eye also focusses on the current object of interest (small muscles change the shape of the lens in the pupil of the eye). The images presented to the eye are generated at some fixed focus, often with effectively infinite *depth of field*. This can be confusing and tiring. There has been some progress recently on using lasers to detect the focal depth of each eye and adjust the images correspondingly, similar to the technology used for eye tracking. However, this is not currently used extensively.

VR motion sickness

We all get annoyed when computers take a long time to change the screen, pop up a window, or play a digital movie. However, with VR the effects of poor display performance can be more serious. In real life when we move our head the image our eyes see changes accordingly. VR systems produce the same effect by using sensors in the goggles or helmet and then using the position of the head to determine the right image to show. If the system is slow in producing these images a lag develops between the user moving his head and the scene changing. If this delay is more than a hundred milliseconds or so the feeling becomes disorienting. The effect is very similar to that of being at sea. You stand on the deck looking out to sea, the boat gently rocking below you. Tiny channels in your ears detect the movement telling your brain that you are moving; your eyes see the horizon moving in one direction and the boat in another. Your brain gets confused and you get sick. Users of VR can experience similar nausea and few can stand it for more than a short while. In fact, keeping laboratories sanitary has been a major push in improving VR technology.

Simulators and VR caves

Because of the problems of delivering a full 3D environment via head-mounted displays, some virtual reality systems work by putting the user within an environment where the virtual world is displayed upon it. The most obvious examples of this are large flight simulators – you go inside a mock-up of an aircraft cockpit and the scenes you would see through the windows are projected onto the virtual windows. In motorbike or skiing simulators in video arcades large screens are positioned to fill the main part of your visual field. You can still look over your shoulder and see your friends, but while you are engaged in the game it surrounds you.

More general-purpose rooms called caves have large displays positioned all around the user, or several back projectors. In these systems the user can look all around and see the virtual world surrounding them.

2.6 PHYSICAL CONTROLS, SENSORS AND SPECIAL DEVICES

As we have discussed, computers are coming out of the box. The mouse keyboard and screen of the traditional computer system are not relevant or possible in applications that now employ computers such as interactive TV, in-car navigation systems or personal entertainment. These devices may have special displays, may use sound, touch and smell as well as visual displays, may have dedicated controls and may sense the environment or your own bio-signs.

2.6.1 Special displays

Apart from the CRT screen there are a number of visual outputs utilized in complex systems, especially in embedded systems. These can take the form of analog representations of numerical values, such as dials, gauges or lights to signify a certain system state. Flashing light-emitting diodes (LEDs) are used on the back of some computers to signify the processor state, whilst gauges and dials are found in process control systems. Once you start in this mode of thinking, you can contemplate numerous visual outputs that are unrelated to the screen. One visual display that has found a specialized niche is the head-up display that is used in aircraft. The pilot is fully occupied looking forward and finds it difficult to look around the cockpit to get information. There are many different things that need to be known, ranging from data from tactical systems to navigational information and aircraft status indicators. The head-up display projects a subset of this information into the pilot's line of vision so that the information is directly in front of her eyes. This obviates the need for large banks of information to be scanned with the corresponding lack of attention to what is happening outside, and makes the pilot's job easier. Less important information is usually presented on a smaller number of dials and gauges in the cockpit to avoid cluttering the head-up display, and these can be monitored less often, during times of low stress.

2.6.2 Sound output

Another mode of output that we should consider is that of auditory signals. Often designed to be used in conjunction with screen displays, auditory outputs are poorly understood: we do not yet know how to utilize sound in a sensible way to achieve maximum effect and information transference. We have discussed speech previously, but other sounds such as beeps, bongs, clanks, whistles and whirrs are all used to varying effect. As well as conveying system output, sounds offer an important level of feedback in interactive systems. Keyboards can be set to emit a click each time a key is pressed, and this appears to speed up interactive performance. Telephone keypads often sound different tones when the keys are pressed; a noise occurring signifies that the key has been successfully pressed, whilst the actual tone provides some information about the particular key that was pressed. The advantage of auditory feedback is evident when we consider a simple device such as a doorbell. If we press it and hear nothing, we are left undecided. Should we press it again, in case we did not do it right the first time, or did it ring but we did not hear it? And if we press it again but it actually did ring, will the people in the house think we are very rude, ringing insistently? We feel awkward and a little stressed. If we were using a computer system instead of a doorbell and were faced with a similar problem, we would not enjoy the interaction and would not perform as well. Yet it is a simple problem that could be easily rectified by a better initial design, using sound. Chapter 10 will discuss the use of the auditory channel in more detail.

2.6.3 Touch, feel and smell

Our other senses are used less in normal computer applications, but you may have played computer games where the joystick or artificial steering wheel vibrated, perhaps when a car was about to go off the track. In some VR applications, such as the use in medical domains to 'practice' surgical procedures, the *feel* of an instrument moving through different tissue types is very important. The devices used to emulate these procedures have *force feedback*, giving different amounts of resistance depending on the state of the virtual operation. These various forms of force, resistance and texture that influence our physical senses are called *haptic* devices.

Haptic devices are not limited to virtual environments, but are used in specialist interfaces in the real world too. Electronic braille displays either have pins that rise or fall to give different patterns, or may involve small vibration pins. Force feedback has been used in the design of in-car controls.

In fact, the car gives a very good example of the power of tactile feedback. If you drive over a small bump in the road the car is sent slightly off course; however, the chances are that you will correct yourself before you are consciously aware of the bump. Within your body you have reactions that push back slightly against pressure to keep your limbs where you 'want' them, or move your limbs out of the way when you brush against something unexpected. These responses occur in your lower brain and are very fast, not involving any conscious effort. So, haptic devices can access very fast responses, but these responses are not fully controlled. This can be used effectively in design, but of course also with caution.

Texture is more difficult as it depends on small changes between neighboring points on the skin. Also, most of our senses notice change rather than fixed stimuli, so we usually feel textures when we move our fingers over a surface, not just when resting on it. Technology for this is just beginning to become available

There is evidence that smell is one of the strongest cues to memory. Various historical recreations such as the Jorvik Centre in York, England, use smells to create a feeling of immersion in their static displays of past life. Some arcade games also generate smells, for example, burning rubber as your racing car skids on the track. These examples both use a fixed smell in a particular location. There have been several attempts to produce devices to allow smells to be recreated dynamically in response to games or even internet sites. The technical difficulty is that our noses do not have a small set of basic smells that are mixed (like salt/sweet/sour/bitter/savoury on our tongue), but instead there are thousands of different types of receptor responding to different chemicals in the air. The general pattern of devices to generate smells is to have a large repertoire of tiny scent-containing capsules that are released in varying amounts on demand – rather like a printer cartridge with hundreds of ink colors! So far there appears to be no mass market for these devices, but they may eventually develop from niche markets.

Smell is a complex multi-dimensional sense and has a peculiar ability to trigger memory, but cannot be changed rapidly. These qualities may prove valuable in areas where a general sense of location and awareness is desirable. For example, a project at the Massachusetts Institute of Technology explored the use of a small battery of scent generators which may be particularly valuable for *ambient displays* and background awareness [198, 161].

DESIGN FOCUS

Feeling the road

In the BMW 7 Series you will find a single haptic feedback control for many of the functions that would normally have dedicated controls. It uses technology developed by Immersion Corporation who are also behind the force feedback found in many medical and entertainment haptic devices. The iDrive control slides backwards and forwards and rotates to give access to various menus and lists of options. The haptic feedback allows the user to feel 'clicks' appropriate to the number of items in the various menu lists.

See: www.immersion.com/ and www.bmw.com/ Picture courtesy of BMW AG

2.6.4 Physical controls

Look at Figure 2.13. In it you can see the controls for a microwave, a washing machine and a personal MiniDisc player. See how they each use very different physical devices: the microwave has a flat plastic sheet with soft buttons, the washing machine large switches and knobs, and the MiniDisc has small buttons and an interesting multi-function end.

A desktop computer system has to serve many functions and so has generic keys and controls that can be used for a variety of purposes. In contrast, these dedicated control panels have been designed for a particular device and for a single use. This is why they differ so much.

Looking first at the microwave, it has a flat plastic control panel. The buttons on the panel are pressed and 'give' slightly. The choice of the smooth panel is probably partly for visual design – it looks streamlined! However, there are also good practical reasons. The microwave is used in the kitchen whilst cooking, with hands that may be greasy or have food on them. The smooth controls have no gaps where food can accumulate and clog buttons, so it can easily be kept clean and hygienic.

When using the washing machine you are handling dirty clothes, which may be grubby, but not to the same extent, so the smooth easy-clean panel is less important (although some washing machines do have smooth panels). It has several major

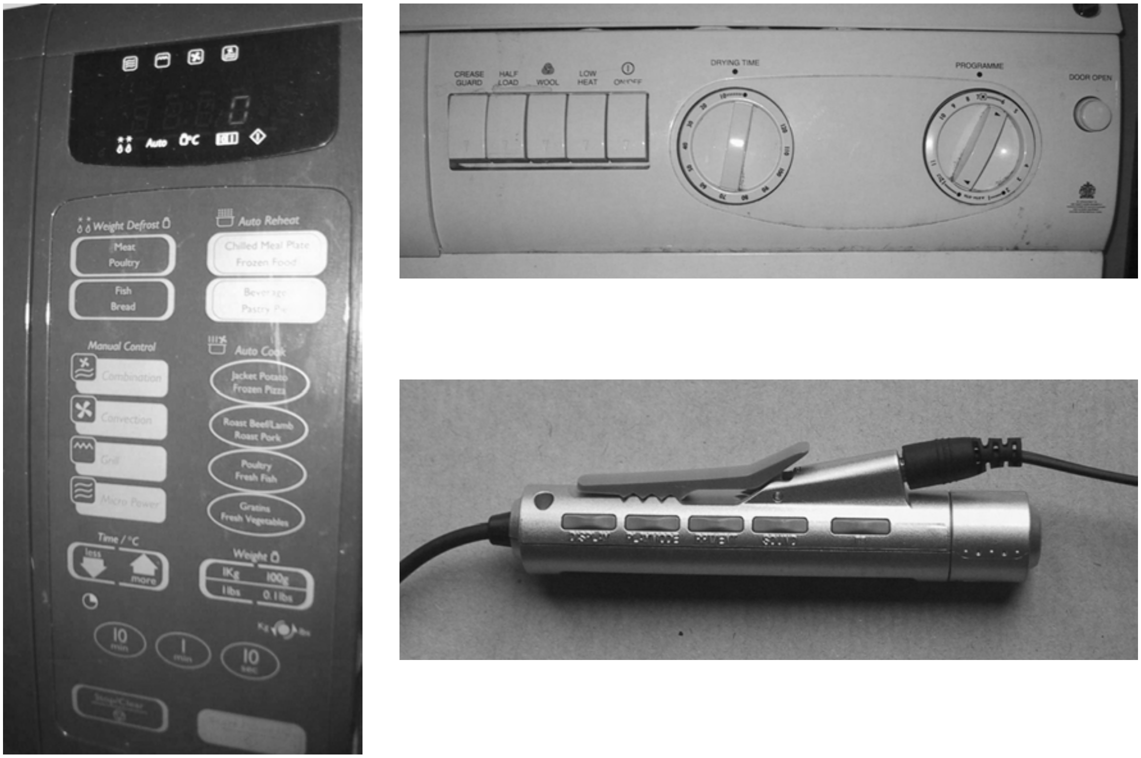


Figure 2.13 Physical controls on microwave, washing machine and MiniDisc. Source: Photograph bottom right by Alan Dix with permission from Sony (UK)

settings and the large buttons act both as control and display. Also the dials for dryer timer and the washing program act both as a means to set the desired time or program and to display the current state whilst the wash is in progress.

Finally, the MiniDisc controller needs to be small and unobtrusive. It has tiny buttons, but the end control is most interesting. It twists from side to side and also can be pulled and twisted. This means the same control can be used for two different purposes. This form of multi-function control is common in small devices.

We discussed the immediacy of haptic feedback and these lessons are also important at the level of creating physical devices; do keys, dials, etc., feel as if they have been pressed or turned? Getting the right level of resistance can make the device work naturally, give you feedback that you have done something, or let you know that you are controlling something. Where for some reason this is not possible, something has to be done to prevent the user getting confused, perhaps pressing buttons twice; for example, the smooth control panel of the microwave in Figure 2.13 offers no tactile feedback, but beeps for each keypress. We will discuss these design issues further when we look at user experience in Chapter 3 (Section 3.9).

Whereas texture is difficult to generate, it is easy to build into materials. This can make a difference to the ease of use of a device. For example, a touchpad is smooth, but a keyboard nipple is usually rubbery. If they were the other way round it would be hard to drag your finger across the touchpad or to operate the nipple without slipping. Texture can also be used to disambiguate. For example, most keyboards have a small raised dot on the 'home' keys for touch typists and some calculators and phones do the same on the '5' key. This is especially useful in applications when the eyes are elsewhere.

2.6.5 Environment and bio-sensing

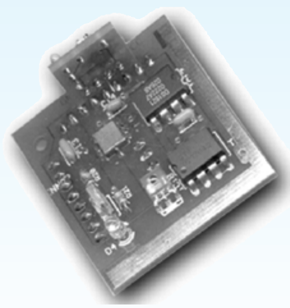
In a public washroom there are often no controls for the wash basins, you simply put your hands underneath and (hope that) the water flows. Similarly when you open the door of a car, the courtesy light turns on. The washbasin is controlled by a small infrared sensor that is triggered when your hands are in the basin (although it is

Design Focus

Smart-Its – making using sensors easy

Building systems with physical sensors is no easy task. You need a soldering iron, plenty of experience in electronics, and even more patience. Although some issues are unique to each sensor or project, many of the basic building blocks are similar – connecting simple microprocessors to memory and networks, connecting various standard sensors such as temperature, tilt, etc.

The Smart-Its project has made this job easier by creating a collection of components and an architecture for adding new sensors. There are a number of basic Smart-It boards – the photo on the left shows a microprocessor with wireless connectivity. Onto these boards are plugged a variety of modules – in the center is a sensor board including temperature and light, and on the right is a power controller.



See: www.smart-its.org/ Source: Courtesy of Hans Gellersen sometimes hard to find the 'sweet spot' where this happens!). The courtesy lights are triggered by a small switch in the car door.

Although we are not always conscious of them, there are many sensors in our environment – controlling automatic doors, energy saving lights, etc. and devices monitoring our behavior such as security tags in shops. The vision of ubiquitous computing (see Chapters 4 and 20) suggests that our world will be filled with such devices. Certainly the gap between science fiction and day-to-day life is narrow; for example, in the film *Minority Report* (20th Century Fox) iris scanners identify each passer-by to feed them dedicated advertisements, but you can buy just such an iris scanner as a security add-on for your home computer.

There are many different sensors available to measure virtually anything: temperature, movement (ultrasound, infrared, etc.), location (GPS, global positioning, in mobile devices), weight (pressure sensors). In addition audio and video information can be analyzed to identify individuals and to detect what they are doing. This all sounds big brother like, but is also used in ordinary applications, such as the washbasin.

Sensors can also be used to capture physiological signs such as body temperature, unconscious reactions such as blink rate, or unconscious aspects of activities such as typing rate, vocabulary shifts (e.g. modal verbs). For example, in a speech-based game, Tsukahara and Ward use gaps in speech and prosody (patterns of rhythm, pitch and loudness in speech) to infer the user's emotional state and thus the nature of acceptable responses [350] and Allanson discusses a variety of physiological sensors to create 'electrophysiological interactive computer systems' [12].

2.7 PAPER: PRINTING AND SCANNING

Some years ago, a recurrent theme of information technology was the *paperless office*. In the paperless office, documents would be produced, dispatched, read and filed online. The only time electronic information would be committed to paper would be when it went out of the office to ordinary customers, or to other firms who were laggards in this technological race. This vision was fuelled by rocketing property prices, and the realization that the floor space for a wastepaper basket could cost thousands in rent each year. Some years on, many traditional paper files are now online, but the desire for the completely paperless office has faded. Offices still have wastepaper baskets, and extra floor space is needed for the special computer tables to house 14-inch color monitors.

In this section, we will look at some of the available technology that exists to get information to and from paper. We will look first at printing, the basic technology, and issues raised by it. We will then go on to discuss the movement from paper back into electronic media. Although the paperless office is no longer seen as the goal, the less-paper office is perhaps closer, now that the technologies for moving between media are better.

2.7.1 Printing

If anything, computer systems have made it easier to produce paper documents. It is so easy to run off many copies of a letter (or book), in order to get it looking 'just right'. Older printers had a fixed set of characters available on a printhead. These varied from the traditional line printer to golf-ball and daisy-wheel printers. To change a typeface or the size of type meant changing the printhead, and was an awkward, and frequently messy, job, but for many years the daisy-wheel printer was the only means of producing high-quality output at an affordable price. However, the drop in the price of laser printers coupled with the availability of other cheap high-quality printers means that daisy-wheels are fast becoming a rarity.

All of the popular printing technologies, like screens, build the image on the paper as a series of dots. This enables, in theory, any character set or graphic to be printed,

Common types of dot-based printers

Dot-matrix printers

These use an inked ribbon, like a typewriter, but instead of a single character-shaped head striking the paper, a line of *pins* is used, each of which can strike the ribbon and hence dot the paper. Horizontal resolution can be varied by altering the speed of the head across the paper, and vertical resolution can be improved by sending the head twice across the paper at a slightly different position. So, dot-matrix printers can produce fast draft-quality output or slower 'letter'-quality output. They are cheap to run, but could not compete with the quality of jet and laser printers for general office and home printing. They are now only used for bulk printing, or where carbon paper is required for payslips, check printing, etc.)

Ink-jet and bubble-jet printers

These operate by sending tiny blobs of ink from the printhead to the paper. The ink is squirted at pressure from an ink-jet, whereas bubble-jets use heat to create a bubble. Both are quite quiet in operation. The ink from the bubble-jet (being a bubble rather than a droplet) dries more quickly than the ink-jet and so is less likely to smear. Both approach laser quality, but the bubble-jet dots tend to be more accurately positioned and of a less broken shape.

Laser printer

This uses similar technology to a photocopier: 'dots' of electrostatic charge are deposited on a drum, which then picks up toner (black powder). This is then rolled onto the paper and cured by heat. The curing is why laser printed documents come out warm, and the electrostatic charge is why they smell of ozone! In addition, some toner can be highly toxic if inhaled, but this is more a problem for full-time maintenance workers than end-users changing the occasional toner cartridge.

Laser printers give nearly typeset-quality output, with top-end printers used by desktop publishing firms. Indeed, many books are nowadays produced using laser printers. The authors of this book have produced camera-ready copy for other books on 300 and 600 dpi laser printers, although this book required higher quality and the first edition was typeset at 1200 dpi onto special bromide paper.

limited only by the resolution of the dots. This resolution is measured in *dots per inch* (dpi). Imagine a sheet of graph paper, and building up an image by putting dots at the intersection of each line. The number of lines per inch in each direction is the resolution in dpi. For some mechanical printers this is slightly confused: the dots printed may be bigger than the gaps, neighboring printheads may not be able to print simultaneously and may be offset relative to one another (a diamond-shaped rather than rectangular grid). These differences do not make too much difference to the user, but mean that, given two printers at the same nominal resolution, the output of one looks better than that of the other, because it has managed the physical constraints better.

The most common types of dot-based printers are dot-matrix printers, ink-jet printers and laser printers. These are listed roughly in order of increasing resolution and quality, where dot-matrix printers typically have a resolution of 80–120 dpi rising to about 300–600 dpi for ink-jet printers and 600–2400 dpi for laser printers. By varying the quantity of ink and quality of paper, ink-jet printers can be used to print photo-quality prints from digital photographs.

Printing in the workplace

Although ink-jet and laser printers have the lion's share of the office and home printer market, there are many more specialist applications that require different technology.

Most shop tills use dot-matrix printing where the arrangement is often very clever, with one printhead serving several purposes. The till will usually print one till roll which stays within the machine, recording all transactions for audit purposes. An identical receipt is printed for the customer. In addition, many will print onto the customer's own check or produce a credit card slip for the customer to sign. Sometimes the multiple copies are produced using two or more layers of paper where the top layer receives the ink and the lower layers use pressure-sensitive paper – not possible using ink-jet or laser technology. Alternatively, a single printhead may move back and forth over several small paper rolls within the same machine, as well as moving over the slot for the customer's own check.

As any printer owner will tell you, office printers are troublesome, especially as they age. Different printing technology is therefore needed in harsh environments or where a low level of supervision is required. Thermal printers use special heat-sensitive paper that changes color when heated. The printhead simply heats the paper where it wants a dot. Often only one line of dots is produced per pass, in contrast to dot-matrix and ink-jet printers, which have several pins or jets in parallel. The image is then produced using several passes per line, achieving a resolution similar to a dot-matrix. Thermal paper is relatively expensive and not particularly nice to look at, but thermal printers are mechanically simple and require little maintenance (no ink or toner splashing about). Thermal printers are used in niche applications, for example industrial equipment, some portable printers, and fax machines (although many now use plain paper).

As well as resolution, printers vary in speed and cost. Typically, office-quality ink-jet or laser printers produce between four and eight pages per minute. Dot-matrix printers are more often rated in *characters per second* (cps), and typical speeds may be 200 cps for draft and 50 cps for letter-quality print. In practice, this means no more than a page or so per minute. These are maximum speeds for simple text, and printers may operate much more slowly for graphics.

Color ink-jet printers are substantially cheaper than even monochrome laser printers. However, the recurrent costs of consumables may easily dominate this initial cost. Both jet and laser printers have special-purpose parts (print cartridges, toner, print drums), which need to be replaced every few thousand sheets; and they must also use high-grade paper. It may be more difficult to find suitable grades of recycled paper for laser printers.

2.7.2 Fonts and page description languages

Some printers can act in a mode whereby any characters sent to them (encoded in ASCII, see Section 2.8.5) are printed, typewriter style, in a single font. Another case, simple in theory, is when you have a bitmap picture and want to print it. The dots to print are sent to the printer, and no further interpretation is needed. However, in practice, it is rarely so simple.

Many printed documents are far more complex – they incorporate text in many different fonts and many sizes, often italicized, emboldened and underlined. Within the text you will find line drawings, digitized photographs and pictures generated from ‘paint’ packages, including the ubiquitous ‘clip art’. Sometimes the computer does all the work, converting the page image into a bitmap of the right size to be sent to the printer. Alternatively, a description of the page may be sent to the printer. At the simplest level, this will include commands to set the print position on the page, and change the font size.

More sophisticated printers can accept a *page description language*, the most common of which is PostScript. This is a form of programming language for printing. It includes some standard programming constructs, but also some special ones: paths for drawing lines and curves, sophisticated character and font handling and scaled bitmaps. The idea is that the description of a page is far smaller than the associated bitmap, reducing the time taken to send the page to the printer. A bitmap version of an A4 laser printer page at 300 dpi takes 8 Mbytes; to send this down a standard serial printer cable would take 10 minutes! However, a computer in the printer has to interpret the PostScript program to print the page; this is typically faster than 10 minutes, but is still the limiting factor for many print jobs.

Text is printed in a font with a particular size and shape. The size of a font is measured in points (pt). The point is a printer’s measure and is about 1/72 of an inch. The *point size* of the font is related to its height: a 12 point font has about six lines per inch. The shape of a font is determined by its *font name*, for example Times Roman, Courier or Helvetica. Times Roman font is similar to the type of many newspapers, such as *The Times*, whereas Courier has a typewritten shape.

Courier is a fixed-pitch font

Times Roman is a variable-pitch serif font

Minion is also a variable-pitch serif font

Gill Sans is a variable-pitch sans-serif font

A mathematics font: $\alpha\beta\xi\pm\pi\in\forall\infty\perp\neq\aleph\partial\surd\exists$

Figure 2.14 Examples of different fonts

Some fonts, such as Courier, are *fixed pitch*, that is each character has the same width. The alternative is a variable-pitched font, such as Times Roman or Gill Sans, where some characters, such as the 'm', are wider than others, such as the 'i'. Another characteristic of fonts is whether they are *serif* or *sans-serif*. A serif font has fine, short cross-lines at the ends of the strokes, imitating those found on cut stone lettering. A sans-serif font has square-ended strokes. In addition, there are special fonts looking like Gothic lettering or cursive script, and fonts of Greek letters and special mathematical symbols.

This book is set in 10 point Minion font using PostScript. Minion is a variable-pitched serif font. Figure 2.14 shows examples of different fonts.

DESIGN FOCUS

Readability of text

There is a substantial body of knowledge about the readability of text, both on screen and on paper. An MSc student visited a local software company and, on being shown some of their systems, remarked on the fact that they were using upper case throughout their displays. At that stage she had only completed part of an HCI course but she had read Chapter 1 of this book and already knew that WORDS WRITTEN IN BLOCK CAPITALS take longer to read than those in lower case. Recall that this is largely because of the clues given by word shapes and is the principle behind 'look and say' methods of teaching children to read. The company immediately recognized the value of the advice and she instantly rose in their esteem!

However, as with many interface design guidelines there are caveats. Although lower-case words are easier to read, individual letters and nonsense words are clearer in upper case. For example, one writes flight numbers as 'BA793' rather than 'ba793'. This is particularly important when naming keys to press (for example, 'Press Q to quit') as keyboards have upper-case legends.

Font shapes can also make a difference; for printed text, serif fonts make it easier to run one's eye along a line of text. However, they usually reproduce less well on screen where the resolution is poorer.

2.7.3 Screen and page

A common requirement of word processors and desktop publishing software is that *what you see is what you get* (see also Chapters 4 and 17), which is often called by its acronym *WYSIWYG* (pronounced whizz-ee-wig). This means that the appearance of the document on the screen should be the same as its eventual appearance on the printed page. In so far as this means that, for example, centered text is displayed centered on the screen, this is reasonable. However, this should not cloud the fact that screen and paper are very different media.

A typical screen resolution is about 72 dpi compared with a laser printer at over 600 dpi. Some packages can show magnified versions of the document in order to help in this. Most screens use an additive color model using red, green and blue light, whereas printers use a subtractive color model with cyan, magenta, yellow and black inks, so conversions have to be made. In addition, the sizes and aspect ratios are very different. An A4 page is about 11 inches tall by 8 wide (297 × 210 mm), whereas a screen is often of similar dimensions, but wider than it is tall.

These differences cause problems when designing software. Should you try to make the screen image as close to the paper as possible, or should you try to make the best of each? One approach to this would be to print only what could be displayed, but that would waste the extra resolution of the printer. On the other hand, one can try to make the screen as much like paper as possible, which is the intention behind the standard use of black text on a white background, rotatable A4 displays, and tablet PCs. This is a laudable aim, but cannot get rid of all the problems.

A particular problem lies with fonts. Imagine we have a line of 'm's, each having a width of 0.15 inch (4 mm). If we print them on a 72 dpi screen, then we can make the screen character 10 or 11 dots wide, in which case the screen version will be narrower or wider than the printed version. Alternatively, we can print the screen version as near as possible to where the printed characters would lie, in which case the 'm's on the screen would have different spaces between them: 'mm mm mm mm m'. The latter looks horrible on the screen, so most software chooses the former approach. This means that text that aligns on screen may not do so on printing. Some systems use a uniform representation for screen and printer, using the same font descriptions and even, in the case of the Next operating system, PostScript for screen display as well as printer output (also PDF with MacOS X). However, this simply exports the problem from the application program to the operating system.

The differences between screen and printer mean that different forms of graphic design are needed for each. For example, headings and changes in emphasis are made using font style and size on paper, but using color, brightness and line boxes on screen. This is not usually a problem for the display of the user's own documents as the aim is to give the user as good an impression of the printed page as possible, given the limitations. However, if one is designing parallel paper and screen forms, then one has to trade off consistency between the two representations with clarity in each.

An overall similar layout, but with different forms of presentation for details, may be appropriate.

2.7.4 Scanners and optical character recognition

Printers take electronic documents and put them on paper – *scanners* reverse this process. They start by turning the image into a bitmap, but with the aid of *optical character recognition* can convert the page right back into text. The image to be converted may be printed, but may also be a photograph or hand-drawn picture.

There are two main kinds of scanner: flat-bed and hand-held. With a flat-bed scanner, the page is placed on a flat glass plate and the whole page is converted into a bitmap. A variant of the flat-bed is where sheets to be scanned are pulled through the machine, common in multi-function devices (printer/fax/copier). Many flat-bed scanners allow a small pile of sheets to be placed in a feed tray so that they can all be scanned without user intervention. Hand-held scanners are pulled over the image by hand. As the head passes over an area it is read in, yielding a bitmap strip. A roller at the ends ensures that the scanner knows how fast it is being pulled and thus how big the image is. The scanner is typically only 3 or 4 inches (80 or 100 mm) wide and may even be the size of a large pen (mainly used for scanning individual lines of text). This means at least two or three strips must be 'glued' together by software to make a whole page image, quite a difficult process as the strips will overlap and may not be completely parallel to one another, as well as suffering from problems of different brightness and contrast. However, for desktop publishing small images such as photographs are quite common, and as long as one direction is less than the width of the scanner, they can be read in one pass.

Scanners work by shining a beam of light at the page and then recording the intensity and color of the reflection. Like photocopiers, the color of the light that is shone means that some colors may appear darker than others on a monochrome scanner. For example, if the light is pure red, then a red image will reflect the light completely and thus not appear on the scanned image.

Like printers, scanners differ in resolution, commonly between 600 and 2400 dpi, and like printers the quoted resolution needs careful interpretation. Many have a lower resolution scanhead but digitally interpolate additional pixels – the same is true for some digital cameras. Monochrome scanners are typically only found in multi-function devices, but color scanners usually have monochrome modes for black and white or grayscale copying. Scanners will usually return up to 256 levels of gray or RGB (red, green, blue) color. If a pure monochrome image is required (for instance, from a printed page), then it can *threshold* the grayscale image; that is, turn all pixels darker than some particular value black, and the rest white.

Scanners are used extensively in *desktop publishing* (*DTP*) for reading in hand-drawn pictures and photographs. This means that cut and paste can be performed electronically rather than with real glue. In addition, the images can be rotated, scaled and otherwise transformed, using a variety of image manipulation software tools. Such tools are becoming increasingly powerful, allowing complex image transformations to be easily achieved; these range from color correction, through the merging of multiple images to the application of edge-detection and special effects filters. The use of multiple layers allows photomontage effects that would be impossible with traditional photographic or paper techniques. Even where a scanned image is simply going to be printed back out as part of a larger publication, some processing typically has to be performed to match the scanned colors with those produced during printing. For film photographs there are also special film scanners that can scan photographic negatives or color slides. Of course, if the photographs are digital no scanning is necessary.

Another application area is in document storage and retrieval systems, where paper documents are scanned and stored on computer rather than (or sometimes as well as) in a filing cabinet. The costs of maintaining paper records are enormous, and electronic storage can be cheaper, more reliable and more flexible. Storing a bitmap image is neither most useful (in terms of access methods), nor space efficient (as we will see later), so scanning may be combined with optical character recognition to obtain the text rather than the page image of the document.

Optical character recognition (OCR) is the process whereby the computer can 'read' the characters on the page. It is only comparatively recently that print could be reliably read, since the wide variety of typefaces and print sizes makes this more difficult than one would imagine – it is *not* simply a matter of matching a character shape to the image on the page. In fact, OCR is rather a misnomer nowadays as, although the document is optically scanned, the OCR software itself operates on the bitmap image. Current software can recognize 'unseen' fonts and can even produce output in word-processing formats, preserving super- and subscripts, centering, italics and so on.

Another important area is electronic publishing for multimedia and the world wide web. Whereas in desktop publishing the scanned image usually ends up (after editing) back on paper, in electronic publishing the scanned image is destined to be viewed on screen. These images may be used simply as digital photographs or may be made active, whereby clicking on some portion of the image causes pertinent information to be displayed (see Chapter 3 for more on the *point-and-click* style of interaction). One big problem when using electronic images is the plethora of formats for storing graphics (see Section 2.8.5). Another problem is the fact that different computers can display different numbers of colors and that the appearance of the same image on different monitors can be very different.

The importance of electronic publishing and also the ease of electronically manipulating images for printing have made the *digital camera* increasingly popular. Rather than capturing an image on film, a digital camera has a small light-sensitive chip that can directly record an image into memory.

Paper-based interaction

Paper is principally seen as an output medium. You type in some text, format it, print it and read it. The idea of the paperless office was to remove the paper from the write–read loop entirely, but it didn't fundamentally challenge its place in the cycle as an output medium. However, this view of paper as output has changed as OCR technology has improved and scanners become commonplace.

Workers at Xerox Palo Alto Research Center (also known as Xerox PARC) capitalized on this by using paper as a medium of interaction with computer systems [195]. A special identifying mark is printed onto forms and similar output. The printed forms may have check boxes or areas for writing numbers or (in block capitals!) words. The form can then be scanned back in. The system reads the identifying mark and thereby knows what sort of paper form it is dealing with. It doesn't have to use OCR on the printed text of the form as it printed it, but can detect the check boxes that have been filled in and even recognize the text that has been written. The identifying mark the researchers used is composed of backward and forward slashes, '\' and '/', and is called a *glyph*. An alternative would have been to use bar codes, but the slashes were found to fax and scan more reliably. The research version of this system was known as XAX, but it is now marketed as Xerox PaperWorks.

One application of this technology is mail order catalogs. The order form is printed with a glyph. When completed, forms can simply be collected into bundles and scanned in batches, generating orders automatically. If the customer faxes an order the fax-receiving software recognizes the glyph and the order is processed without ever being handled at the company end. Such a *paper user interface* may involve no screens or keyboards whatsoever.

Some types of paper now have identifying marks micro-printed like a form of textured watermark. This can be used both to identify the piece of paper (as the glyph does), and to identify the location on the paper. If this book were printed on such paper it would be possible to point at a word or diagram with a special pen-like device and have it work out what page you are on and where you are pointing and thus take you to appropriate web materials . . . perhaps the fourth edition . . .

It is paradoxical that Xerox PARC, where much of the driving work behind current 'mouse and window' computer interfaces began, has also developed this totally non-screen and non-mouse paradigm. However, the common principle behind each is the novel and appropriate use of different media for graceful interaction.

Worked exercise

What input and output devices would you use for the following systems? For each, compare and contrast alternatives, and if appropriate indicate why the conventional keyboard, mouse and CRT screen may be less suitable.

(a) portable word processor
(b) tourist information system
(c) tractor-mounted crop-spraying controller

(d) air traffic control system
(e) worldwide personal communications system
(f) digital cartographic system.

Answer In the later exercise on basic architecture (see Section 2.8.6), we focus on 'typical' systems, whereas here the emphasis is on the diversity of different devices needed for specialized purposes. You can 'collect' devices – watch out for shop tills, bank tellers, taxi meters, lift buttons, domestic appliances, etc.

(a) Portable word processor
The determining factors are size, weight and battery power. However, remember the purpose: this is a word processor not an address book or even a data entry device.
- (i) LCD screen – low-power requirement
- (ii) trackball or stylus for pointing
- (iii) real keyboard – you can't word process without a reasonable keyboard and stylus handwriting recognition is not good enough
- (iv) small, low-power bubble-jet printer – although not always necessary, this makes the package stand alone. It is probably not so necessary that the printer has a large battery capacity as printing can probably wait until a power point is found.

(b) Tourist information system
This is likely to be in a public place. Most users will only visit the system once, so the information and mode of interaction must be immediately obvious.
- (i) touchscreen only – easy and direct interaction for first-time users (see also Chapter 3)
- (ii) NO mice or styluses – in a public place they wouldn't stay long!

(c) Tractor-mounted crop-spraying controller
A hostile environment with plenty of mud and chemicals. Requires numerical input for flow rates, etc., but probably no text
- (i) touch-sensitive keypad – ordinary keypads would get blocked up
- (ii) small dedicated LED display (LCDs often can't be read in sunlight and large screens are fragile)
- (iii) again no mice or styluses – they would get lost.

(d) Air traffic control system
The emphasis is on immediately available information and rapid interaction. The controller cannot afford to spend time searching for information; all frequently used information must be readily available.
- (i) several specialized displays – including overlays of electronic information on radar
- (ii) light pen or stylus – high-precision direct interaction
- (iii) keyboard – for occasional text input, but consider making it fold out of the way.

(e) Worldwide personal communications system
Basically a super mobile phone! If it is to be kept on hand all the time it must be very light and pocket sized. However, to be a 'communications' system one would imagine that it should also act as a personal address/telephone book, etc.

(i) standard telephone keypad – the most frequent use
(ii) small dedicated LCD display – low power, specialized functions
(iii) possibly stylus for interaction – it allows relatively rich interaction with the address book software, but little space
(iv) a 'docking' facility – the system itself will be too small for a full-sized keyboard(!), but you won't want to enter in all your addresses and telephone numbers by stylus!

(f) Digital cartographic system
This calls for very high-precision input and output facilities. It is similar to CAD in terms of the screen facilities and printing, but in addition will require specialized data capture.
(i) large high-resolution color VDU (20 inch or bigger) – these tend to be enormously big (from back to front). LCD screens, although promising far thinner displays in the long term, cannot at present be made large enough
(ii) digitizing tablet – for tracing data on existing paper maps. It could also double up as a pointing device for some interaction
(iii) possibly thumbwheels – for detailed pointing and positioning tasks
(iv) large-format printer – indeed very large: an A2 or A1 plotter at minimum.

2.8 MEMORY

Like human memory, we can think of the computer's memory as operating at different levels, with those that have the faster access typically having less capacity. By analogy with the human memory, we can group these into short-term and long-term memories (STM and LTM), but the analogy is rather weak – the capacity of the computer's STM is a lot more than seven items! The different levels of computer memory are more commonly called primary and secondary storage.

The details of computer memory are not in themselves of direct interest to the user interface designer. However, the limitations in capacity and access methods are important constraints on the sort of interface that can be designed. After some fairly basic information, we will put the raw memory capacity into perspective with the sort of information which can be stored, as well as again seeing how advances in technology offer more scope for the designer to produce more effective interfaces. In particular, we will see how the capacity of typical memory copes with video images as these are becoming important as part of multimedia applications (see Chapter 21).

2.8.1 RAM and short-term memory (STM)

At the lowest level of computer memory are the registers on the computer chip, but these have little impact on the user except in so far as they affect the general speed of the computer. Most currently active information is held in silicon-chip *random access memory* (*RAM*). Different forms of RAM differ as to their precise access times, power consumption and characteristics. Typical access times are of the order of 10 nanoseconds, that is a hundred-millionth of a second, and information can be accessed at a rate of around 100 Mbytes (million bytes) per second. Typical storage in modern personal computers is between 64 and 256 Mbytes.

Most RAM is *volatile*, that is its contents are lost when the power is turned off. However, many computers have small amount of *non-volatile RAM*, which retains its contents, perhaps with the aid of a small battery. This may be used to store setup information in a large computer, but in a pocket organizer will be the whole memory. Non-volatile RAM is more expensive so is only used where necessary, but with many notebook computers using very low-power static RAM, the divide is shrinking. By strict analogy, non-volatile RAM ought to be classed as LTM, but the important thing we want to emphasize is the gulf between STM and LTM in a traditional computer system.

In PDAs the distinctions become more confused as the battery power means that the system is never completely off, so RAM memory effectively lasts for ever. Some also use flash memory, which is a form of silicon memory that sits between fixed content ROM (read-only memory) chips and normal RAM. Flash memory is relatively slow to write, but once written retains its content even with no power whatsoever. These are sometimes called silicon disks on PDAs. Digital cameras typically store photographs in some form of flash media and small flash-based devices are used to plug into a laptop or desktop's USB port to transfer data.

2.8.2 Disks and long-term memory (LTM)

For most computer users the LTM consists of *disks*, possibly with small tapes for *backup*. The existence of backups, and appropriate software to generate and retrieve them, is an important area for user security. However, we will deal mainly with those forms of storage that impact the interactive computer user.

There are two main kinds of technology used in disks: *magnetic disks* and *optical disks*. The most common storage media, floppy disks and hard (or fixed) disks, are coated with magnetic material, like that found on an audio tape, on which the information is stored. Typical capacities of floppy disks lie between 300 kbytes and 1.4 Mbytes, but as they are removable, you can have as many as you have room for on your desk. Hard disks may store from under 40 Mbytes to several gigabytes (Gbytes), that is several thousand million bytes. With disks there are two access times to consider, the time taken to find the right track on the disk, and the time to read the track. The former dominates random reads, and is typically of the order of 10 ms for hard disks. The transfer rate once the track is found is then very high, perhaps several hundred kilobytes per second. Various forms of large removable media are also available, fitting somewhere between floppy disks and removable hard disks, and are especially important for multimedia storage.

Optical disks use laser light to read and (sometimes) write the information on the disk. There are various high capacity specialist optical devices, but the most common is the *CD-ROM*, using the same technology as audio compact discs. CD-ROMs have a capacity of around 650 megabytes, but cannot be written to at all. They are useful for published material such as online reference books, multimedia and software distribution. Recordable CDs are a form of *WORM* device (write-once read-many) and are more flexible in that information can be written, but (as the name suggests) only once at any location – more like a piece of paper than a blackboard. They are obviously very useful for backups and for producing very secure audit information. Finally, there are fully rewritable optical disks, but the rewrite time is typically much slower than the read time, so they are still primarily for archival not dynamic storage. Many CD-ROM reader/writers can also read DVD format, originally developed for storing movies. Optical media are more robust than magnetic disks and so it is easier to use a *jukebox* arrangement, whereby many optical disks can be brought online automatically as required. This can give an online capacity of many hundreds of gigabytes. However, as magnetic disk capacities have grown faster than the fixed standard of CD-ROMs, some massive capacity stores are moving to large disk arrays.

2.8.3 Understanding speed and capacity

So what effect do the various capacities and speeds have on the user? Thinking of our typical personal computer system, we can summarize some typical capacities as in Table 2.1.

We think first of documents. This book is about 320,000 words, or about 2 Mbytes, so it would hardly make a dent in 256 Mbytes of RAM. (This size – 2 Mbytes – is unformatted and without illustrations; the actual size of the full data files is an order of magnitude bigger, but still well within the capacity of main memory.) To take a more popular work, the Bible would use about 4.5 Mbytes. This would still consume only 2% of main memory, and disappear on a hard disk. However, it might look tight on a smaller PDA. This makes the memory look not too bad, so long as you do not intend to put your entire library online. However, many word processors come with a dictionary and thesaurus, and there is no standard way to use the same one with several products. Together with help files and the program itself, it is not

Table 2.1 Typical capacities of different storage media

	STM small/fast	LTM large/slower
Media:	RAM	Hard disk
Capacity:	256 Mbytes	100 Gbytes
Access time:	10 ns	7 ms
Transfer rate:	100 Mbyte/s	30 Mbyte/s

unusual to find each application consuming tens or even hundreds of megabytes of disk space – it is not difficult to fill a few gigabytes of disk at all!

Similarly, although 256 Mbytes of RAM are enough to hold most (but not all) single programs, windowed systems will run several applications simultaneously, soon using up many megabytes. Operating systems handle this by *paging* unused bits of programs out of RAM onto disk, or even *swapping* the entire program onto disk. This makes little difference to the logical functioning of the program, but has a significant effect on interaction. If you select a window, and the relevant application happens to be currently swapped out onto the disk, it has to be swapped back in. The delay this causes can be considerable, and is both noticeable and annoying on many systems.

Technological change and storage capacity

Most of the changes in this book since the first and second editions have been additions where new developments have come along. However, this portion has had to be scrutinized line by line as the storage capacities of high-end machines when this book was first published in 1993 looked ridiculous as we revised it in 1997 and then again in 2003. One of our aims in this chapter was to give readers a concrete feel for the capacities and computational possibilities in standard computers. However, the pace of advances in this area means that it becomes out of date almost as fast as it is written! This is also a problem for design; it is easy to build a system that is sensible given a particular level of technology, but becomes meaningless later. The solution is either to issue ever more frequent updates and new versions, or to exercise a bit of foresight . . .

The delays due to swapping are a symptom of the *von Neumann bottleneck* between disk and main memory. There is plenty of information in the memory, but it is not where it is wanted, in the machine's RAM. The path between them is limited by the transfer rate of the disk and is too slow. Swapping due to the operating system may be difficult to avoid, but for an interactive system designer some of these problems can be avoided by thinking carefully about where information is stored and when it is transferred. For example, the program can be *lazy* about information transfer. Imagine the user wants to look at a document. Rather than reading in the whole thing before letting the user continue, just enough is read in for the first page to be displayed, and the rest is read during idle moments.

Returning to documents, if they are scanned as bitmaps (and not read using OCR), then the capacity of our system looks even less impressive. Say an 11 × 8 inch (297 × 210 mm) page is scanned with an 8 bit grayscale (256 levels) setting at 1200 dpi. The image contains about one billion bits, that is about 128 Mbyte. So, our 100 Gbyte disk could store 800 pages – just OK for this book, but not for the Bible.

If we turn to video, things are even worse. Imagine we want to store moving video using 12 bits for each pixel (4 bits for each primary color giving 16 levels of brightness), each frame is 512 × 512 pixels, and we store at 25 frames per second.

This is by no means a high-quality image, but each frame requires approximately 400 kbytes giving 10 Mbytes per second. Our disk will manage about three hours of video – one good movie. Lowering our sights to still photographs, good digital cameras usually take 2 to 4 mega pixels at 24 bit color; that is 10 Mbytes of raw uncompressed image – you'd not get all your holiday snaps into main memory!

2.8.4 Compression

In fact, things are not quite so bad, since *compression* techniques can be used to reduce the amount of storage required for text, bitmaps and video. All of these things are highly redundant. Consider text for a moment. In English, we know that if we use the letter 'q' then 'u' is almost bound to follow. At the level of words, some words like 'the' and 'and' appear frequently in text in general, and for any particular work one can find other common terms (this book mentions 'user' and 'computer' rather frequently). Similarly, in a bitmap, if one bit is white, there is a good chance the next will be as well. Compression algorithms take advantage of this redundancy. For example, *Huffman encoding* gives short codes to frequent words [182], and *run-length encoding* represents long runs of the same value by length value pairs. Text can easily be reduced by a factor of five and bitmaps often compress to 1% of their original size.

For video, in addition to compressing each frame, we can take advantage of the fact that successive frames are often similar. We can compute the *difference* between successive frames and then store only this – compressed, of course. More sophisticated algorithms detect when the camera pans and use this information also. These differencing methods fail when the scene changes, and so the process periodically has to restart and send a new, complete (but compressed) image. For storage purposes this is not a problem, but when used for transmission over telephone lines or networks it can mean glitches in the video as the system catches up.

With these reductions it is certainly possible to store low-quality video at 64 kbyte/s; that is, we can store five hours of highly compressed video on our 1 Gbyte hard disk. However, it still makes the humble video cassette look very good value.

Probably the leading edge of video still and photographic compression is *fractal compression*. Fractals have been popularized by the images of the *Mandelbrot set* (that swirling pattern of computer-generated colors seen on many T-shirts and posters). Fractals refer to any image that contains parts which, when suitably scaled, are similar to the whole. If we look at an image, it is possible to find parts which are approximately self-similar, and these parts can be stored as a fractal with only a few numeric parameters. Fractal compression is especially good for textured features, which cause problems for other compression techniques. The *decompression* of the image can be performed to any degree of accuracy, from a very rough soft-focus image, to one *more* detailed than the original. The former is very useful as one can produce poor-quality output quickly, and better quality given more time. The latter is rather remarkable – the fractal compression actually fills in details that are not in the original. These details are not accurate, but look convincing!

2.8.5 Storage format and standards

The most common data types stored by interactive programs are text and bitmap images, with increasing use of video and audio, and this subsection looks at the ridiculous range of file storage standards. We will consider database retrieval in the next subsection.

The basic standard for text storage is the *ASCII* (American standard code for information interchange) character codes, which assign to each standard printable character and several control characters an internationally recognized 7 bit code (decimal values 0–127), which can therefore be stored in an 8 bit byte, or be transmitted as 8 bits including parity. Many systems extend the codes to the values 128–255, including line-drawing characters, mathematical symbols and international letters such as 'æ'. There is a 16 bit extension, the UNICODE standard, which has enough room for a much larger range of characters including the Japanese Kanji character set.

As we have already discussed, modern documents consist of more than just characters. The text is in different fonts and includes formatting information such as centering, page headers and footers. On the whole, the storage of formatted text is vendor specific, since virtually every application has its own file format. This is not helped by the fact that many suppliers attempt to keep their file formats secret, or update them frequently to stop others' products being compatible. With the exception of bare ASCII, the most common shared format is *rich text format* (*RTF*), which encodes formatting information including style sheets. However, even where an application will import or export RTF, it may represent a cut-down version of the full document style.

RTF regards the document as formatted text, that is it concentrates on the appearance. Documents can also be regarded as structured objects: this book has chapters containing sections, subsections . . . paragraphs, sentences, words and characters. There are *ISO standards* for document structure and interchange, which in theory could be used for transfer between packages and sites, but these are rarely used in practice. Just as the PostScript language is used to describe the printed page, *SGML* (*standard generalized markup language*) can be used to store structured text in a reasonably extensible way. You can define your own structures (the definition itself in SGML), and produce documents according to them. XML (extensible markup language), a lightweight version of SGML, is now used extensively for web-based applications.

For bitmap storage the range of formats is seemingly unending. The stored image needs to record the size of the image, the number of bits per pixel, possibly a color map, as well as the bits of the image itself. In addition, an icon may have a 'hot-spot' for use as a cursor. If you think of all the ways of encoding these features, or leaving them implicit, and then consider all the combinations of these different encodings, you can see why there are problems. And all this before we have even considered the effects of compression! There is, in fact, a whole software industry producing packages that convert from one format to another.

Given the range of storage standards (or rather lack of standards), there is no easy advice as to which is best, but if you are writing a new word processor and are about to decide how to store the document on disk, think, just for a moment, before defining yet another format.

2.8.6 Methods of access

Standard database access is by special key fields with an associated index. The user has to know the key before the system can find the information. A telephone directory is a good example of this. You can find out someone's telephone number if you know their name (the key), but you cannot find the name given the number. This is evident in the interface of many computer systems. So often, when you contact an organization, they can only help you if you give your customer number, or last order number. The usability of the system is seriously impaired by a shortsighted reliance on a single key and index. In fact, most database systems will allow multiple keys and indices, allowing you to find a record given partial information. So these problems are avoidable with only slight foresight.

There are valid reasons for not indexing on too many items. Adding extra indices adds to the size of the database, so one has to balance ease of use against storage cost. However, with ever-increasing disk sizes, this is not a good excuse for all but extreme examples. Unfortunately, brought up on lectures about algorithmic efficiency, it is easy for computer scientists to be stingy with storage. Another, more valid, reason for restricting the fields you index is privacy and security. For example, telephone companies will typically hold an online index that, given a telephone number, would return the name and address of the subscriber, but to protect the privacy of their customers, this information is not divulged to the general public.

It is often said that dictionaries are only useful for people who can spell. Bad spellers do not know what a word looks like so cannot look it up to find out. Not only in spelling packages, but in general, an application can help the user by matching badly spelt versions of keywords. One example of this is *do what I mean* (*DWIM*) used in several of Xerox PARC's experimental programming environments. If a command name is misspelt the system prompts the user with a close correct name. Menu-based systems make this less of an issue, but one can easily imagine doing the same with, say, file selection. Another important instance of this principle is *Soundex*, a way of indexing words, especially names. Given a key, Soundex finds those words which sound similar. For example, given McCloud, it would find MacCleod. These are all examples of *forgiving systems*, and in general one should aim to accommodate the user's mistakes. Again, there are exceptions to this: you do not want a bank's automated teller machine (ATM) to give money when the PIN number is *almost* correct!

Not all databases allow long passages of text to be stored in records, perhaps setting a maximum length for text strings, or demanding the length be fixed in advance. Where this is the case, the database seriously restricts interface applications where text forms an important part. At the other extreme, *free text retrieval* systems are centered on unformatted, unstructured text. These systems work by keeping an index of every word in every document, and so you can ask 'give me all documents with the words "human" and "computer" in them'. Programs, such as versions of the UNIX 'grep' command, give some of the same facilities by quickly scanning a list of files for a certain word, but are much slower. On the web, free text search is of course the standard way to find things using search engines.

Worked exercise *What is the basic architecture of a computer system?*

Answer In an HCI context, you should be assessing the architecture from the point of view of the user. The material for this question is scattered throughout the chapter. Look too at personal computer magazines, where adverts and articles will give you some idea of typical capabilities . . . and costs. They may also raise some questions: just what is the difference to the user between an 8 ms and a 10 ms disk drive?

The example answer below gives the general style, although more detail would be expected of a full answer. In particular, you need to develop a feel for capacities either as ball-park figures or in terms of typical capabilities (seconds of video, pages of text).

Example

The basic architecture of a computer system consists of the computer itself (with associated memory), input and output devices for user interaction and various forms of hard-copy devices. (Note, the 'computer science' answer regards output to the user and output to a printer as essentially equivalent. This is not an acceptable user-centered view.)

A typical configuration of user input–output devices would be a screen with a keyboard for typing text and a mouse for pointing and positioning. Depending on circumstance, different pointing devices may be used such as a stylus (for more direct interaction) or a touchpad (especially on portable computers).

The computer itself can be considered as composed of some processing element and memory. The memory is itself divided into short-term memory which is lost when the machine is turned off and permanent memory which persists.

2.9 PROCESSING AND NETWORKS

Computers that run interactive programs will process in the order of 100 million instructions per second. It sounds a lot and yet, like memory, it can soon be used up. Indeed, the first program written by one of the authors (some while ago) 'hung' and all attempts to debug it failed. Later calculation showed that the program would have taken more than the known age of the universe to complete! Failures need not be as spectacular as that to render a system unusable. Consider, for example, one drawing system known to the authors. To draw a line you press down the mouse button at one end, drag the mouse and then release the mouse button at the other end of the line – but not too quickly. You have to press down the button and then actually hold your hand steady for a moment, otherwise the line starts half way! For activities involving the user's hand–eye coordination, delays of even a fraction of a second can be disastrous.

Moore's law

Everyone knows that computers just get faster and faster. However, in 1965 Gordon Moore, co-founder of Intel, noticed a regularity. It seemed that the speed of processors, related closely to the number of transistors that could be squashed on a silicon wafer, was doubling every 18 months – exponential growth. One of the authors bought his first 'proper' computer in 1987; it was a blindingly fast 1.47 MHz IBM compatible (Macs were too expensive). By 2002 a system costing the same in real terms would have had a 1.5 GHz processor – 1000 times faster or 2^{10} in 15 years, that is 10×18 months.

There is a similar pattern for computer memory, except that the doubling time for magnetic storage seems to be closer to one year. For example, when the first edition of this book was written one of the authors had a 20 Mbyte hard disk; now, 11 years later, his disk is 30 Gbytes – around 2^{10} times more storage in just 10 years.

The effects of this are dramatic. If you took a young baby today and started recording a full audio video diary of every moment, day and night, of that child's life, by the time she was an old lady her whole life experience would fit into memory the size of a small grain of dust.

For more on Moore's law and life recording see: /e3/online/moores-law/

2.9.1 Effects of finite processor speed

As we can see, speed of processing can seriously affect the user interface. These effects must be taken into account when designing an interactive system. There are two sorts of faults due to processing speed: those when it is too slow, and those when it is too fast!

We saw one example of the former above. This was a *functional fault*, in that the program did the wrong thing. The system is supposed to draw lines from where the mouse button is depressed to where it is released. However, the program gets it wrong – after realizing the button is down, it does not check the position of the mouse fast enough, and so the user may have moved the mouse before the start position is registered. This is a fault at the implementation stage of the system rather than of the design. But to be fair, the programmer may not be given the right sort of information from lower levels of system software.

A second fault due to slow processing is where, in a sense, the program does the right thing, but the feedback is too slow, leading to strange effects at the interface. In order to avoid faults of the first kind, the system *buffers* the user input; that is, it remembers keypresses and mouse buttons and movement. Unfortunately, this leads to problems of its own. One example of this sort of problem is *cursor tracking*, which happens in character-based text editors. The user is trying to move backwards on the same line to correct an error, and so presses the cursor-left key. The cursor moves and when it is over the correct position, the user releases the key. Unfortunately, the system is behind in responding to the user, and so has a few more cursor-left keys to process – the cursor then overshoots. The user tries to correct this by pressing the cursor-right key, and again overshoots. There is typically no way for the user to tell whether the buffer is empty or not, except by interacting very slowly with the system and observing that the cursor has moved after every keypress.

A similar problem, *icon wars*, occurs on window systems. The user clicks the mouse on a menu or icon, and nothing happens; for some reason the machine is busy or slow. So the user clicks again, tries something else – then, suddenly, all the buffered mouse clicks are interpreted and the screen becomes a blur of flashing windows and menus. This time, it is not so much that the response is too slow – it is fast enough when it happens – but that the response is variable. The delays due to swapping programs in and out of main memory typically cause these problems.

Furthermore, a style of interaction that is optimal on one machine may not be so on a slower machine. In particular, mouse-based interfaces cannot tolerate delays between actions and feedback of more than a fraction of a second, otherwise the immediacy required for successful interaction is lost. If these responses cannot be met then a more old-fashioned, command-based interface may be required.

Whereas it is immediately obvious that slow responses can cause problems for the user, it is not so obvious why one should not always aim for a system to be as fast as possible. However, there are exceptions to this – the user must be able to read and understand the output of the system. For example, one of the authors was once given a demonstration disk for a spreadsheet. Unfortunately, the machine the demo was written on was clearly slower than the author's machine, not much, at worst half the speed, but different enough. The demo passed in a blur over the screen with nothing remaining on the screen long enough to read. Many high-resolution monitors suffer from a similar problem when they display text. Whereas older character-based terminals scrolled new text from the bottom of the screen or redrew from the top, bitmap screens often 'flash' up the new page, giving no indication of direction of movement. A final example is the rate of cursor flashing: the rate is often at a fixed

DESIGN FOCUS

The myth of the infinitely fast machine

The adverse effects of slow processing are made worse because the designers labor under the *myth of the infinitely fast machine* [93]. That is, they design and document their systems as if response will be immediate. Rather than blithely hoping that the eventual machine will be 'fast enough', the designer ought to plan explicitly for slow responses where these are possible. A good example, where buffering is clear and audible (if not visible) to the user, is telephones. Even if the user gets ahead of the telephone when entering a number, the tones can be heard as they are sent over the line. Now this is probably an accident of the design rather than deliberate policy, as there are so many other problems with telephones as interfaces. However, this type of serendipitous feedback should be emulated in other areas.

frequency, so varying the speed of the processor does not change the screen display. But a rate which is acceptable for a CRT screen is too fast for an LCD screen, which is more persistent, and the cursor may become invisible or a slight gray color.

In some ways the solution to these problems is easier: the designer can demand fixed delays (dependent on media and user preference) rather than just going as fast as the machine allows. To plan for the first problem, that of insufficient speed, the designer needs to understand the limitations of the computer system and take account of these at all stages in the design process.

2.9.2 Limitations on interactive performance

There are several factors that can limit the speed of an interactive system:

Computation bound This is rare for an interactive program, but possible, for example when using find/replace in a large document. The system should be designed so that long delays are not in the middle of interaction and so that the user gets some idea of how the job is progressing. For a very long process try to give an indication of duration *before* it starts; and during processing an indication of the stage that the process has reached is helpful. This can be achieved by having a counter or slowly filling bar on the screen that indicates the amount done, or by changing the cursor to indicate that processing is occurring. Many systems notice after they have been computing for some time and then say 'this may take some time: continue (Y/N)?'. Of course, by the time it says this the process may be nearly finished anyway!

Storage channel bound As we discussed in the previous section, the speed of memory access can interfere with interactive performance. We discussed one technique, laziness, for reducing this effect. In addition, if there is plenty of raw computation power and the system is held up solely by memory, it is possible to trade off memory against processing speed. For example, compressed data take less space to store, and is faster to read in and out, but must be compressed before storage and decompressed when retrieved. Thus faster memory access leads to increased processing time. If data is written more often than it is read, one can choose a technique that is expensive to compress but fairly simple to decompress. For many interactive systems the ability to browse quickly is very important, but users will accept delays when saving updated information.

Graphics bound For many modern interfaces, this is the most common bottleneck. It is easy to underestimate the time taken to perform what appear to be simple interface operations. Sometimes clever coding can reduce the time taken by common graphics operations, and there is tremendous variability in performance between programs running on the same hardware. Most computers include a special-purpose *graphics card* to handle many of the most common graphics operations. This is optimized for graphics operations and allows the main processor to do other work such as manipulating documents and other user data.

Network capacity Most computers are linked by networks. At the simplest this can mean using shared files on a remote machine. When accessing such files it can be the speed of the network rather than that of the memory which limits performance. This is discussed in greater detail below.

2.9.3 Networked computing

Computer systems in use today are much more powerful than they were a few years ago, which means that the standard computer on the desktop is quite capable of high-performance interaction without recourse to outside help. However, it is often the case that we use computers not in their standalone mode of operation, but linked together in networks. This brings added benefits in allowing communication between different parties, provided they are connected into the same network, as well as allowing the desktop computer to access resources remote from itself. Such networks are inherently much more powerful than the individual computers that make up the network: increased computing power and memory are only part of the story, since the effects of allowing people much more extensive, faster and easier access to information are highly significant to individuals, groups and institutions.

One of the biggest changes since the first edition of this book has been the explosive growth of the internet and global connectivity. As well as fixed networks it is now normal to use a high bandwidth modem or wireless local area network (LAN) to connect into the internet and world wide web from home or hotel room anywhere in the world. The effects of this on society at large can only be speculated upon at present, but there are already major effects on computer purchases and perhaps the whole face of personal computation. As more and more people buy computers principally to connect to the internet the idea of the *network computer* has arisen – a small computer with no disks whose sole purpose is to connect up to networks.

The internet

The internet has its roots back in 1969 as DARPANET when the US Government's Department of Defense commissioned research into networking. The initial four mainframe computers grew to 23 in 1971 and the system had been renamed ARPANET. Growth has accelerated ever since: in 1984 there were over a thousand machines connected, in 1989 the 100,000 mark had been reached, and the latest estimates are in the millions. All the computers on the system, now known as the internet, speak a set of common languages (protocols); the two most important of these are *Transmission Control Protocol* (*TCP*) which moves data from A to B, and the *Internet Protocol* (*IP*) which specifies which B is being referred to so that the data goes to the correct place. Together these protocols are known as *TCP/IP*. Thus, at its most basic level, the internet is simply millions of computers connected together and talking to each other. Other protocols then build on these low-level capabilities to provide services such as electronic mail, in which participants send messages to each other; news, where articles of interest are posted to a special interest group and can be read by anyone subscribing to that group; and of course the world wide web.

Such networked systems have an effect on interactivity, over and above any additional access to distant peripherals or information sources. Networks sometimes operate over large distances, and the transmission of information may take some appreciable time, which affects the response time of the system and hence the nature of the interactivity. There may be a noticeable delay in response, and if the user is not informed of what is going on, he may assume that his command has been ignored, or lost, and may then repeat it. This lack of feedback is an important factor in the poor performance and frustration users feel when using such systems, and can be alleviated by more sensible use of the capabilities of the desktop machine to inform users of what is happening over the network.

Another effect is that the interaction between human and machine becomes an open loop, rather than a closed one. Many people may be interacting with the machine at once, and their actions may affect the response to your own. Many users accessing a single central machine will slow its response; database updates carried out by one user may mean that the same query by another user at slightly different times may produce different results. The networked computer system, by the very nature of its dispersal, distribution and multi-user access, has been transformed from a fully predictable, deterministic system, under the total control of the user, into a non-deterministic one, with an individual user being unaware of many important things that are happening to the system as a whole. Such systems pose a particular problem since ideals of consistency, informative feedback and predictable response are violated (see Chapter 7 for more on these principles). However, the additional power and flexibility offered by networked systems means that they are likely to be with us for a long time, and these issues need to be carefully addressed in their design.

Worked exercise *How do you think new, fast, high-density memory devices and quick processors have influenced recent developments in HCI? Do they make systems any easier to use? Do they expand the range of applications of computer systems?*

Answer Arguably it is not so much the increase in computer power as the decrease in the cost of that power which has had the most profound effect. Because 'ordinary' users have powerful machines on their desktops it has become possible to view that power as available for the interface rather than hoarded for number-crunching applications.

Modern graphical interaction consumes vast amounts of processing power and would have been completely impossible only a few years ago. There is an extent to which systems have to run faster to stay still, in that as screen size, resolution and color range increase, so does the necessary processing power to maintain the 'same' interaction. However, this extra processing is not really producing the same effect; screen quality is still a major block on effective interaction.

The increase in RAM means that larger programs can be written, effectively allowing the programmer 'elbow room'. This is used in two ways: to allow extra functionality and to support easier interaction. Whether the former really improves usability is debatable – unused functionality is a good marketing point, but is of no benefit to the user. The ease of use of a system is often determined by a host of small features, such as the appropriate choice of default options. These features make the interface seem 'simple', but make the program very complex . . . and large. Certainly the availability of elbow room, both in terms of memory and processing power, has made such features possible.

The increase in both short-term (RAM) and long-term (disks and optical storage) memory has also removed many of the arbitrary limits in systems: it is possible to edit documents of virtually unlimited size and to treat the computer (suitably backed up) as one's primary information repository.

Some whole new application areas have become possible because of advances in memory and processing. Most applications of multimedia including voice recognition and online storage and capture of video and audio, require enormous amounts of processing and/or memory. In particular, large magnetic and optical storage devices have been the key to electronic document storage whereby all paper documents are scanned and stored within a computer system. In some contexts such systems have completely replaced paper-based filing cabinets.

2.10 SUMMARY

In Sections 2.2 and 2.3, we described a range of input devices. These performed two main functions: text entry and pointing. The principal text entry device is the QWERTY keyboard, but we also discussed alternative keyboards, chord keyboards, the telephone keypad and speech input. Pointing devices included the mouse, touchpad, trackball and joystick, as well as a large array of less common alternatives including eyegaze systems.

Section 2.4 dealt mainly with the screen as a direct output device. We discussed several different technologies, in particular CRT and LCD screens and the common properties of all bitmap display devices. We considered some more recent display methods including large displays, situated displays and digital paper.

Section 2.5 looked at the devices used for manipulating and seeing virtual reality and 3D spaces. This included the dataglove, body tracking, head-mounted displays and cave environments.

In Section 2.6 we moved outside the computer entirely and looked at physical devices such as the special displays, knobs and switches of electronic appliances. We also briefly considered sound, touch and smell as outputs from computer systems and environmental and bio-sensing as inputs. These are topics that will be revisited later in the book.

Section 2.7 discussed various forms of printer and scanner. Typical office printers include ink-jet, bubble-jet and laser printers. In addition, dot-matrix and thermal printers are used in specialized equipment. We also discussed font styles and page description languages. Scanners are used to convert printed images and documents into electronic form. They are particularly valuable in desktop publishing and for electronic document storage systems.

In Section 2.8, we considered the typical capacities of computer memory, both of main RAM, likened to human short-term memory, and long-term memory stored on magnetic and optical disks. The storage capacities were compared with document sizes and video images. We saw that a typical hard disk could only hold about two minutes of moving video, but that compression techniques can increase the capacity dramatically. We also discussed storage standards – or rather the lack of them – including the ASCII character set and markup languages. The user ought to be able to access information in ways that are natural and tolerant of small slips. Techniques which can help this included multiple indices, free text databases, DWIM (do what I mean) and Soundex.

Section 2.9 showed how processing speed, whether too slow or too fast, can affect the user interface. In particular, we discussed the effects of buffering: cursor tracking and icon wars. Processing speed is limited by various factors: computation, memory access, graphics and network delays.

The lesson from this chapter is that the interface designer needs to be aware of the properties of the devices with which a system is built. This includes not only input and output devices, but all the factors that influence the behavior of the interface, since all of these influence the nature and style of the interaction.

EXERCISES

2.1 Individually or in a group find as many different examples as you can of physical controls and displays.

(a) List them.
(b) Try to group them, or classify them.
(c) Discuss whether you believe the control or display is suitable for its purpose (Section 3.9.3 may also help).

Exercises 2.2 and 2.3 involve you examining a range of input and output devices in order to understand how they influence interaction.

2.2 A typical computer system comprises a QWERTY keyboard, a mouse and a color screen. There is usually some form of loudspeaker as well. You should know how the keyboard, mouse and screen work – if not, read up on it.

What sort of input does the keyboard support? What sort of input does the mouse support? Are these adequate for all possible applications? If not, to which areas are they most suited? Do these areas map well onto the typical requirements for users of computer systems?

If you were designing a keyboard for a modern computer, and you wanted to produce a faster, easier-to-use layout, what information would you need to know and how would that influence the design?

2.3 Pick a couple of computer input devices that you are aware of (joystick, light pen, touchscreen, trackball, eyegaze, dataglove, etc.) and note down how each has different attributes that support certain forms of interaction. You ought to know a little about all of these devices – if you don't, research them.

2.4 What is the myth of the infinitely fast machine?

2.5 Pick one of the following scenarios, and choose a suitable combination of input and output devices to best support the intended interaction. It may help to identify typical users or classes of user, and identify how the devices chosen support these people in their tasks. Explain the major problems that the input and output devices solve.

(a) *Environmental database*
A computer database is under development that will hold environmental information. This ranges from meteorological measurements through fish catches to descriptions of pollution, and will include topographical details and sketches and photographs. The data has to be accessed only by experts, but they want to be able to describe and retrieve any piece of data within a few seconds.

(b) *Word processor for blind people*
A word processor for blind users is needed, which can also be operated by sighted people. It has to support the standard set of word-processing tasks.

2.6 Describe Fitts' law (see Chapter 1). How does Fitts' law change for different physical selection devices, such as a three-button mouse, a touchpad, or a pen/stylus? (You'll need to do some research for this.)

RECOMMENDED READING

W. Buxton, There's more to interaction than meets the eye: some issues in manual input. In R. Baecker and W. Buxton, editors, *Readings in Human–Computer Interaction: A Multidisciplinary Approach*, Morgan Kaufmann, 1987.

D. J. Mayhew, *Principles and Guidelines in Software User Interface Design*, Chapter 12, Prentice Hall, 1992.
A look at input and output devices, complete with guidelines for using different devices.

A. Dix, Network-based interaction. In J. Jacko and A. Sears, editors, *Human–Computer Interaction Handbook*, Chapter 16, pp. 331–57, Lawrence Erlbaum, 2003.
Includes different kinds of network application and the effects of networks on interaction including rich media. Also look at all of Part II of Jacko and Sears, which includes chapters on input technology and on haptic interfaces.