The last of these has not been a major factor until recently in HCI, but issues of motivation, enjoyment and experience are increasingly important. We are certainly even further from having a unified theory of experience than of task.

The question of whether HCI, or more importantly the design of interactive systems and the user interface in particular, is a science or a craft discipline is an interesting one. Does it involve artistic skill and fortuitous insight or reasoned methodical science? Here we can draw an analogy with architecture. The most impressive structures, the most beautiful buildings, the innovative and imaginative creations that provide aesthetic pleasure, all require inventive inspiration in design and a sense of artistry, and in this sense the discipline is a craft. However, these structures also have to be able to stand up to fulfill their purpose successfully, and to be able to do this the architect has to use science. So it is for HCI: beautiful and/or novel interfaces are artistically pleasing *and* capable of fulfilling the tasks required – a marriage of art and science into a successful whole. We want to reuse lessons learned from the past about how to achieve good results and avoid bad ones. For this we require both craft and science. Innovative ideas lead to more usable systems, but in order to maximize the potential benefit from the ideas, we need to understand not only that they work, but how and why they work. This scientific rationalization allows us to reuse related concepts in similar situations, in much the same way that architects can produce a bridge and know that it will stand, since it is based upon tried and tested principles.

The craft–science tension becomes even more difficult when we consider novel systems. Their increasing complexity means that our personal ideas of good and bad are no longer enough; for a complex system to be well designed we need to rely on something more than simply our intuition. Designers may be able to think about how one user would want to act, but how about groups? And what about new media? Our ideas of how best to share workloads or present video information are open to debate and question even in non-computing situations, and the incorporation of one version of good design into a computer system is quite likely to be unlike anyone else's version. Different people work in different ways, whilst different media color the nature of the interaction; both can dramatically change the very nature of the original task. In order to assist designers, it is unrealistic to assume that they can rely on artistic skill and perfect insight to develop usable systems. Instead we have to provide them with an understanding of the concepts involved, a scientific view of the reasons why certain things are successful whilst others are not, and then allow their creative nature to feed off this information: creative flow, underpinned with science; or maybe scientific method, accelerated by artistic insight. The truth is that HCI is required to be both a craft and a science in order to be successful.

HCI IN THE CURRICULUM

If HCI involves both craft and science then it must, in part at least, be taught. Imagination and skill may be qualities innate in the designer or developed through experience, but the underlying theory must be learned. In the past, when computers were used primarily by expert specialists, concentration on the interface was a luxury that was often relinquished. Now designers cannot afford to ignore the interface in favour of the functionality of their systems: the two are too closely intertwined. If the interface is poor, the functionality is obscured; if it is well designed, it will allow the system's functionality to support the user's task.

Increasingly, therefore, computer science educators cannot afford to ignore HCI. We would go as far as to claim that HCI should be integrated into every computer science or software engineering course, either as a recurring feature of other modules or, preferably, as a module itself. It should not be viewed as an 'optional extra' (although, of course, more advanced HCI options can complement a basic core course). This view is shared by the ACM SIGCHI curriculum development group, who propose a curriculum for such a core course [9]. The topics included in this book, although developed without reference to this curriculum, cover the main emphases of it, and include enough detail and coverage to support specialized options as well.

In courses other than computer science, HCI may well be an option specializing in a particular area, such as cognitive modeling or task analysis. Selected use of the relevant chapters of this book can also support such a course.

HCI must be taken seriously by designers and educators if the requirement for additional complexity in the system is to be matched by increased clarity and usability in the interface. In this book we demonstrate how this can be done in practice.

Design Focus

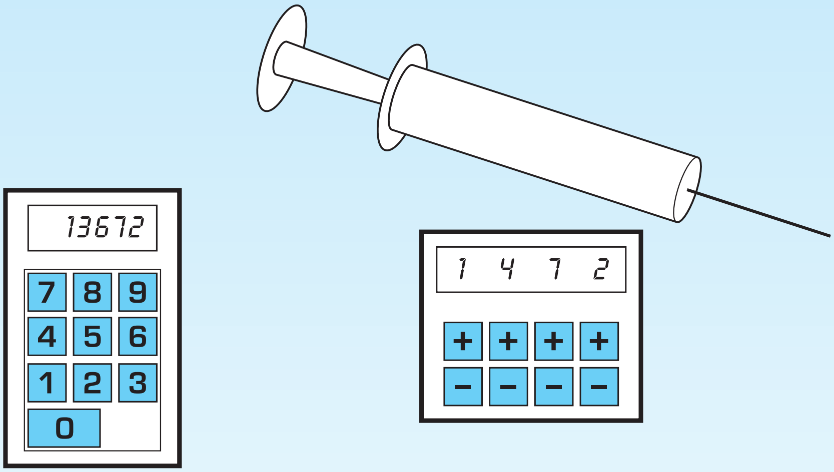
Quick fixes

You should expect to spend both time and money on interface design, just as you would with other parts of a system. So in one sense there are no quick fixes. However, a few simple steps can make a dramatic improvement.

Think 'user'
Probably 90% of the value of any interface design technique is that it forces the designer to remember that someone (and in particular someone else) will use the system under construction.

Try it out
Of course, many designers will build a system that they find easy and pleasant to use, and they find it incomprehensible that anyone else could have trouble with it. Simply sitting someone down with an early version of an interface (without the designer prompting them at each step!) is enormously valuable. Professional usability laboratories will have video equipment, one-way mirrors and other sophisticated monitors, but a notebook and pencil and a home-video camera will suffice (more about evaluation in Chapter 9).

Involve the users
Where possible, the eventual users should be involved in the design process. They have vital knowledge and will soon find flaws. A mechanical syringe was once being developed and a prototype was demonstrated to hospital staff. Happily they quickly noticed the potentially fatal flaw in its interface.



Before consulting users

After consulting users

Figure 0.1 Automatic syringe: setting the dose to 1372. The effect of one key slip before and after user involvement

The doses were entered via a numeric keypad: an accidental keypress and the dose could be out by a factor of 10! The production version had individual increment/decrement buttons for each digit (more about participatory design in Chapter 13).

Iterate

People are complicated, so you won't get it right first time. Programming an interface can be a very difficult and time-consuming business. So, the result becomes precious and the builder will want to defend it and minimize changes. Making early prototypes less precious and easier to throw away is crucial. Happily there are now many interface builder tools that aid this process. For example, mock-ups can be quickly constructed using HyperCard on the Apple Macintosh or Visual Basic on the PC. For visual and layout decisions, paper designs and simple models can be used (more about iterative design in Chapter 5).

PART
1

FOUNDATIONS

In this part we introduce the fundamental components of an interactive system: the human user, the computer system itself and the nature of the interactive process. We then present a view of the history of interactive systems by looking at key interaction paradigms that have been significant.

Chapter 1 discusses the psychological and physiological attributes of the user, providing us with a basic overview of the capabilities and limitations that affect our ability to use computer systems. It is only when we have an understanding of the user at this level that we can understand what makes for successful designs. Chapter 2 considers the computer in a similar way. Input and output devices are described and explained and the effect that their individual characteristics have on the interaction highlighted. The computational power and memory of the computer is another important component in determining what can be achieved in the interaction, whilst due attention is also paid to paper output since this forms one of the major uses of computers and users' tasks today. Having approached interaction from both the human and the computer side, we then turn our attention to the dialog between them in Chapter 3, where we look at models of interaction. In Chapter 4 we take a historical perspective on the evolution of interactive systems and how they have increased the usability of computers in general.

1

THE HUMAN

OVERVIEW

- Humans are limited in their capacity to process information. This has important implications for design.
- Information is received and responses given via a number of input and output channels:
  - visual channel
  - auditory channel
  - haptic channel
  - movement.
- Information is stored in memory:
  - sensory memory
  - short-term (working) memory
  - long-term memory.
- Information is processed and applied:
  - reasoning
  - problem solving
  - skill acquisition
  - error.
- Emotion influences human capabilities.
- Users share common capabilities but are individuals with differences, which should not be ignored.

1.1 INTRODUCTION

This chapter is the first of four in which we introduce some of the 'foundations' of HCI. We start with the human, the central character in any discussion of interactive systems. The human, the *user*, is, after all, the one whom computer systems are designed to assist. The requirements of the user should therefore be our first priority.

In this chapter we will look at areas of human psychology coming under the general banner of *cognitive psychology*. This may seem a far cry from designing and building interactive computer systems, but it is not. In order to design something for someone, we need to understand their capabilities and limitations. We need to know if there are things that they will find difficult or, even, impossible. It will also help us to know what people find easy and how we can help them by encouraging these things. We will look at aspects of cognitive psychology which have a bearing on the use of computer systems: how humans perceive the world around them, how they store and process information and solve problems, and how they physically manipulate objects.

We have already said that we will restrict our study to those things that are relevant to HCI. One way to structure this discussion is to think of the user in a way that highlights these aspects. In other words, to think of a simplified *model* of what is actually going on. Many models have been proposed and it useful to consider one of the most influential in passing, to understand the context of the discussion that is to follow. In 1983, Card, Moran and Newell [56] described the *Model Human Processor*, which is a simplified view of the human processing involved in interacting with computer systems. The model comprises three subsystems: the perceptual system, handling sensory stimulus from the outside world, the motor system, which controls actions, and the cognitive system, which provides the processing needed to connect the two. Each of these subsystems has its own processor and memory, although obviously the complexity of these varies depending on the complexity of the tasks the subsystem has to perform. The model also includes a number of *principles of operation* which dictate the behavior of the systems under certain conditions.

We will use the analogy of the user as an information processing system, but in our model make the analogy closer to that of a conventional computer system. Information comes in, is stored and processed, and information is passed out. We will therefore discuss three components of this system: input–output, memory and processing. In the human, we are dealing with an intelligent information-processing system, and processing therefore includes problem solving, learning, and, consequently, making mistakes. This model is obviously a simplification of the real situation, since memory and processing are required at all levels, as we have seen in the Model Human Processor. However, it is convenient as a way of grasping how information is handled by the human system. The human, unlike the computer, is also influenced by external factors such as the social and organizational environment, and we need to be aware of these influences as well. We will ignore such factors for now and concentrate on the human's information processing capabilities only. We will return to social and organizational influences in Chapter 3 and, in more detail, in Chapter 13.

In this chapter, we will first look at the human's input–output channels, the senses and responders or effectors. This will involve some low-level processing. Secondly, we will consider human memory and how it works. We will then think about how humans perform complex problem solving, how they learn and acquire skills, and why they make mistakes. Finally, we will discuss how these things can help us in the design of computer systems.

1.2 INPUT–OUTPUT CHANNELS

A person's interaction with the outside world occurs through information being received and sent: input and output. In an interaction with a computer the user receives information that is output by the computer, and responds by providing input to the computer – the user's output becomes the computer's input and vice versa. Consequently the use of the terms input and output may lead to confusion so we shall blur the distinction somewhat and concentrate on the channels involved. This blurring is appropriate since, although a particular channel may have a primary role as input or output in the interaction, it is more than likely that it is also used in the other role. For example, sight may be used primarily in receiving information from the computer, but it can also be used to provide information to the computer, for example by fixating on a particular screen point when using an eyegaze system.

Input in the human occurs mainly through the senses and output through the motor control of the effectors. There are five major senses: sight, hearing, touch, taste and smell. Of these, the first three are the most important to HCI. Taste and smell do not currently play a significant role in HCI, and it is not clear whether they could be exploited at all in general computer systems, although they could have a role to play in more specialized systems (smells to give warning of malfunction, for example) or in augmented reality systems. However, vision, hearing and touch are central.

Similarly there are a number of effectors, including the limbs, fingers, eyes, head and vocal system. In the interaction with the computer, the fingers play the primary role, through typing or mouse control, with some use of voice, and eye, head and body position.

Imagine using a personal computer (PC) with a mouse and a keyboard. The application you are using has a graphical interface, with menus, icons and windows. In your interaction with this system you receive information primarily by sight, from what appears on the screen. However, you may also receive information by ear: for example, the computer may 'beep' at you if you make a mistake or to draw attention to something, or there may be a voice commentary in a multimedia presentation. Touch plays a part too in that you will feel the keys moving (also hearing the 'click') or the orientation of the mouse, which provides vital feedback about what you have done. You yourself send information to the computer using your hands, either by hitting keys or moving the mouse. Sight and hearing do not play a direct role in sending information in this example, although they may be used to receive information from a third source (for example, a book, or the words of another person) which is then transmitted to the computer.

In this section we will look at the main elements of such an interaction, first considering the role and limitations of the three primary senses and going on to consider motor control.

1.2.1 Vision

Human vision is a highly complex activity with a range of physical and perceptual limitations, yet it is the primary source of information for the average person. We can roughly divide visual perception into two stages: the physical reception of the stimulus from the outside world, and the processing and interpretation of that stimulus. On the one hand the physical properties of the eye and the visual system mean that there are certain things that cannot be seen by the human; on the other the interpretative capabilities of visual processing allow images to be constructed from incomplete information. We need to understand both stages as both influence what can and cannot be perceived visually by a human being, which in turn directly affects the way that we design computer systems. We will begin by looking at the eye as a physical receptor, and then go on to consider the processing involved in basic vision.

The human eye

Vision begins with light. The eye is a mechanism for receiving light and transforming it into electrical energy. Light is reflected from objects in the world and their image is focussed upside down on the back of the eye. The receptors in the eye transform it into electrical signals which are passed to the brain.

The eye has a number of important components (see Figure 1.1) which we will look at in more detail. The *cornea* and *lens* at the front of the eye focus the light into a sharp image on the back of the eye, the *retina*. The retina is light sensitive and contains two types of *photoreceptor*: *rods* and *cones*.

Rods are highly sensitive to light and therefore allow us to see under a low level of illumination. However, they are unable to resolve fine detail and are subject to light saturation. This is the reason for the temporary blindness we get when moving from a darkened room into sunlight: the rods have been active and are saturated by the sudden light. The cones do not operate either as they are suppressed by the rods. We are therefore temporarily unable to see at all. There are approximately 120 million rods per eye which are mainly situated towards the edges of the retina. Rods therefore dominate peripheral vision.

Cones are the second type of receptor in the eye. They are less sensitive to light than the rods and can therefore tolerate more light. There are three types of cone, each sensitive to a different wavelength of light. This allows color vision. The eye has approximately 6 million cones, mainly concentrated on the *fovea*, a small area of the retina on which images are fixated.

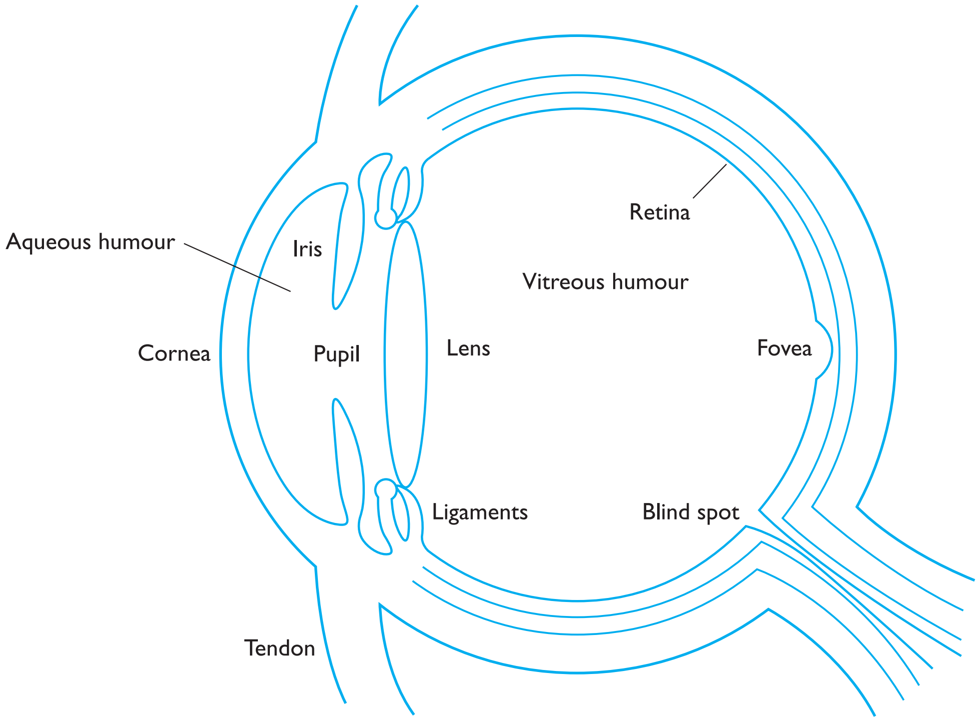


Figure 1.1 The human eye

Although the retina is mainly covered with photoreceptors there is one *blind spot* where the optic nerve enters the eye. The blind spot has no rods or cones, yet our visual system compensates for this so that in normal circumstances we are unaware of it.

The retina also has specialized nerve cells called *ganglion cells*. There are two types: X-cells, which are concentrated in the fovea and are responsible for the early detection of pattern; and Y-cells which are more widely distributed in the retina and are responsible for the early detection of movement. The distribution of these cells means that, while we may not be able to detect changes in pattern in peripheral vision, we can perceive movement.

Visual perception

Understanding the basic construction of the eye goes some way to explaining the physical mechanisms of vision but visual perception is more than this. The information received by the visual apparatus must be filtered and passed to processing elements which allow us to recognize coherent scenes, disambiguate relative distances and differentiate color. We will consider some of the capabilities and limitations of visual processing later, but first we will look a little more closely at how we perceive size and depth, brightness and color, each of which is crucial to the design of effective visual interfaces.

DESIGN FOCUS

Getting noticed

The extensive knowledge about the human visual system can be brought to bear in practical design. For example, our ability to read or distinguish falls off inversely as the distance from our point of focus increases. This is due to the fact that the cones are packed more densely towards the center of our visual field. You can see this in the following image. Fixate on the dot in the center. The letters on the left should all be equally readable, those on the right all equally harder.

A B C D E F • H I J K

This loss of discrimination sets limits on the amount that can be seen or read without moving one's eyes. A user concentrating on the middle of the screen cannot be expected to read help text on the bottom line.

However, although our ability to discriminate static text diminishes, the rods, which are concentrated more in the outer parts of our visual field, are very sensitive to changes; hence we see movement well at the edge of our vision. So if you want a user to see an error message at the bottom of the screen it had better be flashing! On the other hand clever moving icons, however impressive they are, will be distracting even when the user is not looking directly at them.

Perceiving size and depth Imagine you are standing on a hilltop. Beside you on the summit you can see rocks, sheep and a small tree. On the hillside is a farmhouse with outbuildings and farm vehicles. Someone is on the track, walking toward the summit. Below in the valley is a small market town.

Even in describing such a scene the notions of size and distance predominate. Our visual system is easily able to interpret the images which it receives to take account of these things. We can identify similar objects regardless of the fact that they appear to us to be of vastly different sizes. In fact, we can use this information to judge distances.

So how does the eye perceive size, depth and relative distances? To understand this we must consider how the image appears on the retina. As we noted in the previous section, reflected light from the object forms an upside-down image on the retina. The size of that image is specified as a *visual angle*. Figure 1.2 illustrates how the visual angle is calculated.

If we were to draw a line from the top of the object to a central point on the front of the eye and a second line from the bottom of the object to the same point, the visual angle of the object is the angle between these two lines. Visual angle is affected by both the size of the object and its distance from the eye. Therefore if two objects are at the same distance, the larger one will have the larger visual angle. Similarly, if two objects of the same size are placed at different distances from the eye, the

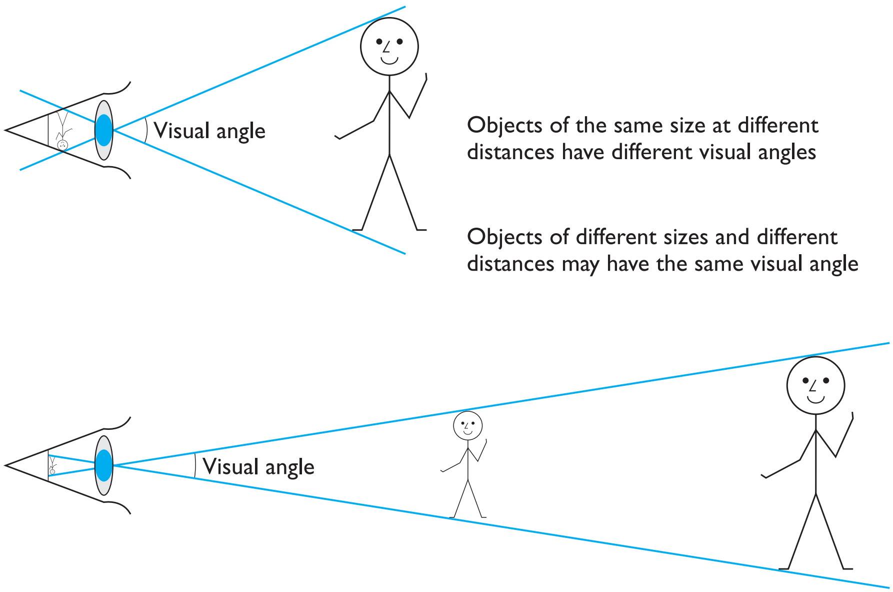


Figure 1.2 Visual angle

furthest one will have the smaller visual angle. The visual angle indicates how much of the field of view is taken by the object. The visual angle measurement is given in either degrees or *minutes of arc*, where 1 degree is equivalent to 60 minutes of arc, and 1 minute of arc to 60 seconds of arc.

So how does an object's visual angle affect our perception of its size? First, if the visual angle of an object is too small we will be unable to perceive it at all. *Visual acuity* is the ability of a person to perceive fine detail. A number of measurements have been established to test visual acuity, most of which are included in standard eye tests. For example, a person with normal vision can detect a single line if it has a visual angle of 0.5 seconds of arc. Spaces between lines can be detected at 30 seconds to 1 minute of visual arc. These represent the limits of human visual acuity.

Assuming that we can perceive the object, does its visual angle affect our perception of its size? Given that the visual angle of an object is reduced as it gets further away, we might expect that we would perceive the object as smaller. In fact, our perception of an object's size remains constant even if its visual angle changes. So a person's height is perceived as constant even if they move further from you. This is the *law of size constancy*, and it indicates that our perception of size relies on factors other than the visual angle.

One of these factors is our perception of depth. If we return to the hilltop scene there are a number of *cues* which we can use to determine the relative positions and distances of the objects which we see. If objects overlap, the object which is partially covered is perceived to be in the background, and therefore further away. Similarly, the size and height of the object in our field of view provides a cue to its distance.

A third cue is familiarity: if we expect an object to be of a certain size then we can judge its distance accordingly. This has been exploited for humour in advertising: one advertisement for beer shows a man walking away from a bottle in the foreground. As he walks, he bumps into the bottle, which is in fact a giant one in the background!

Perceiving brightness A second aspect of visual perception is the perception of *brightness*. Brightness is in fact a subjective reaction to levels of light. It is affected by *luminance* which is the amount of light emitted by an object. The luminance of an object is dependent on the amount of light falling on the object's surface and its reflective properties. Luminance is a physical characteristic and can be measured using a *photometer*. *Contrast* is related to luminance: it is a function of the luminance of an object and the luminance of its background.

Although brightness is a subjective response, it can be described in terms of the amount of luminance that gives a *just noticeable difference* in brightness. However, the visual system itself also compensates for changes in brightness. In dim lighting, the rods predominate vision. Since there are fewer rods on the fovea, objects in low lighting can be seen less easily when fixated upon, and are more visible in peripheral vision. In normal lighting, the cones take over.

Visual acuity increases with increased luminance. This may be an argument for using high display luminance. However, as luminance increases, *flicker* also increases. The eye will perceive a light switched on and off rapidly as constantly on. But if the speed of switching is less than 50 Hz then the light is perceived to flicker. In high luminance flicker can be perceived at over 50 Hz. Flicker is also more noticeable in peripheral vision. This means that the larger the display (and consequently the more peripheral vision that it occupies), the more it will appear to flicker.

Perceiving color A third factor that we need to consider is perception of color. Color is usually regarded as being made up of three components: *hue*, *intensity* and *saturation*. Hue is determined by the spectral wavelength of the light. Blues have short wavelengths, greens medium and reds long. Approximately 150 different hues can be discriminated by the average person. Intensity is the brightness of the color, and saturation is the amount of whiteness in the color. By varying these two, we can perceive in the region of 7 million different colors. However, the number of colors that can be identified by an individual without training is far fewer (in the region of 10).

The eye perceives color because the cones are sensitive to light of different wavelengths. There are three different types of cone, each sensitive to a different color (blue, green and red). Color vision is best in the fovea, and worst at the periphery where rods predominate. It should also be noted that only 3–4% of the fovea is occupied by cones which are sensitive to blue light, making blue acuity lower.

Finally, we should remember that around 8% of males and 1% of females suffer from color blindness, most commonly being unable to discriminate between red and green.

The capabilities and limitations of visual processing

In considering the way in which we perceive images we have already encountered some of the capabilities and limitations of the human visual processing system. However, we have concentrated largely on low-level perception. Visual processing involves the transformation and interpretation of a complete image, from the light that is thrown onto the retina. As we have already noted, our expectations affect the way an image is perceived. For example, if we know that an object is a particular size, we will perceive it as that size no matter how far it is from us.

Visual processing compensates for the movement of the image on the retina which occurs as we move around and as the object which we see moves. Although the retinal image is moving, the image that we perceive is stable. Similarly, color and brightness of objects are perceived as constant, in spite of changes in luminance.

This ability to interpret and exploit our expectations can be used to resolve ambiguity. For example, consider the image shown in Figure 1.3. What do you perceive? Now consider Figure 1.4 and Figure 1.5. The context in which the object appears

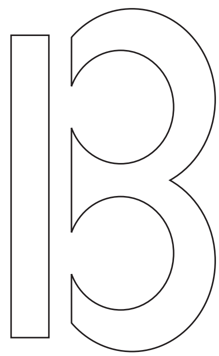


Figure 1.3 An ambiguous shape?

Figure 1.4 ABC

Figure 1.5 12 13 14

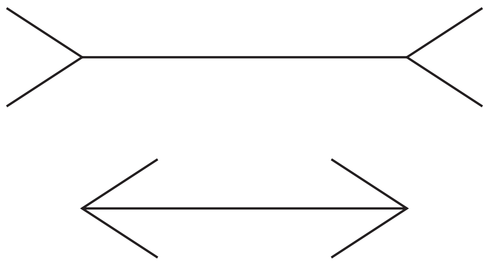


Figure 1.6 The Muller–Lyer illusion – which line is longer?

allows our expectations to clearly disambiguate the interpretation of the object, as either a B or a 13.

However, it can also create optical illusions. For example, consider Figure 1.6. Which line is longer? Most people when presented with this will say that the top line is longer than the bottom. In fact, the two lines are the same length. This may be due to a false application of the law of size constancy: the top line appears like a concave edge, the bottom like a convex edge. The former therefore seems further away than the latter and is therefore scaled to appear larger. A similar illusion is the Ponzo illusion (Figure 1.7). Here the top line appears longer, owing to the distance effect, although both lines are the same length. These illusions demonstrate that our perception of size is not completely reliable.

Another illusion created by our expectations compensating an image is the proofreading illusion. Read the text in Figure 1.8 quickly. What does it say? Most people reading this rapidly will read it correctly, although closer inspection shows that the word ‘the’ is repeated in the second and third line.

These are just a few examples of how the visual system compensates, and sometimes overcompensates, to allow us to perceive the world around us.

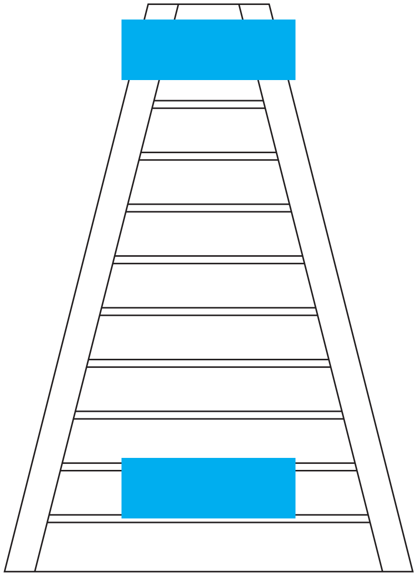


Figure 1.7 The Ponzo illusion – are these the same size?

The quick brown fox jumps over the the lazy dog.

Figure 1.8 Is this text correct?

Design Focus

Where's the middle?

Optical illusions highlight the differences between the way things are and the way we perceive them – and in interface design we need to be aware that we will not always perceive things exactly as they are. The way that objects are composed together will affect the way we perceive them, and we do not perceive geometric shapes exactly as they are drawn. For example, we tend to magnify horizontal lines and reduce vertical. So a square needs to be slightly increased in height to appear square and lines will appear thicker if horizontal rather than vertical.

Optical illusions also affect page symmetry. We tend to see the center of a page as being a little above the actual center – so if a page is arranged symmetrically around the actual center, we will see it as too low down. In graphic design this is known as the *optical center* – and bottom page margins tend to be increased by 50% to compensate.

Reading

So far we have concentrated on the perception of images in general. However, the perception and processing of text is a special case that is important to interface design, which invariably requires some textual display. We will therefore end this section by looking at *reading*. There are several stages in the reading process. First, the visual pattern of the word on the page is perceived. It is then decoded with reference to an internal representation of language. The final stages of language processing include syntactic and semantic analysis and operate on phrases or sentences.

We are most concerned with the first two stages of this process and how they influence interface design. During reading, the eye makes jerky movements called *saccades* followed by fixations. Perception occurs during the fixation periods, which account for approximately 94% of the time elapsed. The eye moves backwards over the text as well as forwards, in what are known as *regressions*. If the text is complex there will be more regressions.

Adults read approximately 250 words a minute. It is unlikely that words are scanned serially, character by character, since experiments have shown that words can be recognized as quickly as single characters. Instead, familiar words are recognized using word shape. This means that removing the word shape clues (for example, by capitalizing words) is detrimental to reading speed and accuracy.

The speed at which text can be read is a measure of its legibility. Experiments have shown that standard font sizes of 9 to 12 points are equally legible, given proportional spacing between lines [346]. Similarly line lengths of between 2.3 and 5.2 inches (58 and 132 mm) are equally legible. However, there is evidence that reading from a computer screen is slower than from a book [244]. This is thought to be due to a number of factors including a longer line length, fewer words to a page, orientation and the familiarity of the medium of the page. These factors can of course be reduced by careful design of textual interfaces.

A final word about the use of contrast in visual display: a negative contrast (dark characters on a light screen) provides higher luminance and, therefore, increased acuity, than a positive contrast. This will in turn increase legibility. However, it will also be more prone to flicker. Experimental evidence suggests that in practice negative contrast displays are preferred and result in more accurate performance [30].

1.2.2 Hearing

The sense of hearing is often considered secondary to sight, but we tend to underestimate the amount of information that we receive through our ears. Close your eyes for a moment and listen. What sounds can you hear? Where are they coming from? What is making them? As I sit at my desk I can hear cars passing on the road outside, machinery working on a site nearby, the drone of a plane overhead and bird song. But I can also tell *where* the sounds are coming from, and estimate how far away they are. So from the sounds I hear I can tell that a car is passing on a particular road near my house, and which direction it is traveling in. I know that building work is in progress in a particular location, and that a certain type of bird is perched in the tree in my garden.

The auditory system can convey a lot of information about our environment. But how does it work?

The human ear

Just as vision begins with light, hearing begins with vibrations in the air or *sound waves*. The ear receives these vibrations and transmits them, through various stages, to the auditory nerves. The ear comprises three sections, commonly known as the *outer ear*, *middle ear* and *inner ear*.

The outer ear is the visible part of the ear. It has two parts: the *pinna*, which is the structure that is attached to the sides of the head, and the *auditory canal*, along which sound waves are passed to the middle ear. The outer ear serves two purposes. First, it protects the sensitive middle ear from damage. The auditory canal contains wax which prevents dust, dirt and over-inquisitive insects reaching the middle ear. It also maintains the middle ear at a constant temperature. Secondly, the pinna and auditory canal serve to amplify some sounds.

The middle ear is a small cavity connected to the outer ear by the *tympanic membrane*, or ear drum, and to the inner ear by the *cochlea*. Within the cavity are the *ossicles*, the smallest bones in the body. Sound waves pass along the auditory canal and vibrate the ear drum which in turn vibrates the ossicles, which transmit the vibrations to the cochlea, and so into the inner ear. This 'relay' is required because, unlike the air-filled outer and middle ears, the inner ear is filled with a denser cochlean liquid. If passed directly from the air to the liquid, the transmission of the sound waves would be poor. By transmitting them via the ossicles the sound waves are concentrated and amplified.

The waves are passed into the liquid-filled cochlea in the inner ear. Within the cochlea are delicate hair cells or *cilia* that bend because of the vibrations in the cochlean liquid and release a chemical transmitter which causes impulses in the auditory nerve.

Processing sound

As we have seen, sound is changes or vibrations in air pressure. It has a number of characteristics which we can differentiate. *Pitch* is the frequency of the sound. A low frequency produces a low pitch, a high frequency, a high pitch. *Loudness* is proportional to the amplitude of the sound; the frequency remains constant. *Timbre* relates to the type of the sound: sounds may have the same pitch and loudness but be made by different instruments and so vary in timbre. We can also identify a sound's location, since the two ears receive slightly different sounds, owing to the time difference between the sound reaching the two ears and the reduction in intensity caused by the sound waves reflecting from the head.

The human ear can hear frequencies from about 20 Hz to 15 kHz. It can distinguish frequency changes of less than 1.5 Hz at low frequencies but is less accurate at high frequencies. Different frequencies trigger activity in neurons in different parts of the auditory system, and cause different rates of firing of nerve impulses.

The auditory system performs some filtering of the sounds received, allowing us to ignore background noise and concentrate on important information. We are selective in our hearing, as illustrated by the *cocktail party effect*, where we can pick out our name spoken across a crowded noisy room. However, if sounds are too loud, or frequencies too similar, we are unable to differentiate sound.

As we have seen, sound can convey a remarkable amount of information. It is rarely used to its potential in interface design, usually being confined to warning sounds and notifications. The exception is multimedia, which may include music, voice commentary and sound effects. However, the ear can differentiate quite subtle sound changes and can recognize familiar sounds without concentrating attention on the sound source. This suggests that sound could be used more extensively in interface design, to convey information about the system state, for example. This is discussed in more detail in Chapter 10.

Worked exercise *Suggest ideas for an interface which uses the properties of sound effectively.*

Answer You might approach this exercise by considering how sound could be added to an application with which you are familiar. Use your imagination. This is also a good subject for a literature survey (starting with the references in Chapter 10).

Speech sounds can obviously be used to convey information. This is useful not only for the visually impaired but also for any application where the user's attention has to be divided (for example, power plant control, flight control, etc.). Uses of non-speech sounds include the following:

- Attention – to attract the user's attention to a critical situation or to the end of a process, for example.

- Status information – continuous background sounds can be used to convey status information. For example, monitoring the progress of a process (without the need for visual attention).
- Confirmation – a sound associated with an action to confirm that the action has been carried out. For example, associating a sound with deleting a file.
- Navigation – using changing sound to indicate where the user is in a system. For example, what about sound to support navigation in hypertext?

1.2.3 Touch

The third and last of the senses that we will consider is touch or *haptic perception*. Although this sense is often viewed as less important than sight or hearing, imagine life without it. Touch provides us with vital information about our environment. It tells us when we touch something hot or cold, and can therefore act as a warning. It also provides us with feedback when we attempt to lift an object, for example. Consider the act of picking up a glass of water. If we could only see the glass and not feel when our hand made contact with it or feel its shape, the speed and accuracy of the action would be reduced. This is the experience of users of certain *virtual reality* games: they can see the computer-generated objects which they need to manipulate but they have no physical sensation of touching them. Watching such users can be an informative and amusing experience! Touch is therefore an important means of feedback, and this is no less so in using computer systems. Feeling buttons depress is an important part of the task of pressing the button. Also, we should be aware that, although for the average person, haptic perception is a secondary source of information, for those whose other senses are impaired, it may be vitally important. For such users, interfaces such as braille may be the primary source of information in the interaction. We should not therefore underestimate the importance of touch.

The apparatus of touch differs from that of sight and hearing in that it is not localized. We receive stimuli through the skin. The skin contains three types of sensory receptor: *thermoreceptors* respond to heat and cold, *nociceptors* respond to intense pressure, heat and pain, and *mechanoreceptors* respond to pressure. It is the last of these that we are concerned with in relation to human–computer interaction.

There are two kinds of mechanoreceptor, which respond to different types of pressure. *Rapidly adapting mechanoreceptors* respond to immediate pressure as the skin is indented. These receptors also react more quickly with increased pressure. However, they stop responding if continuous pressure is applied. *Slowly adapting mechanoreceptors* respond to continuously applied pressure.

Although the whole of the body contains such receptors, some areas have greater sensitivity or acuity than others. It is possible to measure the acuity of different areas of the body using the *two-point threshold test*. Take two pencils, held so their tips are about 12 mm apart. Touch the points to your thumb and see if you can feel two points. If you cannot, move the points a little further apart. When you can feel two points, measure the distance between them. The greater the distance, the lower the sensitivity. You can repeat this test on different parts of your body. You should find that the measure on the forearm is around 10 times that of the finger or thumb. The fingers and thumbs have the highest acuity.

A second aspect of haptic perception is *kinesthesis*: awareness of the position of the body and limbs. This is due to receptors in the joints. Again there are three types: rapidly adapting, which respond when a limb is moved in a particular direction; slowly adapting, which respond to both movement and static position; and positional receptors, which only respond when a limb is in a static position. This perception affects both comfort and performance. For example, for a touch typist, awareness of the relative positions of the fingers and feedback from the keyboard are very important.

Handling the goods

E-commerce has become very successful in some areas of sales, such as travel services, books and CDs, and food. However, in some retail areas, such as clothes shopping, e-commerce has been less successful. Why?

When buying train and airline tickets and, to some extent, books and food, the experience of shopping is less important than the convenience. So, as long as we know what we want, we are happy to shop online. With clothes, the experience of shopping is far more important. We need to be able to handle the goods, feel the texture of the material, check the weight to test quality. Even if we know that something will fit us we still want to be able to handle it before buying.

Research into haptic interaction (see Chapter 2 and Chapter 10) is looking at ways of solving this problem. By using special force feedback and tactile hardware, users are able to feel surfaces and shape. For example, a demonstration environment called TouchCity allows people to walk around a virtual shopping mall, pick up products and feel their texture and weight. A key problem with the commercial use of such an application, however, is that the haptic experience requires expensive hardware not yet available to the average e-shopper. However, in future, such immersive e-commerce experiences are likely to be the norm. (See www.novint.com/)

1.2.4 Movement

Before leaving this section on the human's input–output channels, we need to consider motor control and how the way we move affects our interaction with computers. A simple action such as hitting a button in response to a question involves a number of processing stages. The stimulus (of the question) is received through the sensory receptors and transmitted to the brain. The question is processed and a valid response generated. The brain then tells the appropriate muscles to respond. Each of these stages takes time, which can be roughly divided into reaction time and movement time.

Movement time is dependent largely on the physical characteristics of the subjects: their age and fitness, for example. Reaction time varies according to the sensory channel through which the stimulus is received. A person can react to an auditory signal in approximately 150 ms, to a visual signal in 200 ms and to pain in 700 ms. However, a combined signal will result in the quickest response. Factors such as skill or practice can reduce reaction time, and fatigue can increase it.

A second measure of motor skill is accuracy. One question that we should ask is whether speed of reaction results in reduced accuracy. This is dependent on the task and the user. In some cases, requiring increased reaction time reduces accuracy. This is the premise behind many arcade and video games where less skilled users fail at levels of play that require faster responses. However, for skilled operators this is not necessarily the case. Studies of keyboard operators have shown that, although the faster operators were up to twice as fast as the others, the slower ones made 10 times the errors.

Speed and accuracy of movement are important considerations in the design of interactive systems, primarily in terms of the time taken to move to a particular target on a screen. The target may be a button, a menu item or an icon, for example. The time taken to hit a target is a function of the size of the target and the distance that has to be moved. This is formalized in *Fitts' law* [135]. There are many variations of this formula, which have varying constants, but they are all very similar. One common form is

$$\text{Movement time} = a + b \log_2(\text{distance/size} + 1)$$

where a and b are empirically determined constants.

This affects the type of target we design. Since users will find it more difficult to manipulate small objects, targets should generally be as large as possible and the distance to be moved as small as possible. This has led to suggestions that pie-chart-shaped menus are preferable to lists since all options are equidistant. However, the trade-off is increased use of screen estate, so the choice may not be so simple. If lists are used, the most frequently used options can be placed closest to the user's start point (for example, at the top of the menu). The implications of Fitts' law in design are discussed in more detail in Chapter 12.

1.3 HUMAN MEMORY

Have you ever played the memory game? The idea is that each player has to recount a list of objects and add one more to the end. There are many variations but the objects are all loosely related: 'I went to the market and bought a lemon, some oranges, bacon . . .' or 'I went to the zoo and saw monkeys, and lions, and tigers . . .' and so on. As the list grows objects are missed out or recalled in the wrong order and so people are eliminated from the game. The winner is the person remaining at the end. Such games rely on our ability to store and retrieve information, even seemingly arbitrary items. This is the job of our memory system.

Indeed, much of our everyday activity relies on memory. As well as storing all our factual knowledge, our memory contains our knowledge of actions or procedures.

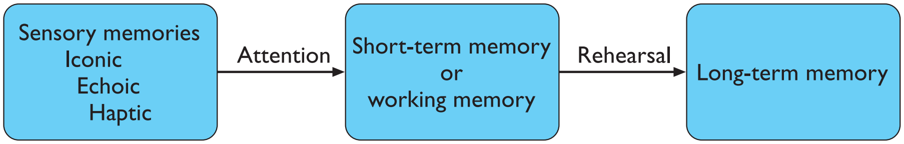


Figure 1.9 A model of the structure of memory

It allows us to repeat actions, to use language, and to use new information received via our senses. It also gives us our sense of identity, by preserving information from our past experiences.

But how does our memory work? How do we remember arbitrary lists such as those generated in the memory game? Why do some people remember more easily than others? And what happens when we forget?

In order to answer questions such as these, we need to understand some of the capabilities and limitations of human memory. Memory is the second part of our model of the human as an information-processing system. However, as we noted earlier, such a division is simplistic since, as we shall see, memory is associated with each level of processing. Bearing this in mind, we will consider the way in which memory is structured and the activities that take place within the system.

It is generally agreed that there are three types of memory or memory function: *sensory buffers*, *short-term memory* or *working memory*, and *long-term memory*. There is some disagreement as to whether these are three separate systems or different functions of the same system. We will not concern ourselves here with the details of this debate, which is discussed in detail by Baddeley [21], but will indicate the evidence used by both sides as we go along. For our purposes, it is sufficient to note three separate types of memory. These memories interact, with information being processed and passed between memory stores, as shown in Figure 1.9.

1.3.1 Sensory memory

The sensory memories act as buffers for stimuli received through the senses. A sensory memory exists for each sensory channel: *iconic memory* for visual stimuli, *echoic memory* for aural stimuli and *haptic memory* for touch. These memories are constantly overwritten by new information coming in on these channels.

We can demonstrate the existence of iconic memory by moving a finger in front of the eye. Can you see it in more than one place at once? This indicates a persistence of the image after the stimulus has been removed. A similar effect is noticed most vividly at firework displays where moving sparklers leave a persistent image. Information remains in iconic memory very briefly, in the order of 0.5 seconds.

Similarly, the existence of echoic memory is evidenced by our ability to ascertain the direction from which a sound originates. This is due to information being received by both ears. However, since this information is received at different times, we must store the stimulus in the meantime. Echoic memory allows brief 'play-back' of information. Have you ever had someone ask you a question when you are reading? You ask them to repeat the question, only to realize that you know what was asked after all. This experience, too, is evidence of the existence of echoic memory.

Information is passed from sensory memory into short-term memory by attention, thereby filtering the stimuli to only those which are of interest at a given time. Attention is the concentration of the mind on one out of a number of competing stimuli or thoughts. It is clear that we are able to focus our attention selectively, choosing to attend to one thing rather than another. This is due to the limited capacity of our sensory and mental processes. If we did not selectively attend to the stimuli coming into our senses, we would be overloaded. We can choose which stimuli to attend to, and this choice is governed to an extent by our *arousal*, our level of interest or need. This explains the cocktail party phenomenon mentioned earlier: we can attend to one conversation over the background noise, but we may choose to switch our attention to a conversation across the room if we hear our name mentioned. Information received by sensory memories is quickly passed into a more permanent memory store, or overwritten and lost.

1.3.2 Short-term memory

Short-term memory or working memory acts as a 'scratch-pad' for temporary recall of information. It is used to store information which is only required fleetingly. For example, calculate the multiplication 35×6 in your head. The chances are that you will have done this calculation in stages, perhaps 5×6 and then 30×6 and added the results; or you may have used the fact that $6 = 2 \times 3$ and calculated $2 \times 35 = 70$ followed by 3×70. To perform calculations such as this we need to store the intermediate stages for use later. Or consider reading. In order to comprehend this sentence you need to hold in your mind the beginning of the sentence as you read the rest. Both of these tasks use short-term memory.

Short-term memory can be accessed rapidly, in the order of 70 ms. However, it also decays rapidly, meaning that information can only be held there temporarily, in the order of 200 ms.

Short-term memory also has a limited capacity. There are two basic methods for measuring memory capacity. The first involves determining the length of a sequence which can be remembered in order. The second allows items to be freely recalled in any order. Using the first measure, the average person can remember 7 ± 2 digits. This was established in experiments by Miller [234]. Try it. Look at the following number sequence:

265397620853

Now write down as much of the sequence as you can remember. Did you get it all right? If not, how many digits could you remember? If you remembered between five and nine digits your *digit span* is average.

Now try the following sequence:

44 113 245 8920

Did you recall that more easily? Here the digits are grouped or *chunked*. A generalization of the 7 ± 2 rule is that we can remember 7 ± 2 *chunks* of information. Therefore chunking information can increase the short-term memory capacity. The limited capacity of short-term memory produces a subconscious desire to create chunks, and so optimize the use of the memory. The successful formation of a chunk is known as *closure*. This process can be generalized to account for the desire to complete or close tasks held in short-term memory. If a subject fails to do this or is prevented from doing so by interference, the subject is liable to lose track of what she is doing and make consequent errors.

Design Focus

Cashing in

Closure gives you a nice 'done it' when we complete some part of a task. At this point our minds have a tendency to flush short-term memory in order to get on with the next job. Early automatic teller machines (ATMs) gave the customer money before returning their bank card. On receiving the money the customer would reach closure and hence often forget to take the card. Modern ATMs return the card first!

The sequence of chunks given above also makes use of pattern abstraction: it is written in the form of a UK telephone number which makes it easier to remember. We may even recognize the first sets of digits as the international code for the UK and the dialing code for Leeds – chunks of information. Patterns can be useful as aids to memory. For example, most people would have difficulty remembering the following sequence of chunks:

HEC ATR ANU PTH ETR EET

However, if you notice that by moving the last character to the first position, you get the statement 'the cat ran up the tree', the sequence is easy to recall.

In experiments where subjects were able to recall words freely, evidence shows that recall of the last words presented is better than recall of those in the middle [296]. This is known as the *recency effect*. However, if the subject is asked to perform another task between presentation and recall (for example, counting backwards) the recency effect is eliminated. The recall of the other words is unaffected. This suggests that short-term memory recall is damaged by interference of other information. However, the fact that this interference does not affect recall of earlier items provides some evidence for the existence of separate long-term and short-term memories. The early items are held in a long-term store which is unaffected by the recency effect.

Interference does not necessarily impair recall in short-term memory. Baddeley asked subjects to remember six-digit numbers and attend to sentence processing at the same time [21]. They were asked to answer questions on sentences, such as 'A precedes B: AB is true or false?'. Surprisingly, this did not result in interference, suggesting that in fact short-term memory is not a unitary system but is made up of a number of components, including a visual channel and an articulatory channel. The task of sentence processing used the visual channel, while the task of remembering digits used the articulatory channel, so interference only occurs if tasks utilize the same channel.

These findings led Baddeley to propose a model of working memory that incorporated a number of elements together with a central processing executive. This is illustrated in Figure 1.10.

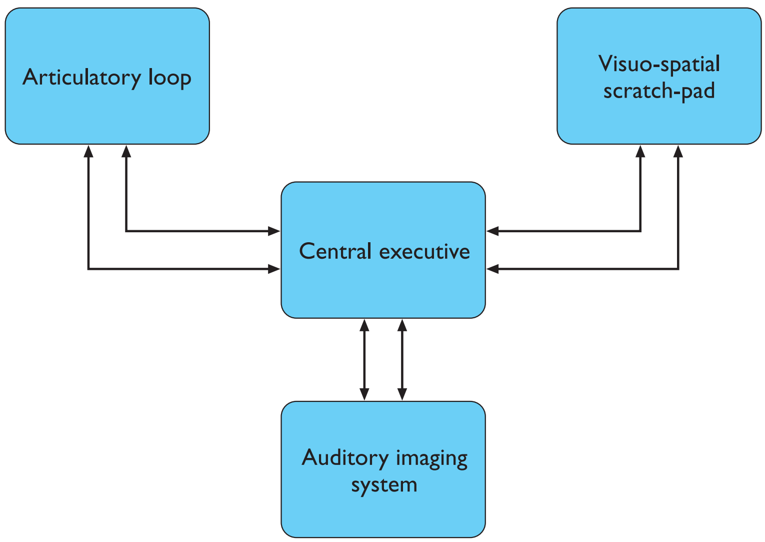


Figure 1.10 A more detailed model of short-term memory

Design Focus

7 ± 2 revisited

When we looked at short-term memory, we noted the general rule that people can hold 7 ± 2 items or chunks of information in short-term memory. It is a principle that people tend to remember but it can be misapplied. For example, it is often suggested that this means that lists, menus and other groups of items should be designed to be no more than 7 items long. But use of menus and lists of course has little to do with short-term memory – they are available in the environment as cues and so do not need to be remembered.

On the other hand the 7 ± 2 rule would apply in command line interfaces. Imagine a scenario where a UNIX user looks up a command in the manual. Perhaps the command has a number of parameters of options, to be applied in a particular order, and it is going to be applied to several files that have long path names. The user then has to hold the command, its parameters and the file path names in short-term memory while he types them in. Here we could say that the task may cause problems if the number of items or chunks in the command line string is more than 7.

1.3.3 Long-term memory

If short-term memory is our working memory or 'scratch-pad', long-term memory is our main resource. Here we store factual information, experiential knowledge, procedural rules of behavior – in fact, everything that we 'know'. It differs from short-term memory in a number of significant ways. First, it has a huge, if not unlimited, capacity. Secondly, it has a relatively slow access time of approximately a tenth of a second. Thirdly, forgetting occurs more slowly in long-term memory, if at all. These distinctions provide further evidence of a memory structure with several parts.

Long-term memory is intended for the long-term storage of information. Information is placed there from working memory through rehearsal. Unlike working memory there is little decay: long-term recall after minutes is the same as that after hours or days.

Long-term memory structure

There are two types of long-term memory: *episodic memory* and *semantic memory*. Episodic memory represents our memory of events and experiences in a serial form. It is from this memory that we can reconstruct the actual events that took place at a given point in our lives. Semantic memory, on the other hand, is a structured record of facts, concepts and skills that we have acquired. The information in semantic memory is derived from that in our episodic memory, such that we can learn new facts or concepts from our experiences.

Semantic memory is structured in some way to allow access to information, representation of relationships between pieces of information, and inference. One model for the way in which semantic memory is structured is as a network. Items are

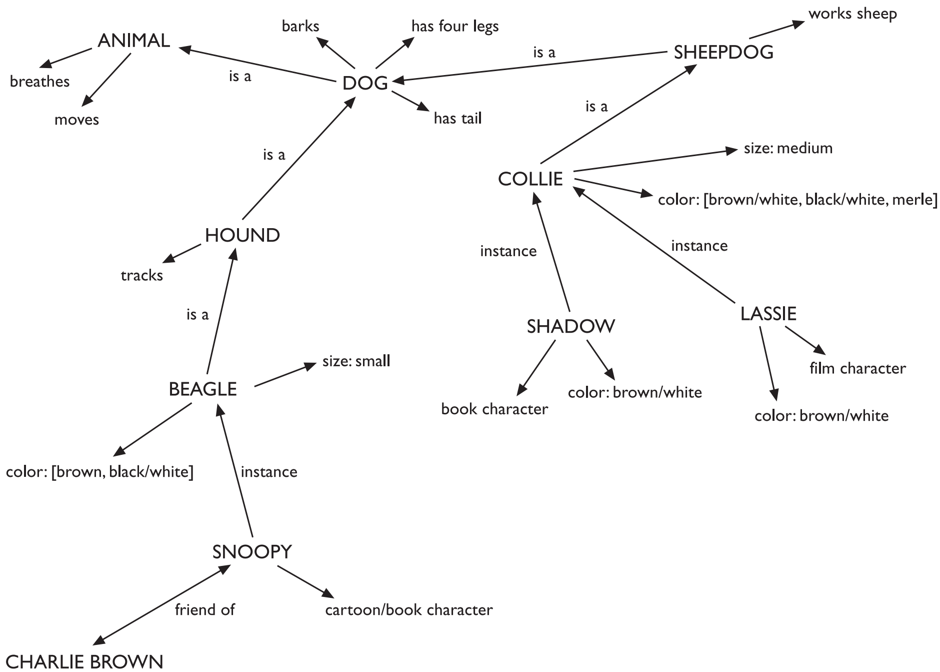


Figure 1.11 Long-term memory may store information in a semantic network

associated to each other in classes, and may inherit attributes from parent classes. This model is known as a *semantic network*. As an example, our knowledge about dogs may be stored in a network such as that shown in Figure 1.11.

Specific breed attributes may be stored with each given breed, yet general dog information is stored at a higher level. This allows us to generalize about specific cases. For instance, we may not have been told that the sheepdog Shadow has four legs and a tail, but we can infer this information from our general knowledge about sheepdogs and dogs in general. Note also that there are connections within the network which link into other domains of knowledge, for example cartoon characters. This illustrates how our knowledge is organized by association.

The viability of semantic networks as a model of memory organization has been demonstrated by Collins and Quillian [74]. Subjects were asked questions about different properties of related objects and their reaction times were measured. The types of question asked (taking examples from our own network) were 'Can a collie breathe?', 'Is a beagle a hound?' and 'Does a hound track?' In spite of the fact that the answers to such questions may seem obvious, subjects took longer to answer questions such as 'Can a collie breathe?' than ones such as 'Does a hound track?' The reason for this, it is suggested, is that in the former case subjects had to search further through the memory hierarchy to find the answer, since information is stored at its most abstract level.

A number of other memory structures have been proposed to explain how we represent and store different types of knowledge. Each of these represents a different

DOG

Fixed
- legs: 4

Default
- diet: carnivorous
- sound: bark

Variable
- size:
- color:

COLLIE

Fixed
- breed of: DOG
- type: sheepdog

Default
- size: 65 cm

Variable
- color:

Figure 1.12 A frame-based representation of knowledge

aspect of knowledge and, as such, the models can be viewed as complementary rather than mutually exclusive. Semantic networks represent the associations and relationships between single items in memory. However, they do not allow us to model the representation of more complex objects or events, which are perhaps composed of a number of items or activities. Structured representations such as *frames* and *scripts* organize information into data structures. *Slots* in these structures allow attribute values to be added. Frame slots may contain default, fixed or variable information. A frame is instantiated when the slots are filled with appropriate values. Frames and scripts can be linked together in networks to represent hierarchical structured knowledge.

Returning to the 'dog' domain, a frame-based representation of the knowledge may look something like Figure 1.12. The fixed slots are those for which the attribute value is set, default slots represent the usual attribute value, although this may be overridden in particular instantiations (for example, the Basenji does not bark), and variable slots can be filled with particular values in a given instance. Slots can also contain procedural knowledge. Actions or operations can be associated with a slot and performed, for example, whenever the value of the slot is changed.

Frames extend semantic nets to include structured, hierarchical information. They represent knowledge items in a way which makes explicit the relative importance of each piece of information.

Scripts attempt to model the representation of stereotypical knowledge about situations. Consider the following sentence:

> John took his dog to the surgery. After seeing the vet, he left.

From our knowledge of the activities of dog owners and vets, we may fill in a substantial amount of detail. The animal was ill. The vet examined and treated the animal. John paid for the treatment before leaving. We are less likely to assume the alternative reading of the sentence, that John took an instant dislike to the vet on sight and did not stay long enough to talk to him!

Script for a visit to the vet

Entry conditions:	*dog ill* *vet open* *owner has money*	Roles:	*vet examines* *diagnoses* *treats* *owner brings dog in* *pays* *takes dog out*
Result:	*dog better* *owner poorer* *vet richer*	Scenes:	*arriving at reception* *waiting in room* *examination* *paying*
Props:	*examination table* *medicine* *instruments*	Tracks:	*dog needs medicine* *dog needs operation*

Figure 1.13 A script for visiting the vet

A script represents this default or stereotypical information, allowing us to interpret partial descriptions or cues fully. A script comprises a number of elements, which, like slots, can be filled with appropriate information:

Entry conditions Conditions that must be satisfied for the script to be activated.

Result Conditions that will be true after the script is terminated.

Props Objects involved in the events described in the script.

Roles Actions performed by particular participants.

Scenes The sequences of events that occur.

Tracks A variation on the general pattern representing an alternative scenario.

An example script for going to the vet is shown in Figure 1.13.

A final type of knowledge representation which we hold in memory is the representation of procedural knowledge, our knowledge of how to do something. A common model for this is the production system. Condition–action rules are stored in long-term memory. Information coming into short-term memory can match a condition in one of these rules and result in the action being executed. For example, a pair of production rules might be

IF dog is wagging tail
THEN pat dog

IF dog is growling
THEN run away

If we then meet a growling dog, the condition in the second rule is matched, and we respond by turning tail and running. (Not to be recommended by the way!)

Long-term memory processes

So much for the structure of memory, but what about the processes which it uses? There are three main activities related to long-term memory: storage or remembering of information, forgetting and information retrieval. We shall consider each of these in turn.

First, how does information get into long-term memory and how can we improve this process? Information from short-term memory is stored in long-term memory by rehearsal. The repeated exposure to a stimulus or the rehearsal of a piece of information transfers it into long-term memory.

This process can be optimized in a number of ways. Ebbinghaus performed numerous experiments on memory, using himself as a subject [117]. In these experiments he tested his ability to learn and repeat nonsense syllables, comparing his recall minutes, hours and days after the learning process. He discovered that the amount learned was directly proportional to the amount of time spent learning. This is known as the *total time hypothesis*. However, experiments by Baddeley and others suggest that learning time is most effective if it is distributed over time [22]. For example, in an experiment in which Post Office workers were taught to type, those whose training period was divided into weekly sessions of one hour performed better than those who spent two or four hours a week learning (although the former obviously took more weeks to complete their training). This is known as the *distribution of practice effect*.

However, repetition is not enough to learn information well. If information is not meaningful it is more difficult to remember. This is illustrated by the fact that it is more difficult to remember a set of words representing concepts than a set of words representing objects. Try it. First try to remember the words in list A and test yourself.

List A: Faith Age Cold Tenet Quiet Logic Idea Value Past Large

Now try list B.

List B: Boat Tree Cat Child Rug Plate Church Gun Flame Head

The second list was probably easier to remember than the first since you could visualize the objects in the second list.

Sentences are easier still to memorize. Bartlett performed experiments on remembering meaningful information (as opposed to meaningless such as Ebbinghaus used) [28]. In one such experiment he got subjects to learn a story about an unfamiliar culture and then retell it. He found that subjects would retell the story replacing unfamiliar words and concepts with words which were meaningful to them. Stories were effectively translated into the subject's own culture. This is related to the semantic structuring of long-term memory: if information is meaningful and familiar, it can be related to existing structures and more easily incorporated into memory.

Memorable or secure?

As online activities become more widespread, people are having to remember more and more access information, such as passwords and security checks. The average active internet user may have separate passwords and user names for several email accounts, mailing lists, e-shopping sites, e-banking, online auctions and more! Remembering these passwords is not easy.

From a security perspective it is important that passwords are random. Words and names are very easy to crack, hence the recommendation that passwords are frequently changed and constructed from random strings of letters and numbers. But in reality these are the hardest things for people to commit to memory. Hence many people will use the same password for all their online activities (rarely if ever changing it) and will choose a word or a name that is easy for them to remember, in spite of the obviously increased security risks. Security here is in conflict with memorability!

A solution to this is to construct a nonsense password out of letters or numbers that will have meaning to you but will not make up a word in a dictionary (e.g. initials of names, numbers from significant dates or postcodes, and so on). Then what is remembered is the meaningful rule for constructing the password, and not a meaningless string of alphanumeric characters.

So if structure, familiarity and concreteness help us in learning information, what causes us to lose this information, to forget? There are two main theories of forgetting: *decay* and *interference*. The first theory suggests that the information held in long-term memory may eventually be forgotten. Ebbinghaus concluded from his experiments with nonsense syllables that information in memory decayed logarithmically, that is that it was lost rapidly to begin with, and then more slowly. *Jost's law*, which follows from this, states that if two memory traces are equally strong at a given time the older one will be more durable.

The second theory is that information is lost from memory through interference. If we acquire new information it causes the loss of old information. This is termed *retroactive interference*. A common example of this is the fact that if you change telephone numbers, learning your new number makes it more difficult to remember your old number. This is because the new association masks the old. However, sometimes the old memory trace breaks through and interferes with new information. This is called *proactive inhibition*. An example of this is when you find yourself driving to your old house rather than your new one.

Forgetting is also affected by emotional factors. In experiments, subjects given emotive words and non-emotive words found the former harder to remember in the short term but easier in the long term. Indeed, this observation tallies with our experience of selective memory. We tend to remember positive information rather than negative (hence nostalgia for the 'good old days'), and highly emotive events rather than mundane.

It is debatable whether we ever actually forget anything or whether it just becomes increasingly difficult to access certain items from memory. This question is in some ways moot since it is impossible to prove that we *do* forget: appearing to have forgotten something may just be caused by not being able to retrieve it! However, there is evidence to suggest that we may not lose information completely from long-term memory. First, proactive inhibition demonstrates the recovery of old information even after it has been ‘lost’ by interference. Secondly, there is the ‘tip of the tongue’ experience, which indicates that some information is present but cannot be satisfactorily accessed. Thirdly, information may not be recalled but may be recognized, or may be recalled only with prompting.

This leads us to the third process of memory: information retrieval. Here we need to distinguish between two types of information retrieval, recall and recognition. In recall the information is reproduced from memory. In recognition, the presentation of the information provides the knowledge that the information has been seen before. Recognition is the less complex cognitive activity since the information is provided as a cue.

However, recall can be assisted by the provision of retrieval cues, which enable the subject quickly to access the information in memory. One such cue is the use of categories. In an experiment subjects were asked to recall lists of words, some of which were organized into categories and some of which were randomly organized. The words that were related to a category were easier to recall than the others [38]. Recall is even more successful if subjects are allowed to categorize their own lists of words during learning. For example, consider the following list of words:

child red plane dog friend blood cold tree big angry

Now make up a story that links the words using as vivid imagery as possible. Now try to recall as many of the words as you can. Did you find this easier than the previous experiment where the words were unrelated?

The use of vivid imagery is a common cue to help people remember information. It is known that people often visualize a scene that is described to them. They can then answer questions based on their visualization. Indeed, subjects given a description of a scene often embellish it with additional information. Consider the following description and imagine the scene:

> The engines roared above the noise of the crowd. Even in the blistering heat people rose to their feet and waved their hands in excitement. The flag fell and they were off. Within seconds the car had pulled away from the pack and was careering round the bend at a desperate pace. Its wheels momentarily left the ground as it cornered. Coming down the straight the sun glinted on its shimmering paint. The driver gripped the wheel with fierce concentration. Sweat lay in fine drops on his brow.

Without looking back to the passage, what color is the car?

If you could answer that question you have visualized the scene, including the car’s color. In fact, the color of the car is not mentioned in the description at all.

Improve your memory

Many people can perform astonishing feats of memory: recalling the sequence of cards in a pack (or multiple packs – up to six have been reported), or recounting π to 1000 decimal places, for example. There are also adverts to 'Improve Your Memory' (usually leading to success, or wealth, or other such inducement), and so the question arises: can you improve your memory abilities? The answer is yes; this exercise shows you one technique.

Look at the list below of numbers and associated words:

1	bun	6	sticks
2	shoe	7	heaven
3	tree	8	gate
4	door	9	wine
5	hive	10	hen

Notice that the words sound similar to the numbers. Now think about the words one at a time and visualize them, in as much detail as possible. For example, for '1', think of a large, sticky iced bun, the base spiralling round and round, with raisins in it, covered in sweet, white, gooey icing. Now do the rest, using as much visualization as you can muster: imagine how things would look, smell, taste, sound, and so on.

This is your reference list, and you need to know it off by heart.

Having learnt it, look at a pile of at least a dozen odd items collected together by a colleague. The task is to look at the collection of objects for only 30 seconds, and then list as many as possible without making a mistake or viewing the collection again. Most people can manage between five and eight items, if they do not know any memory-enhancing techniques like the following.

Mentally pick one (say, for example, a paper clip), and call it number one. Now visualize it interacting with the bun. It can get stuck into the icing on the top of the bun, and make your fingers all gooey and sticky when you try to remove it. If you ate the bun without noticing, you'd get a crunched tooth when you bit into it – imagine how that would feel. When you've really got a graphic scenario developed, move on to the next item, call it number two, and again visualize it interacting with the reference item, shoe. Continue down your list, until you have done 10 things.

This should take you about the 30 seconds allowed. Then hide the collection and try and recall the numbers in order, the associated reference word, and then the image associated with that word. You should find that you can recall the 10 associated items practically every time. The technique can be easily extended by extending your reference list.

1.4 THINKING: REASONING AND PROBLEM SOLVING

We have considered how information finds its way into and out of the human system and how it is stored. Finally, we come to look at how it is processed and manipulated. This is perhaps the area which is most complex and which separates humans from other information-processing systems, both artificial and natural. Although it is clear that animals receive and store information, there is little evidence to suggest that they can use it in quite the same way as humans. Similarly, artificial intelligence has produced machines which can see (albeit in a limited way) and store information. But their ability to use that information is limited to small domains.

Humans, on the other hand, are able to use information to reason and solve problems, and indeed do these activities when the information is partial or unavailable. Human thought is conscious and self-aware: while we may not always be able to identify the processes we use, we can identify the products of these processes, our thoughts. In addition, we are able to think about things of which we have no experience, and solve problems which we have never seen before. How is this done?

Thinking can require different amounts of knowledge. Some thinking activities are very directed and the knowledge required is constrained. Others require vast amounts of knowledge from different domains. For example, performing a subtraction calculation requires a relatively small amount of knowledge, from a constrained domain, whereas understanding newspaper headlines demands knowledge of politics, social structures, public figures and world events.

In this section we will consider two categories of thinking: reasoning and problem solving. In practice these are not distinct since the activity of solving a problem may well involve reasoning and vice versa. However, the distinction is a common one and is helpful in clarifying the processes involved.

1.4.1 Reasoning

Reasoning is the process by which we use the knowledge we have to draw conclusions or infer something new about the domain of interest. There are a number of different types of reasoning: *deductive*, *inductive* and *abductive*. We use each of these types of reasoning in everyday life, but they differ in significant ways.

Deductive reasoning

Deductive reasoning derives the logically necessary conclusion from the given premises. For example,

If it is Friday then she will go to work
It is Friday
Therefore she will go to work.

It is important to note that this is the *logical* conclusion from the premises; it does not necessarily have to correspond to our notion of truth. So, for example,

If it is raining then the ground is dry
It is raining
Therefore the ground is dry.

is a perfectly valid deduction, even though it conflicts with our knowledge of what is true in the world.

Deductive reasoning is therefore often misapplied. Given the premises

Some people are babies
Some babies cry

many people will infer that 'Some people cry'. This is in fact an invalid deduction since we are not told that all babies are people. It is therefore logically possible that the babies who cry are those who are not people.

It is at this point, where truth and validity clash, that human deduction is poorest. One explanation for this is that people bring their world knowledge into the reasoning process. There is good reason for this. It allows us to take short cuts which make dialog and interaction between people informative but efficient. We assume a certain amount of shared knowledge in our dealings with each other, which in turn allows us to interpret the inferences and deductions implied by others. If validity rather than truth was preferred, all premises would have to be made explicit.

Inductive reasoning

Induction is generalizing from cases we have seen to infer information about cases we have not seen. For example, if every elephant we have ever seen has a trunk, we infer that all elephants have trunks. Of course, this inference is unreliable and cannot be proved to be true; it can only be proved to be false. We can disprove the inference simply by producing an elephant without a trunk. However, we can never prove it true because, no matter how many elephants with trunks we have seen or are known to exist, the next one we see may be trunkless. The best that we can do is gather evidence to support our inductive inference.

In spite of its unreliability, induction is a useful process, which we use constantly in learning about our environment. We can never see all the elephants that have ever lived or will ever live, but we have certain knowledge about elephants which we are prepared to trust for all practical purposes, which has largely been inferred by induction. Even if we saw an elephant without a trunk, we would be unlikely to move from our position that 'All elephants have trunks', since we are better at using positive than negative evidence. This is illustrated in an experiment first devised by Wason [365]. You are presented with four cards as in Figure 1.14. Each card has a number on one side and a letter on the other. Which cards would you need to pick up to test the truth of the statement 'If a card has a vowel on one side it has an even number on the other'?

A common response to this (was it yours?) is to check the E and the 4. However, this uses only positive evidence. In fact, to test the truth of the statement we need to check negative evidence: if we can find a card which has an odd number on one side and a vowel on the other we have disproved the statement. We must therefore check E and 7. (It does not matter what is on the other side of the other cards: the statement does not say that all even numbers have vowels, just that all vowels have even numbers.)

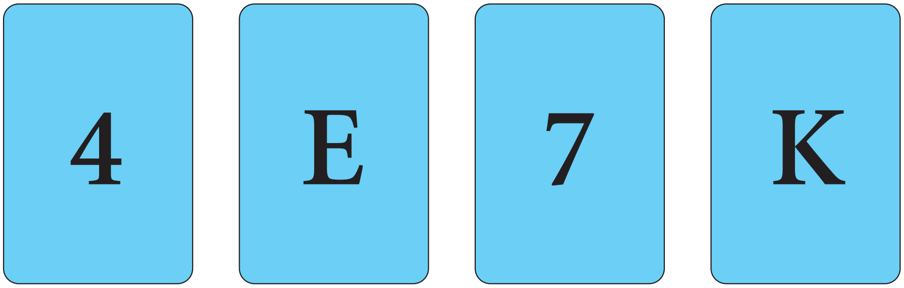


Figure 1.14 Wason's cards

Filling the gaps

Look again at Wason's cards in Figure 1.14. In the text we say that you only need to check the E and the 7. This is correct, but only because we very carefully stated in the text that 'each card has a number on one side and a letter on the other'. If the problem were stated without that condition then the K would also need to be examined in case it has a vowel on the other side. In fact, when the problem is so stated, even the most careful subjects ignore this possibility. Why? Because the nature of the problem implicitly suggests that each card has a number on one side and a letter on the other.

This is similar to the embellishment of the story at the end of Section 1.3.3. In fact, we constantly fill in gaps in the evidence that reaches us through our senses. Although this can lead to errors in our reasoning it is also essential for us to function. In the real world we rarely have all the evidence necessary for logical deductions and at all levels of perception and reasoning we fill in details in order to allow higher levels of reasoning to work.

Abductive reasoning

The third type of reasoning is abduction. Abduction reasons from a fact to the action or state that caused it. This is the method we use to derive explanations for the events we observe. For example, suppose we know that Sam always drives too fast when she has been drinking. If we see Sam driving too fast we may infer that she has been drinking. Of course, this too is unreliable since there may be another reason why she is driving fast: she may have been called to an emergency, for example.

In spite of its unreliability, it is clear that people do infer explanations in this way, and hold onto them until they have evidence to support an alternative theory or explanation. This can lead to problems in using interactive systems. If an event always follows an action, the user will infer that the event is caused by the action unless evidence to the contrary is made available. If, in fact, the event and the action are unrelated, confusion and even error often result.

1.4.2 Problem solving

If reasoning is a means of inferring new information from what is already known, problem solving is the process of finding a solution to an unfamiliar task, using the knowledge we have. Human problem solving is characterized by the ability to adapt the information we have to deal with new situations. However, often solutions seem to be original and creative. There are a number of different views of how people solve problems. The earliest, dating back to the first half of the twentieth century, is the *Gestalt* view that problem solving involves both reuse of knowledge and insight. This has been largely superseded but the questions it was trying to address remain and its influence can be seen in later research. A second major theory, proposed in the 1970s by Newell and Simon, was the *problem space theory*, which takes the view that the mind is a limited information processor. Later variations on this drew on the earlier theory and attempted to reinterpret Gestalt theory in terms of information-processing theories. We will look briefly at each of these views.

Gestalt theory

Gestalt psychologists were answering the claim, made by behaviorists, that problem solving is a matter of reproducing known responses or trial and error. This explanation was considered by the Gestalt school to be insufficient to account for human problem-solving behavior. Instead, they claimed, problem solving is both *productive* and *reproductive*. Reproductive problem solving draws on previous experience as the behaviorists claimed, but productive problem solving involves insight and restructuring of the problem. Indeed, reproductive problem solving could be a hindrance to finding a solution, since a person may 'fixate' on the known aspects of the problem and so be unable to see novel interpretations that might lead to a solution.

Gestalt psychologists backed up their claims with experimental evidence. Kohler provided evidence of apparent insight being demonstrated by apes, which he observed joining sticks together in order to reach food outside their cages [202]. However, this was difficult to verify since the apes had once been wild and so could have been using previous knowledge.

Other experiments observed human problem-solving behavior. One well-known example of this is Maier's *pendulum problem* [224]. The problem was this: the subjects were in a room with two pieces of string hanging from the ceiling. Also in the room were other objects including pliers, poles and extensions. The task set was to tie the pieces of string together. However, they were too far apart to catch hold of both at once. Although various solutions were proposed by subjects, few chose to use the weight of the pliers as a pendulum to 'swing' the strings together. However, when the experimenter brushed against the string, setting it in motion, this solution presented itself to subjects. Maier interpreted this as an example of productive restructuring. The movement of the string had given insight and allowed the subjects to see the problem in a new way. The experiment also illustrates fixation: subjects were initially unable to see beyond their view of the role or use of a pair of pliers.

Although Gestalt theory is attractive in terms of its description of human problem solving, it does not provide sufficient evidence or structure to support its theories. It does not explain when restructuring occurs or what insight is, for example. However, the move away from behaviorist theories was helpful in paving the way for the information-processing theory that was to follow.

Problem space theory

Newell and Simon proposed that problem solving centers on the problem space. The problem space comprises *problem states*, and problem solving involves generating these states using legal state transition operators. The problem has an initial state and a goal state and people use the operators to move from the former to the latter. Such problem spaces may be huge, and so *heuristics* are employed to select appropriate operators to reach the goal. One such heuristic is *means–ends analysis*. In means–ends analysis the initial state is compared with the goal state and an operator chosen to reduce the difference between the two. For example, imagine you are reorganizing your office and you want to move your desk from the north wall of the room to the window. Your initial state is that the desk is at the north wall. The goal state is that the desk is by the window. The main difference between these two is the location of your desk. You have a number of operators which you can apply to moving things: you can carry them or push them or drag them, etc. However, you know that to carry something it must be light and that your desk is heavy. You therefore have a new subgoal: to make the desk light. Your operators for this may involve removing drawers, and so on.

An important feature of Newell and Simon's model is that it operates within the constraints of the human processing system, and so searching the problem space is limited by the capacity of short-term memory, and the speed at which information can be retrieved. Within the problem space framework, experience allows us to solve problems more easily since we can structure the problem space appropriately and choose operators efficiently.

Newell and Simon's theory, and their *General Problem Solver* model which is based on it, have largely been applied to problem solving in well-defined domains, for example solving puzzles. These problems may be unfamiliar but the knowledge that is required to solve them is present in the statement of the problem and the expected solution is clear. In real-world problems finding the knowledge required to solve the problem may be part of the problem, or specifying the goal may be difficult. Problems such as these require significant domain knowledge: for example, to solve a programming problem you need knowledge of the language and the domain in which the program operates. In this instance specifying the goal clearly may be a significant part of solving the problem.

However, the problem space framework provides a clear theory of problem solving, which can be extended, as we shall see when we look at skill acquisition in the next section, to deal with knowledge-intensive problem solving. First we will look briefly at the use of analogy in problem solving.

Worked exercise *Identify the goals and operators involved in the problem 'delete the second paragraph of the document' on a word processor. Now use a word processor to delete a paragraph and note your actions, goals and subgoals. How well did they match your earlier description?*

Answer Assume you have a document open and you are at some arbitrary position within it. You also need to decide which operators are available and what their preconditions and results are. Based on an imaginary word processor we assume the following operators (you may wish to use your own WP package):

Operator	Precondition	Result
delete_paragraph	Cursor at start of paragraph	Paragraph deleted
move_to_paragraph	Cursor anywhere in document	Cursor moves to start of next paragraph (except where there is no next paragraph when no effect)
move_to_start	Cursor anywhere in document	Cursor at start of document

Goal: *delete second paragraph in document*
Looking at the operators an obvious one to resolve this goal is delete_paragraph which has the precondition 'cursor at start of paragraph'. We therefore have a new subgoal: *move_to_paragraph*. The precondition is 'cursor anywhere in document' (which we can meet) but we want the second paragraph so we must initially be in the first.

We set up a new subgoal, move_to_start, with precondition 'cursor anywhere in document' and result 'cursor at start of document'. We can then apply *move_to_paragraph* and finally *delete_paragraph*.

We assume some knowledge here (that the second paragraph is the paragraph after the first one).

Analogy in problem solving

A third element of problem solving is the use of analogy. Here we are interested in how people solve novel problems. One suggestion is that this is done by mapping knowledge relating to a similar known domain to the new problem – called *analogical mapping*. Similarities between the known domain and the new one are noted and operators from the known domain are transferred to the new one.

This process has been investigated using analogous stories. Gick and Holyoak [149] gave subjects the following problem:

> A doctor is treating a malignant tumor. In order to destroy it he needs to blast it with high-intensity rays. However, these will also destroy the healthy tissue surrounding the tumor. If he lessens the rays' intensity the tumor will remain. How does he destroy the tumor?

The solution to this problem is to fire low-intensity rays from different directions converging on the tumor. That way, the healthy tissue receives harmless low-intensity rays while the tumor receives the rays combined, making a high-intensity dose. The investigators found that only 10% of subjects reached this solution without help. However, this rose to 80% when they were given this analogous story and told that it may help them:

> A general is attacking a fortress. He can't send all his men in together as the roads are mined to explode if large numbers of men cross them. He therefore splits his men into small groups and sends them in on separate roads.

In spite of this, it seems that people often miss analogous information, unless it is semantically close to the problem domain. When subjects were not told to use the story, many failed to see the analogy. However, the number spotting the analogy rose when the story was made semantically close to the problem, for example a general using rays to destroy a castle.

The use of analogy is reminiscent of the Gestalt view of productive restructuring and insight. Old knowledge is used to solve a new problem.

1.4.3 Skill acquisition

All of the problem solving that we have considered so far has concentrated on handling unfamiliar problems. However, for much of the time, the problems that we face are not completely new. Instead, we gradually acquire skill in a particular domain area. But how is such skill acquired and what difference does it make to our problem-solving performance? We can gain insight into how skilled behavior works, and how skills are acquired, by considering the difference between novice and expert behavior in given domains.

Chess: of human and artificial intelligence

A few years ago, Deep Blue, a chess-playing computer, beat Gary Kasparov, the world's top Grand Master, in a full tournament. This was the long-awaited breakthrough for the artificial intelligence (AI) community, who have traditionally seen chess as the ultimate test of their art. However, despite the fact that computer chess programs can play at Grand Master level against human players, this does not mean they play in the same way. For each move played, Deep Blue investigated many millions of alternative moves and counter-moves. In contrast, a human chess player will only consider a few dozen. But, if the human player is good, these will usually be the right few dozen. The ability to spot patterns allows a human to address a problem with far less effort than a brute force approach. In chess, the number of moves is such that finally brute force, applied fast enough, has overcome human pattern-matching skill. In Go, which has far more possible moves, computer programs do not even reach a good club level of play. Many models of the mental processes have been heavily influenced by computation. It is worth remembering that although there are similarities, computer 'intelligence' is very different from that of humans.

A commonly studied domain is chess playing. It is particularly suitable since it lends itself easily to representation in terms of problem space theory. The initial state is the opening board position; the goal state is one player checkmating the other; operators to move states are legal moves of chess. It is therefore possible to examine skilled behavior within the context of the problem space theory of problem solving.

Studies of chess players by DeGroot, Chase and Simon, among others, produced some interesting observations [64, 65, 88, 89]. In all the experiments the behavior of chess masters was compared with less experienced chess players. The first observation was that players did not consider large numbers of moves in choosing their move, nor did they look ahead more than six moves (often far fewer). Masters considered no more alternatives than the less experienced, but they took less time to make a decision and produced better moves.

So what makes the difference between skilled and less skilled behavior in chess? It appears that chess masters remember board configurations and good moves associated with them. When given actual board positions to remember, masters are much better at reconstructing the board than the less experienced. However, when given random configurations (which were unfamiliar), the groups of players were equally bad at reconstructing the positions. It seems therefore that expert players 'chunk' the board configuration in order to hold it in short-term memory. Expert players use larger chunks than the less experienced and can therefore remember more detail.

This behavior is also seen among skilled computer programmers. They can also reconstruct programs more effectively than novices since they have the structures available to build appropriate chunks. They acquire plans representing code to solve particular problems. When that problem is encountered in a new domain or new program they will recall that particular plan and reuse it.

Another observed difference between skilled and less skilled problem solving is in the way that different problems are grouped. Novices tend to group problems according to superficial characteristics such as the objects or features common to both. Experts, on the other hand, demonstrate a deeper understanding of the problems and group them according to underlying conceptual similarities which may not be at all obvious from the problem descriptions.

Each of these differences stems from a better encoding of knowledge in the expert: information structures are fine tuned at a deep level to enable efficient and accurate retrieval. But how does this happen? How is skill such as this acquired? One model of skill acquisition is Anderson's *ACT** model [14]. ACT* identifies three basic levels of skill:

1. The learner uses general-purpose rules which interpret facts about a problem. This is slow and demanding on memory access.
2. The learner develops rules specific to the task.
3. The rules are tuned to speed up performance.

General mechanisms are provided to account for the transitions between these levels. For example, *proceduralization* is a mechanism to move from the first to the second. It removes the parts of the rule which demand memory access and replaces variables with specific values. *Generalization*, on the other hand, is a mechanism which moves from the second level to the third. It generalizes from the specific cases to general properties of those cases. Commonalities between rules are condensed to produce a general-purpose rule.

These are best illustrated by example. Imagine you are learning to cook. Initially you may have a general rule to tell you how long a dish needs to be in the oven, and a number of explicit representations of dishes in memory. You can instantiate the rule by retrieving information from memory.

```
IF cook[type, ingredients, time]
THEN
    cook for: time
cook[casserole, [chicken,carrots,potatoes], 2 hours]
cook[casserole, [beef,dumplings,carrots], 2 hours]
cook[cake, [flour,sugar,butter,eggs], 45 mins]
```

Gradually your knowledge becomes proceduralized and you have specific rules for each case:

```
IF type is casserole
AND ingredients are [chicken,carrots,potatoes]
THEN
    cook for: 2 hours
IF type is casserole
AND ingredients are [beef,dumplings,carrots]
THEN
    cook for: 2 hours
IF type is cake
AND ingredients are [flour,sugar,butter,eggs]
THEN
    cook for: 45 mins
```

Finally, you may generalize from these rules to produce general-purpose rules, which exploit their commonalities:

```
IF type is casserole
AND ingredients are ANYTHING
THEN
    cook for: 2 hours
```

The first stage uses knowledge extensively. The second stage relies upon known procedures. The third stage represents skilled behavior. Such behavior may in fact become automatic and as such be difficult to make explicit. For example, think of an activity at which you are skilled, perhaps driving a car or riding a bike. Try to describe to someone the exact procedure which you go through to do this. You will find this quite difficult. In fact experts tend to have to rehearse their actions mentally in order to identify exactly what they do. Such skilled behavior is efficient but may cause errors when the context of the activity changes.

1.4.4 Errors and mental models

Human capability for interpreting and manipulating information is quite impressive. However, we do make mistakes. Some are trivial, resulting in no more than temporary inconvenience or annoyance. Others may be more serious, requiring substantial effort to correct. Occasionally an error may have catastrophic effects, as we see when 'human error' results in a plane crash or nuclear plant leak.

Why do we make mistakes and can we avoid them? In order to answer the latter part of the question we must first look at what is going on when we make an error. There are several different types of error. As we saw in the last section some errors result from changes in the context of skilled behavior. If a pattern of behavior has become automatic and we change some aspect of it, the more familiar pattern may break through and cause an error. A familiar example of this is where we intend to stop at the shop on the way home from work but in fact drive past. Here, the activity of driving home is the more familiar and overrides the less familiar intention.

Other errors result from an incorrect understanding, or model, of a situation or system. People build their own theories to understand the causal behavior of systems. These have been termed *mental models*. They have a number of characteristics. Mental models are often partial: the person does not have a full understanding of the working of the whole system. They are unstable and are subject to change. They can be internally inconsistent, since the person may not have worked through the logical consequences of their beliefs. They are often unscientific and may be based on superstition rather than evidence. Often they are based on an incorrect interpretation of the evidence.

Design Focus

Human error and false memories

In the second edition of this book, one of the authors added the following story:

> During the Second World War a new cockpit design was introduced for Spitfires. The pilots were trained and flew successfully during training, but would unaccountably bail out when engaged in dog fights. The new design had exchanged the positions of the gun trigger and ejector controls. In the heat of battle the old responses resurfaced and the pilots ejected. Human error, yes, but the designer's error, not the pilot's.

It is a good story, but after the book was published we got several emails saying 'Spitfires didn't have ejector seats'. It was Kai-Mikael Jää-Aro who was able to find what may have been the original to the story (and incidentally inform us what model of Spitfire was in our photo and who the pilot was!). He pointed us to and translated the story of Sierra 44, an S35E Draken reconnaissance aircraft.[1] The full story involves just about every perceptual and cognitive error imaginable, but the point that links to

1. Pej Kristoffersson, 1984. Sigurd 44 – Historien om hur man gör bort sig så att det märks by, *Flygrevyn* 2/1984, pp. 44–6.

the (false) Spitfire story is that in the Draken the red buttons for releasing the fuel 'drop' tanks and for the canopy release differed only in very small writing. In an emergency (burning fuel tanks) the pilot accidentally released the canopy and so ended up flying home cabriolet style.

There is a second story of human error here – the author's memory. When the book was written he could not recall where he had come across the story but was convinced it was to do with a Spitfire. It may be that he had been told the story by someone else who had got it mixed up, but it is as likely that he simply remembered the rough outline of the story and then 'reconstructed' the rest. In fact that is exactly how our memories work. Our brains do not bother to lay down every little detail, but when we 'remember' we rebuild what the incident 'must have been' using our world knowledge. This process is completely unconscious and can lead to what are known as *false memories*. This is particularly problematic in witness statements in criminal trials as early questioning by police or lawyers can unintentionally lead to witnesses being sure they have seen things that they have not. Numerous controlled psychological experiments have demonstrated this effect which furthermore is strongly influenced by biasing factors such as the race of supposed criminals.

To save his blushes we have not said here which author's failing memory was responsible for the Spitfire story, but you can read more on this story and also find who it was on the book website at: /e3/online/spitfire/

Courtesy of popperfoto.com

Assuming a person builds a mental model of the system being dealt with, errors may occur if the actual operation differs from the mental model. For example, on one occasion we were staying in a hotel in Germany, attending a conference. In the lobby of the hotel was a lift. Beside the lift door was a button. Our model of the system, based on previous experience of lifts, was that the button would call the lift. We pressed the button and the lobby light went out! In fact the button was a light switch and the lift button was on the inside rim of the lift, hidden from view.

Although both the light switch and the lift button were inconsistent with our mental models of these controls, we would probably have managed if they had been encountered separately. If there had been no button beside the lift we would have looked more closely and found the one on the inner rim. But since the light switch reflected our model of a lift button we looked no further. During our stay we observed many more new guests making the same error.

This illustrates the importance of a correct mental model and the dangers of ignoring conventions. There are certain conventions that we use to interpret the world and ideally designs should support these. If these are to be violated, explicit support must be given to enable us to form a correct mental model. A label on the button saying 'light switch' would have been sufficient.

1.5 EMOTION

So far in this chapter we have concentrated on human perceptual and cognitive abilities. But human experience is far more complex than this. Our emotional response to situations affects how we perform. For example, positive emotions enable us to think more creatively, to solve complex problems, whereas negative emotion pushes us into narrow, focussed thinking. A problem that may be easy to solve when we are relaxed, will become difficult if we are frustrated or afraid.

Psychologists have studied emotional response for decades and there are many theories as to what is happening when we feel an emotion and why such a response occurs. More than a century ago, William James proposed what has become known as the James–Lange theory (Lange was a contemporary of James whose theories were similar): that emotion was the interpretation of a physiological response, rather than the other way around. So while we may feel that we respond *to* an emotion, James contended that we respond physiologically to a stimulus and interpret that as emotion:

> Common sense says, we lose our fortune, are sorry and weep; we meet a bear, are frightened and run; we are insulted by a rival, are angry and strike. The hypothesis here . . . is that we feel sorry because we cry, angry because we strike, afraid because we tremble.
>
> (W. James, *Principles of Psychology*, page 449. Henry Holt, New York, 1890.)

Others, however, disagree. Cannon [54a], for example, argued that our physiological processes are in fact too slow to account for our emotional reactions, and that the physiological responses for some emotional states are too similar (e.g. anger and fear), yet they can be easily distinguished. Experience in studies with the use of drugs that stimulate broadly the same physiological responses as anger or fear seems to support this: participants reported physical symptoms but not the emotion, which suggests that emotional response is more than a recognition of physiological changes.

Schachter and Singer [312a] proposed a third interpretation: that emotion results from a person evaluating physical responses in the light of the whole situation. So whereas the same physiological response can result from a range of different situations, the emotion that is felt is based on a cognitive evaluation of the circumstance and will depend on what the person attributes this to. So the same physiological response of a pounding heart will be interpreted as excitement if we are in a competition and fear if we find ourselves under attack.

Whatever the exact process, what is clear is that emotion involves both physical and cognitive events. Our body responds biologically to an external stimulus and we interpret that in some way as a particular emotion. That biological response – known as *affect* – changes the way we deal with different situations, and this has an impact on the way we interact with computer systems. As Donald Norman says:

> Negative affect can make it harder to do even easy tasks; positive affect can make it easier to do difficult tasks.
>
> (D. A. Norman, Emotion and design: attractive things work better. *Interactions Magazine*, ix(4): 36–42, 2002.)

So what are the implications of this for design? It suggests that in situations of stress, people will be less able to cope with complex problem solving or managing difficult interfaces, whereas if people are relaxed they will be more forgiving of limitations in the design. This does not give us an excuse to design bad interfaces but does suggest that if we build interfaces that promote positive responses – for example by using aesthetics or reward – then they are likely be more successful.

1.6 INDIVIDUAL DIFFERENCES

In this chapter we have been discussing humans in general. We have made the assumption that everyone has similar capabilities and limitations and that we can therefore make generalizations. To an extent this is true: the psychological principles and properties that we have discussed apply to the majority of people. Notwithstanding this, we should remember that, although we share processes in common, humans, and therefore users, are not all the same. We should be aware of individual differences so that we can account for them as far as possible within our designs. These differences may be long term, such as sex, physical capabilities and intellectual capabilities. Others are shorter term and include the effect of stress or fatigue on the user. Still others change through time, such as age.

These differences should be taken into account in our designs. It is useful to consider, for any design decision, if there are likely to be users within the target group who will be adversely affected by our decision. At the extremes a decision may exclude a section of the user population. For example, the current emphasis on visual interfaces excludes those who are visually impaired, unless the design also makes use of the other sensory channels. On a more mundane level, designs should allow for users who are under pressure, feeling ill or distracted by other concerns: they should not push users to their perceptual or cognitive limits.

We will consider the issues of universal accessibility in more detail in Chapter 10.

1.7 PSYCHOLOGY AND THE DESIGN OF INTERACTIVE SYSTEMS

So far we have looked briefly at the way in which humans receive, process and store information, solve problems and acquire skill. But how can we apply what we have learned to designing interactive systems? Sometimes, straightforward conclusions can be drawn. For example, we can deduce that recognition is easier than recall and allow users to select commands from a set (such as a menu) rather than input them directly. However, in the majority of cases, application is not so obvious or simple. In fact, it may be dangerous, leading us to make generalizations which are not valid. In order to apply a psychological principle or result properly in design, we need to understand its context, both in terms of where it fits in the wider field of psychology and in terms of the details of the actual experiments, the measures used and the subjects involved, for example. This may appear daunting, particularly to the novice designer who wants to acknowledge the relevance of cognitive psychology but does not have the background to derive appropriate conclusions. Fortunately, principles and results from research in psychology have been distilled into guidelines for design, models to support design and techniques for evaluating design. Parts 2 and 3 of this book include discussion of a range of guidelines, models and techniques, based on cognitive psychology, which can be used to support the design process.

1.7.1 Guidelines

Throughout this chapter we have discussed the strengths and weaknesses of human cognitive and perceptual processes but, for the most part, we have avoided attempting to apply these directly to design. This is because such an attempt could only be partial and simplistic, and may give the impression that this is all psychology has to offer.

However, general design principles and guidelines can be and have been derived from the theories we have discussed. Some of these are relatively straightforward: for instance, recall is assisted by the provision of retrieval cues so interfaces should incorporate recognizable cues wherever possible. Others are more complex and context dependent. In Chapter 7 we discuss principles and guidelines further, many of which are derived from psychological theory. The interested reader is also referred to Gardiner and Christie [140] which illustrates how guidelines can be derived from psychological theory.

1.7.2 Models to support design

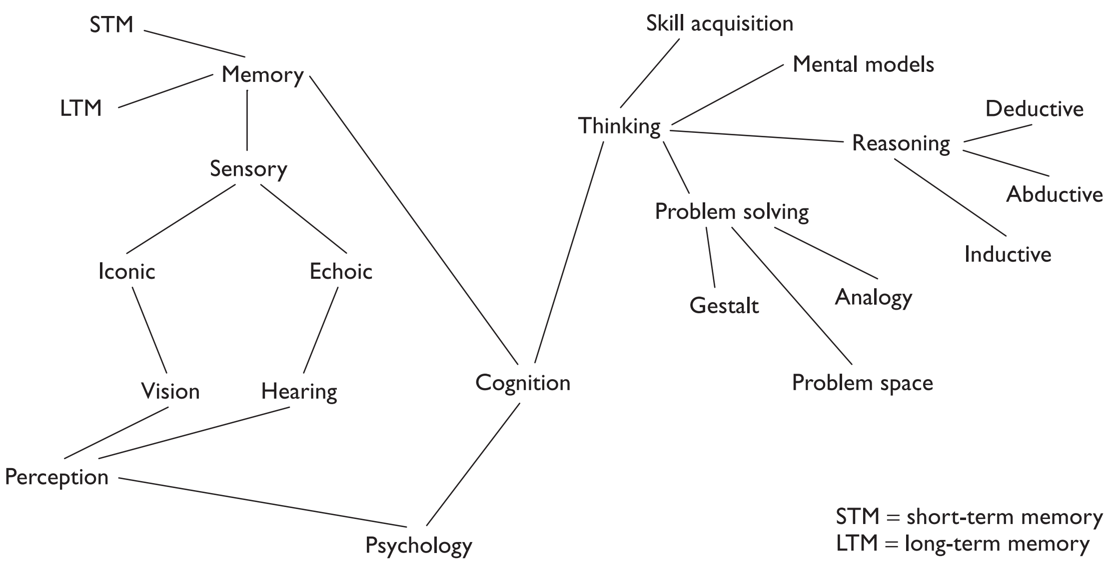
As well as guidelines and principles, psychological theory has led to the development of analytic and predictive models of user behavior. Some of these include a specific model of human problem solving, others of physical activity, and others attempt a more comprehensive view of cognition. Some predict how a typical computer user would behave in a given situation, others analyze why particular user behavior occurred. All are based on cognitive theory. We discuss these models in detail in Chapter 12.

1.7.3 Techniques for evaluation

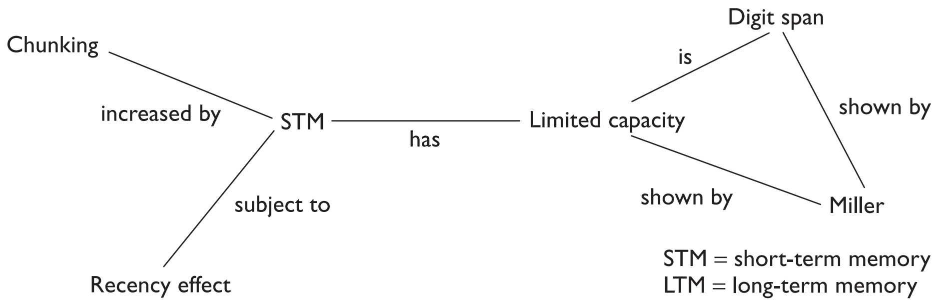
In addition to providing us with a wealth of theoretical understanding of the human user, psychology also provides a range of empirical techniques which we can employ to evaluate our designs and our systems. In order to use these effectively we need to understand the scope and benefits of each method. Chapter 9 provides an overview of these techniques and an indication of the circumstances under which each should be used.

Worked exercise *Produce a semantic network of the main information in this chapter.*

Answer This network is potentially huge so it is probably unnecessary to devise the whole thing! Be selective. One helpful way to tackle the exercise is to approach it in both a top-down and a bottom-up manner. Top-down will give you a general overview of topics and how they relate; bottom-up can fill in the details of a particular field. These can then be



Top-down view



Bottom-up view

'glued' together to build up the whole picture. You may be able to tackle this problem in a group, each taking one part of it. We will not provide the full network here but will give examples of the level of detail anticipated for the overview and the detailed versions. In the overview we have not included labels on the arcs for clarity.

1.8 SUMMARY

In this chapter we have considered the human as an information processor, receiving inputs from the world, storing, manipulating and using information, and reacting to the information received. Information is received through the senses, particularly, in the case of computer use, through sight, hearing and touch. It is stored in memory, either temporarily in sensory or working memory, or permanently in long-term memory. It can then be used in reasoning and problem solving. Recurrent familiar situations allow people to acquire skills in a particular domain, as their information structures become better defined. However, this can also lead to error, if the context changes.

Human perception and cognition are complex and sophisticated but they are not without their limitations. We have considered some of these limitations in this chapter. An understanding of the capabilities and limitations of the human as information processor can help us to design interactive systems which support the former and compensate for the latter. The principles, guidelines and models which can be derived from cognitive psychology and the techniques which it provides are invaluable tools for the designer of interactive systems.

EXERCISES

1.1 Devise experiments to test the properties of (i) short-term memory, (ii) long-term memory, using the experiments described in this chapter to help you. Try out your experiments on your friends. Are your results consistent with the properties described in this chapter?

1.2 Observe skilled and novice operators in a familiar domain, for example touch and 'hunt-and-peck' typists, expert and novice game players, or expert and novice users of a computer application. What differences can you discern between their behaviors?

1.3 From what you have learned about cognitive psychology devise appropriate guidelines for use by interface designers. You may find it helpful to group these under key headings, for example visual perception, memory, problem solving, etc., although some may overlap such groupings.

1.4 What are *mental models*, and why are they important in interface design?

1.5 What can a system designer do to minimize the memory load of the user?

1.6 Human short-term memory has a limited span. This is a series of experiments to determine what that span is. (You will need some other people to take part in these experiments with you – they do not need to be studying the course – try it with a group of friends.)

(a) *Kim's game*
Divide into groups. Each group gathers together an assortment of objects – pens, pencils, paper-clips, books, sticky notes, etc. The stranger the object, the better! You need a large number of them – at least 12 to 15. Place them in some compact arrangement on a table, so that all items are visible. Then, swap with another group for 30 seconds only and look at their pile. Return to your table, and on your own try to write down all the items in the other group's pile.

Compare your list with what they actually have in their pile. Compare the number of things you remembered with how the rest of your group did. Now think introspectively: what helped you remember certain things? Did you recognize things in their pile that you had in yours? Did that help? Do not pack the things away just yet.

Calculate the average score for your group. Compare that with the averages from the other group(s).

Questions: What conclusions can you draw from this experiment? What does this indicate about the capacity of short-term memory? What does it indicate that helps improve the capacity of short-term memory?

(b) *'I went to market . . .'*
In your group, one person starts off with 'I went to market and I bought a fish' (or some other produce, or whatever!). The next person continues 'I went to market and I bought a fish and I bought a bread roll as well'. The process continues, with each person adding some item to the list each time. Keep going around the group until you cannot remember the list accurately. Make a note of the first time someone gets it wrong, and then record the number of items that you can successfully remember. Some of you will find it hard to remember more than a few, others will fare much better. Do this a few more times with different lists, and then calculate your average score, and your group's average score.

Questions: What does this tell you about short-term memory? What do you do that helps you remember? What do you estimate is the typical capacity of human short-term memory? Is this a good test for short-term memory?

(c) *Improving your memory*
Try experiment 1.6(a) again, using the techniques on page 39.

Has your recall ability improved? Has your group's average improved? What does this show you about memory?

1.7 Locate one source (through the library or the web) that reports on empirical evidence on human limitations. Provide a full reference to the source. In one paragraph, summarize what the result of the research states in terms of a physical human limitation.

In a separate paragraph, write your thoughts on how you think this evidence on human capabilities impacts interactive system design.

RECOMMENDED READING

E. B. Goldstein, *Sensation and Perception*, 6th edition, Wadsworth, 2001.
A textbook covering human senses and perception in detail. Easy to read with many home experiments to illustrate the points made.

A. Baddeley, *Human Memory: Theory and Practice*, revised edition, Allyn & Bacon, 1997.
The latest and most complete of Baddeley's texts on memory. Provides up-to-date discussion on the different views of memory structure as well as a detailed survey of experimental work on memory.

M. W. Eysenck and M. T. Keane, *Cognitive Psychology: A Student's Handbook*, 4th edition, Psychology Press, 2000.
A comprehensive and readable textbook giving more detail on cognitive psychology, including memory, problem solving and skill acquisition.

S. K. Card, T. P. Moran and A. Newell, *The Psychology of Human–Computer Interaction*, Lawrence Erlbaum Associates, 1983.
A classic text looking at the human as an information processor in interaction with the computer. Develops and describes the Model Human Processor in detail.

A. Newell and H. Simon, *Human Problem Solving*, Prentice Hall, 1972.
Describes the problem space view of problem solving in more detail.

M. M. Gardiner and B. Christie, editors, *Applying Cognitive Psychology to User-Interface Design*, John Wiley, 1987.
A collection of essays on the implications of different aspects of cognitive psychology to interface design. Includes memory, thinking, language and skill acquisition. Provides detailed guidelines for applying psychological principles in design practice.

A. Monk, editor, *Fundamentals of Human Computer Interaction*, Academic Press, 1985.
A good collection of articles giving brief coverage of aspects of human psychology including perception, memory, thinking and reading. Also contains articles on experimental design which provide useful introductions.

ACT-R site. Website of resources and examples of the use of the cognitive architecture ACT-R, which is the latest development of Anderson's ACT model, http://act-r.psy.cmu.edu/

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

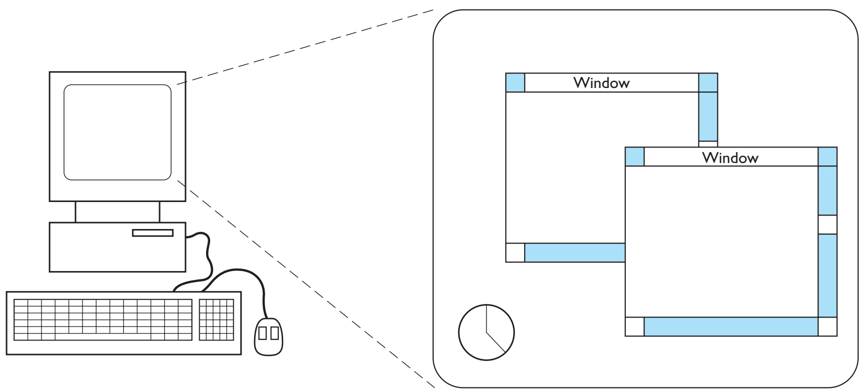


Figure 2.1 A typical computer system

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?

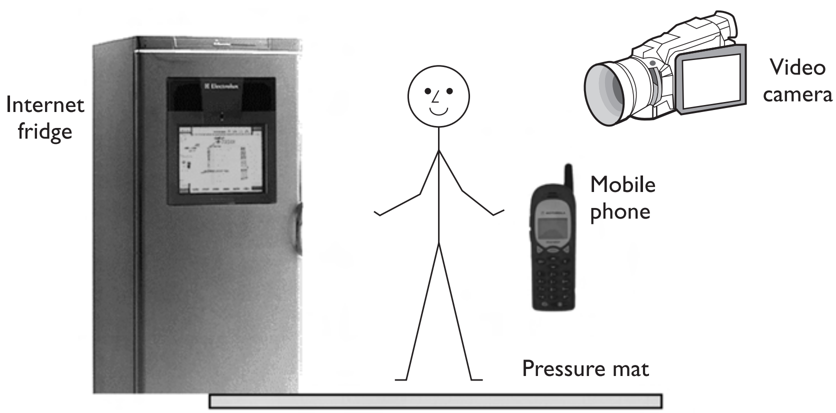


Figure 2.2 A typical computer system? Photo courtesy Electrolux

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.

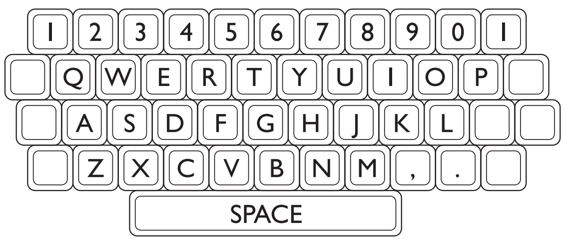


Figure 2.3 The standard QWERTY keyboard

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.